Report of the Commission of Inquiry into Excess Lead Found in Drinking Water

(The Redacted Version)

With a view to avoiding any prejudice (actual or perceived) to the relevant criminal investigations and criminal prosecutions (if so decided to be justified after the relevant investigations), certain parts of paragraphs 369, 411 and 414 of this Report have been redacted.

The Honourable Mr Justice Andrew Chan Hing Wai
Mr Alan Lai Nin, GBS, JP

May 2016

www.coi-drinkingwater.gov.hk

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LIST OF APPENDICES

LIST OF WITNESSES

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
1.	Professor Anthony Cheung Bing Leung	Chairman of the Hong Kong Housing Authority	2/11/2015 3/11/2015
2.	Ms Ada Fung Yin Suen	Deputy Director of Housing (Development and Construction), the Housing Department (HD)	3/11/2015 4/11/2015 5/11/2015 6/11/2015 26/1/2016
3.	Mr Yim Yu Chau	Chief Architect (Kai Ching Estate and Wing Cheong Estate) of HD	11/11/2015 12/11/2015 13/11/2015
4.	Mr Ng Tat Kwan	Chief Building Services Engineer (Kai Ching Estate, and Un Chau Estate Phases 2 and 4) of HD	13/11/2015 16/11/2015 17/11/2015
5.	Mr William Ho Wai Lim	Chief Manager / Management of HD	17/11/2015
6.	Mr Yim Ka Ho	Senior Property Service Manager of HD	17/11/2015
7.	Ms Ann Mary Tam Kwai Yee	Chief Architect (Kwai Luen Estate Phase 2) of HD	17/11/2015 18/11/2015
8.	Mr Suen Wai Man	Chief Architect (Shek Kip Mei Estate Phase 2) of HD	18/11/2015
9.	Ms Theresa Yim Siu Ling	Chief Architect (Tung Wui Estate and Kai Ching Estate) of HD	19/11/2015 20/11/2015
10.	Mr Chiu Pbut Kay	Chief Architect (Un Chau Estate Phases 2 and 4) of HD	20/11/2015

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
11.	Ms Rosa Lok So Fun	Chief Architect (Ching Ho Estate Phase 1, Choi Fook Estate and Hung Hom Estate Phase 2) of HD	25/11/2015 26/11/2015
12.	Ms Sonia Yung Tak Ling	Chief Architect (Yan On Estate) of HD	26/11/2015
13.	Mr Ricky Yeung Yiu Fai	Chief Architect (Lower Ngau Tau Kok Estate Phase 1) of HD	26/11/2015
14.	Mr Eric Leung Chi Kwong	Chief Building Services Engineer (Kwai Luen Estate Phase 2, Wing Cheong Estate, Lower Ngau Tau Kok Estate Phase 1, Shek Kip Mei Estate Phase 2, Tung Wui Estate, Hung Hom Estate Phase 2, Yan On Estate, Choi Fook Estate and Ching Ho Estate Phase 1) of HD	27/11/2015
15.	Mr Wong Tin Cheung	Chairman of Yau Lee Construction Company Limited[1] (Yau Lee) General Manager of Ming Hop Company Limited[2] (Ming Hop)	1/12/2015
16.	Mr Ng Hak Ming	Licensed Plumber (Un Chau Estate Phases 2 and 4, Ching Ho Estate Phase 1, Choi Fook Estate, Yan On Estate, Lower Ngau Tau Kok Estate Phase 1, Shek Kip Mei Estate Phase 2)	2/12/2015

[1] Main Contractor of Un Chau Estate Phases 2 and 4, Ching Ho Estate Phase 1, Choi Fook Estate, Yan On Estate, Lower Ngau Tau Kok Estate Phase 1, Shek Kip Mei Estate Phase 2.

[2] Subcontractor of Yau Lee.

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
17.	Mr Leo Tam Sin Ting	Architectural Quality Control Coordinator of Yau Lee (Anderson Road site)	2/12/2015
18.	Mr Chau Chi Wai	Former Site Agent of Yau Lee (Yan On Estate)	2/12/2015
19.	Mr Ching Chi Fai	Senior Engineer of Ming Hop (Anderson Road site)	3/12/2015
20.	Mr Mok Hoi Kwong	Sole proprietor of Wing Hing Plumbing Drainage[3] (Wing Hing) (Un Chau Estate Phases 2 and 4, Ching Ho Estate Phase 1, Yan On Estate, Lower Ngau Tau Kok Estate Phase 1, and Shek Kip Mei Estate Phase 2)	3/12/2015
21.	Mr Siu Kin Wong	Sole proprietor of Hang Lee Engineering Company[4] (Hang Lee) (Choi Fook Estate)	3/12/2015 4/12/2015
22.	Mr Yee Yat Ming	Former Architectural Quality Control Coordinator of Yau Lee (Choi Fook Estate)	4/12/2015
23.	Mr Michael Sung Tsang Hung	General Manager of the Building Construction Department of China State Construction Engineering (Hong Kong) Limited[5] (China State)	7/12/2015
24.	Mr Chan Siu Wing	Site Agent of China State (Hung Hom Estate Phase 2)	8/12/2015

[3] Subcontractor of Ming Hop.
[4] Subcontractor of Ming Hop.
[5] Main contractor of Hung Hom Estate Phase 2 and Kai Ching Estate.

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
25.	Mr Lee Hung Fai	Deputy General Foreman of China State (Hung Hom Estate Phase 2)	8/12/2015 9/12/2015
26.	Mr Patrick Leung Man Wai	Senior Building Services Engineer of China State (Kai Ching Estate)	9/12/2015 10/12/2015
27.	Mr Siu Wai Ning	Senior Building Services Foreman of China State (Kai Ching Estate)	10/12/2015
28.	Mr Lam Kai Wong	Building Services Engineer of China State (Kai Ching Estate)	10/12/2015 11/12/2015
29.	Professor David Bellinger	(Expert for the Commission) Professor of Neurology and Professor of Psychology, the Harvard Medical School Professor in the Department of Environmental Health, the Harvard School of Public Health Development Psychologist	15/12/2015 16/12/2015
30.	Mr Au Choi Wa	Deputy General Manager of Shui On Building Contractors Limited (Shui On)	16/12/2015 17/12/2015
31.	Mr Ching Shiu Hong	Senior Construction Manager of Shui On (Project Manager of Kwai Luen Estate Phase 2)	17/12/2015
32.	Mr Wan Wai Ho	Construction Manager of Shui On (Site Agent of Kwai Luen Estate Phase 2)	17/12/2015 18/12/2015

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
33.	Mr Leung Wai Keung	Technical Director of Paul Y. General Contractors Limited (Paul Y) (Project Director for Wing Cheong Estate and Tung Wui Estate)	4/1/2016
34.	Mr Cheung Tat Yam	Managing Director of Golden Day Engineering Company Limited (Golden Day) and Licensed Plumber (Hung Hom Estate Phase 2, Tung Wui Estate and Wing Cheong Estate)	5/1/2016
35.	Mr Yung Kwok Choi	Former Project Manager of Golden Day (Hung Hom Estate Phase 2, Tung Wui Estate and Wing Cheong Estate)	6/1/2016
36.	Ms Lam Lai King	Procurement staff of Golden Day	6/1/2016 7/1/2016
37.	Mr Hui Wang San	Site Supervisor of Golden Day (Hung Hom Estate Phase 2 and Wing Cheong Estate)	7/1/2016 11/1/2016
38.	Mr Chau See Ming	Site Supervisor of Golden Day (Tung Wui Estate)	11/1/2016
39.	Mr Wong Kam Man	Project staff of Golden Day	11/1/2016
40.	Ms Mok Wai Yin	Clerk of Golden Day	12/1/2016
41.	Mr Ho Man Piu	Managing Director of Ho Biu Kee Construction Engineering Company Limited (Ho Biu Kee)	12/1/2016 13/1/2016
42.	Mr Kevin Kwong Ka Fu	Quantity Surveyor of Ho Biu Kee	13/1/2016 14/1/2016 15/1/2016

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
43.	Mr Chan Siu Wah	Former staff of Ho Biu Kee (Person-in-charge of Kai Ching Estate)	14/1/2016
44.	Ms Wong Wai Ping	Personal Assistant to the Managing Director of Ho Biu Kee	15/1/2016
45.	Mr Leung Wai Kin	Project Manager of Ho Biu Kee	15/1/2016 20/1/2016
46.	Mr Lam Tak Sum	Licensed Plumber (Kai Ching Estate and Kwai Luen Estate Phase 2)	18/1/2016 19/1/2016 27/1/2016
47.	Mr Chow Ka Ping	Director of Prosperity Building Materials Company Limited	19/1/2016
48.	Mr Lui Hin Lun	Partner of Wo Hing Manufacturing Company	19/1/2016
49.	Mr Wong Kwai Hung	Officer-in-charge/Work Supervisor of Ho Biu Kee (Officer-in-charge of Kwai Luen Estate Phase 2 and Block Supervisor of Blocks 1 and 2 of Kai Ching Estate)	20/1/2016
50.	Ms Jess Chiu Wai Kuen	Purchasing Officer of Ho Biu Kee	20/1/2016 21/1/2016
51.	Mr Leung Sai Chi	Assistant Director (Estate Management) of HD	21/1/2016
52.	Mr Wong Bay	Former HD's representative on the Advisory Committee on Quality of Water Supplies (ACQWS)	21/1/2016 22/1/2016

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
53.	Mr Chan Siu Tack	HD's representative on the ACQWS	22/1/2016
54.	Mr Christopher To Wing	Executive Director of the Construction Industry Council (CIC)	26/1/2016
55.	Mr Li Cheung On	Trade Test Superintendent of CIC	26/1/2016 27/1/2016
56.	Mr Lo Wing Hong	Principal Lecturer and Head of the Construction Department of the Institute of Vocational Education (Morrison Hill) of the Vocational Training Council (VTC)	27/1/2016 28/1/2016
57.	Mr Chan Tze Kin	Instructor of VTC	28/1/2016
58.	Mr Leung Man	Senior Instructor of VTC	28/1/2016
59.	Mr Kenneth Chan Sheung Yan	Chairman of the Hong Kong Plumbing and Sanitary Ware Trade Association	29/1/2016
60.	Mr Enoch Lam Tin Sing	Director of Water Supplies, the Water Supplies Department (WSD)	1/2/2016 2/2/2016 3/2/2016
61.	Mr Chan Kin Man	Chief Waterworks Chemist of WSD	3/2/2016 4/2/2016 5/2/2016

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
62.	Professor Joseph Lee Hun Wei	(Expert for the Commission) Chair Professor, Department of Civil and Environmental Engineering, the Hong Kong University of Science and Technology (HKUST) Vice President for Research and Graduate Studies, HKUST	15/2/2016 16/2/2016
63.	Professor John Fawell	(Expert for the Commission) Biologist/Toxicologist (Consultant on drinking water and environment)	16/2/2016 17/2/2016 18/2/2016
64.	Mr Hugo Kan	Licensed Plumber Expert witness for WSD	19/2/2016
65.	Mr Wong Chung Leung	Deputy Director of WSD	19/2/2016 22/2/2016 23/2/2016 24/2/2016
66.	Mr Leung Wing Lim	Assistant Director of WSD	24/2/2016
67.	Mr Lam Ching Man	Assistant Director of WSD	24/2/2016 25/2/2016 26/2/2016
68.	Mr Chan Hing	Engineer of WSD	26/2/2016
69.	Mr Cheung Yip Kui	Senior Engineer of WSD	26/2/2016 29/2/2016

	Name	Organisation, position and relevance to the Inquiry	Date of giving evidence
70.	Mr Chau Sai Wai	Chief Engineer of WSD	29/2/2016
71.	Mr Paul Ho Key Wei	Engineer of WSD	29/2/2016
72.	Dr Chan Hon Fai	Chairman of the Advisory Committee on Water Resources and Quality of Water Supplies Member of the Task Force on Investigation of Excessive Lead Content in Drinking Water	29/2/2016

LIST OF ABBREVIATIONS

A	
ACQWS	Advisory Committee on the Quality of Water Supplies
ADHD	Attention Deficit Hyperactivity Disorder
AP(s)	Authorised Person(s)
AQCC	Architectural Quality Control Coordinator
B	
BS	British Standard
C	
CA(s)	Chief Architect(s)
CBSE(s)	Chief Building Services Engineer(s)
CFD	Computational Fluid Dynamics
China State	China State Construction Engineering (Hong Kong) Limited
Ching Ho	Ching Ho Estate Phase 1
Choi Fook	Choi Fook Estate
CIC	Construction Industry Council
the Coalition	Coalition of the Victims of Contaminated Drinking Water
the Commission	Commission of Inquiry into Excess Lead Found in Drinking Water
CWRO	Construction Workers Registration Ordinance (Cap 583)
G	
Golden Day	Golden Day Engineering Company Limited
Guidelines	World Health Organisation's Guidelines for Drinking-water Quality
H	
HA	Hong Kong Housing Authority
Hang Lee	Hang Lee Engineering Company
HD	Housing Department
HKIA	Hong Kong Institute of Architects
HKCA	Hong Kong Construction Association

HKIE	Hong Kong Institution of Engineers
HKSAR	Hong Kong Special Administration Region
HKUST	Hong Kong University of Science and Technology
Ho Biu Kee	Ho Biu Kee Construction Engineering Company Limited
Hung Hom	Hung Hom Estate Phase 2

J

JECFA	Joint Food and Agriculture Organisation of the United Nations / World Health Organisation Expert Committee on Food Additives

K

Kai Ching	Kai Ching Estate
Kwai Luen	Kwai Luen Estate Phase 2

L

LGCQ	Liaison Group on Construction Quality
Lower Ngau Tau Kok	Lower Ngau Tau Kok Estate Phase 1
LP(s)	Licensed Plumber(s)
Lung Yat	Lung Yat Estate

M

μg/dL	micrograms per decilitre
μg/L	micrograms per litre
Ming Hop	Ming Hop Company Limited

O

the Ordinance	Commissions of Inquiry Ordinance (Cap. 86)

P

Paul Y	Paul Y. General Contractors Limited
PRH	Public rental housing
Prosperity	Prosperity Building Materials Company Limited
PSWTA	Hong Kong Plumbing and Sanitary Ware Trade Association

R

Review Committee	Review Committee on Quality Assurance Issues Relating to Fresh Water Supply of Public Housing Estates

S

Shek Kip Mei	Shek Kip Mei Estate Phase 2
Shui On	Shui On Building Contractors Limited

T

Task Force	Task Force on Investigation of Excess Lead Content in Drinking Water
Tung Wui	Tung Wui Estate

U

Un Chau	Un Chau Estate Phases 2 and 4
uPVC-lined pipes	Unplasticised polyvinyl chloride lined galvanised steel pipes
USCDC	United States Centres for Disease Control and Prevention
USEPA	United States Environmental Protection Agency

V

VTC	Vocational Training Council

W

WA	Water Authority
WHO	World Health Organisation
Wing Cheong	Wing Cheong Estate
Wing Hing	Wing Hing Plumbing Drainage
Wo Hing	Wo Hing Manufacturing Company
WSD	Water Supplies Department
WSP(s)	Water Safety Plan(s)
WWO	Waterworks Ordinance (Cap. 102)
WWR	Waterworks Regulations (Cap. 102A)

Y

Yan On	Yan On Estate
Yau Lee	Yau Lee Construction Company Limited

THE REPORT

I. INTRODUCTION

1. On 5 July 2015, a Legislative Council member held a press conference to announce that heavy metals were found in the water samples taken from some public and private buildings in Kowloon. Four samples from Kai Ching Estate (Kai Ching), a public rental housing (PRH) estate in Kowloon City, were found to contain more than 10 µg/L (micrograms per litre) of lead in drinking water, in excess of the provisional guideline value set out in the World Health Organisation (WHO)'s Guidelines for Drinking-water Quality (Guidelines) published in 2011.

Excess Lead in Public Rental Housing Estates

2. Kai Ching is one of the PRH estates completed in 2013. At present, there are 170 PRH estates in Hong Kong, housing about 30% of the population.

3. The Government took follow-up action by collecting water samples from different locations in Kai Ching for lead testing. According to announcements made by the Government between 9 and 11 July 2015, the lead content of seven water samples (out of 115 collected from Kai Ching) had exceeded the WHO provisional guideline value. Lead was found in the solder used on water pipes.

4. In the course of July 2015, the scope of water sampling tests had been extended several times :

(a) on 13 July, to cover four PRH estates, namely Lung Yat Estate (Lung Yat), Cheung Sha Wan Estate, Shui Chuen O Estate, and Kwai Luen Estate Phase 2 (Kwai Luen), where the fresh water plumbing systems were installed by the same Licensed Plumber (LP) who was responsible for the plumbing system at Kai Ching;

(b) on 15 July, to cover PRH estates completed since 2013, as well as Kwai Luen Estate Phase 1 which was completed in 2011;

(c) on 20 July, to cover PRH estates completed in 2011 and 2012; and

(d) on 24 July, to cover PRH estates completed in or after 2005, and eventually extending to all other PRH estates.

5. Water sampling and testing for all PRH estates was completed by 18 November 2015. Water samples from the following 11 PRH developments showed lead content above the WHO provisional guideline value:

(1) Kwai Luen (completed in 2014);

(2) Kai Ching (completed in 2013);

(3) Wing Cheong Estate (Wing Cheong) (completed in 2013);

(4) Lower Ngau Tau Kok Estate Phase 1 (Lower Ngau Tau Kok) (completed in 2012);

(5) Shek Kip Mei Estate Phase 2 (Shek Kip Mei) (completed

in 2012);

(6) Tung Wui Estate (Tung Wui) (completed in 2012);

(7) Hung Hom Estate Phase 2 (Hung Hom) (completed in 2011);

(8) Yan On Estate (Yan On) (completed in 2011);

(9) Choi Fook Estate (Choi Fook) (completed in 2010);

(10) Un Chau Estate Phases 2 and 4 (Un Chau) (completed in 2008); and

(11) Ching Ho Estate Phase 1 (Ching Ho) (completed in 2008).

Blood Tests and Medical Follow-up for Affected Persons

6. Following the incidents, the Department of Health and the Hospital Authority determined that children aged below six, pregnant women and lactating women were the most vulnerable groups of people affected by lead. Residents belonging to these groups in all the affected estates as well as residents residing in households with excess lead found in water samples were arranged to receive blood lead testing. In addition, children aged six to eight residing in the affected estates were also arranged to receive blood lead testing.

7. A health care plan developed by the Department of Health and the Hospital Authority was introduced. As far as PRH estates are concerned, lead exposure assessments and continuous blood lead level monitoring were arranged for all residents with borderline raised blood lead levels. In addition, children under 12 with elevated blood lead levels were provided with preliminary developmental assessments;

whereas young persons aged 12 to 18, adults, pregnant women and lactating women received health evaluations and follow-up as appropriate.

Investigation Undertaken by the Government

8. The Government set up the Task Force on Investigation of Excessive Lead Content in Drinking Water (Task Force) on 15 July 2015 to carry out investigation and to ascertain the causes in relation to incidents of lead in drinking water in PRH estates and to recommend measures to prevent recurrence of similar incidents in future. The Task Force was led by the Water Supplies Department (WSD) and its membership included representatives from relevant Government departments and academics/experts outside the Government. The Task Force conducted tests on different components along the water supply chain such as valves, joints, pipes and fittings, and published its final report on 31 October 2015.

9. The Hong Kong Housing Authority (HA) set up the Review Committee on Quality Assurance Issues Relating to Fresh Water Supply of Public Housing Estates (Review Committee) on 24 July 2015, with a view to reviewing the present arrangements for quality control and monitoring in relation to the installation of fresh water supply system in PRH estates. The Review Committee published its final report on 8 January 2016.

The Appointment of the Commission

10. The Commission of Inquiry into Excess Lead Found in Drinking Water (the Commission) was appointed by order of the Chief Executive in Council on 13 August 2015, pursuant to section 2 of the Commissions of Inquiry Ordinance (Cap. 86) (the Ordinance). The Terms of Reference of the Commission are to:

(a) ascertain the causes of excess lead found in drinking water in PRH developments;
(b) review and evaluate the adequacy of the present regulatory and monitoring system in respect of drinking water in Hong Kong; and
(c) make recommendations with regard to the safety of drinking water in Hong Kong.

11. Pursuant to section 3 of the Ordinance, the Chief Executive in Council has also directed, among other things, that the determination of any criminal or civil liability of any party (whether individual or legal entity) shall be outside the Terms of Reference of the Commission.

The Appointment of Counsel, Solicitors and Expert Witnesses

Counsel and Solicitors

12. On 15 September 2015, Messrs Lo & Lo were engaged as solicitors for the Commission. Pursuant to section 6(4) of the Ordinance, on 2 October 2015, Mr Paul Shieh, S.C., Mr Richard Khaw, and Miss

Bonnie Cheng were appointed as Counsel for the Commission.

Expert Witnesses

13. Pursuant to the power granted to the Commission, a total of three experts had been appointed :

(a) Professor David Bellinger : Neurologist and Developmental Psychologist

14. On 16 October 2015, Professor David Bellinger, a neurologist and developmental psychologist from the U.S.A., was appointed to assist the Commission in the inquiry. Professor Bellinger is a professor of neurology and psychology at the Harvard Medical School, and a professor in the Department of Environmental Health at the Harvard School of Public Health. He is also the Chairman of the WHO Committee which is responsible for the formulation of guidelines for United Nations member states on the diagnosis and treatment of lead poisoning. Professor Bellinger submitted his expert report to the Commission on 1 December 2015 (**Appendix 1**) and gave evidence at the Commission's hearing on 15-16 December 2015. He explained the health effects of elevated blood lead level in general on different categories of persons, including children, pregnant women and lactating mothers, etc. He also explained the guidelines adopted by WHO on the content of lead in drinking water and on blood lead levels, and gave opinions on the adequacy and suitability of the care plan adopted by the Hong Kong Special Administrative Region (HKSAR) Government.

(b) Professor John Fawell : Biologist and Toxicologist

15. On 19 October 2015, Professor John Fawell, a biologist and toxicologist from the U.K., was appointed to assist the Commission in the inquiry. Professor Fawell has worked extensively with WHO for nearly 30 years on drinking water quality, and since 1988 has been a member of the coordinating team for the Guidelines and other WHO's publications. Professor Fawell submitted a preliminary joint expert report (together with Professor Joseph Lee) and a final expert report to the Commission on 12 November 2015 and 4 February 2016 respectively (**Appendices 2 and 3**), and gave evidence at the Commission's hearing on 16-18 February 2016. Professor Fawell expressed his opinions on the findings of the Task Force's Final Report. He explained the history and development of the Guidelines and the rationale behind the determination of guideline value. He also reviewed the adequacy of the existing regulatory and monitoring regimes on quality of drinking water in Hong Kong and made various recommendations.

(c) Professor Joseph Lee : Civil Engineer

16. On 28 October 2015, Professor Joseph Lee, a civil engineer, was appointed to assist the Commission in the inquiry. Professor Lee is the Chair Professor of the Department of Civil and Environmental Engineering, and the Vice President for Research and Graduate Studies of the Hong Kong University of Science and Technology (HKUST). Professor Lee submitted his preliminary joint expert report (together with Professor John Fawell) and a final expert to the Commission on

12 November 2015 and 5 February 2016 respectively (**Appendices 2 and 4**), and gave evidence at the Commission's hearing on 15-16 February 2016. Professor Lee and his research team from HKUST conducted independent investigation into the factual causes of excess lead in drinking water and examined the methodology adopted by the Task Force and its findings.

The Commission's Rules and Procedures

17. Pursuant to section 4(1)(m) of the Ordinance, at the preliminary hearing held on 20 October 2015, the Commission determined the rules and procedures to be followed at the inquiry (**Appendix 5**).

Participation and Representation of Parties in the Proceedings

18. The Commission noted that the 11 affected PRH estates were built by HA, a statutory body established under the Housing Ordinance (Cap. 283) to develop and implement Hong Kong's public housing programme. The Housing Department (HD) is the executive arm of HA. Acting as a developer, HA engaged main contractors in the construction of the affected PRH estates. The main contractors further contracted out all plumbing works to subcontractors / sub-subcontractors in order to fulfil their contractual obligations.

19. The construction of plumbing installations is governed by the Waterworks Ordinance (Cap. 102) (WWO). Section 15 of WWO stipulates that no inside service shall be constructed, installed, maintained, altered, repaired or removed by a person other than a licensed plumber or

a public officer authorised by the Water Authority (WA), except for alterations or repairs which are, in the opinion of WA, of a minor nature, or the rewashing of a tap.

20. Against the above background, pursuant to sections 6(1) and (2) of the Ordinance and upon applications made by interested parties, the Commission has determined that various parties may participate and be legally represented in the proceedings on the basis that their conduct is or may fall within the ambit of the inquiry or that they are in any way implicated or concerned in the subject matter of the inquiry. The persons in respect of whom such determinations have been made are:

Government and public bodies

(1) WSD, represented by Dr William Wong, S.C., leading Mr Abraham Chan and Mr Lewis Law, on the instructions of the Department of Justice.

(2) HA, represented by Mr Ambrose Ho, S.C., leading Mr Michael Yin, on the instructions of Messrs Stephenson Harwood.

Contractors, licensed plumbers and other parties involved in the construction of the 11 affected public rental housing developments

(3) Yau Lee Construction Company Limited (Yau Lee), Ming Hop Co. Ltd. (Ming Hop), and Mr Ng Hak Ming (a licensed plumber), represented by Ms Maggie Wong, Mr

Kenneth Chung, Mr Tony Li and Ms Tanie Toh on the instructions of Messrs T. H. Koo & Associates.

(4) China State Construction Engineering (Hong Kong) Limited (China State), represented by Mr Ian Pennicott, S.C., leading Ms Catrina Lam, on the instructions of Messrs Mayer Brown JSM.

(5) Paul Y. General Contractors Limited (Paul Y), represented by Dr Gerard McCoy, S.C., leading Mr Eric Chung and Mr Daniel Hui, on the instructions of Messrs Deacons.

(6) Shui On Building Contractors Limited (Shui On), represented by Mr Osmond Lam and Ms Baltic Cheng on the instructions of Messrs Mayer Brown JSM.

(7) Ho Biu Kee Construction Engineering Company Limited (Ho Biu Kee), represented by Mr Yeung Ming Tai and Mr Lee Kin Wang on the instructions of Messrs Chiu, Szeto & Cheng.

(8) Golden Day Engineering Company Limited (Golden Day) and Mr Cheung Tat Yam (a licensed plumber), represented by Mr Alfred Wu and Mr Kevin Kong of Messrs Norton Rose Fulbright[6].

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[6] Mr Yung Kwok Choi (a former employee of Golden Day) and Ms Lam Lai King (a current employee of Golden Day) had separate legal representation. Mr Yung was represented by Ms Frances Lok on the instructions of Messrs Gall. Ms Lam Lai King was represented by Mr Lawrence Hui on the instructions of Messrs ONC Lawyers.

(9) Wing Hing Plumbing Drainage (Wing Hing), represented by Mr Mok Hoi Kwong, acting in person.

(10) Hang Lee Engineering Company (Hang Lee), represented by Mr Siu Kin Wong, acting in person.

(11) Mr Lam Tak Sum (a licensed plumber), acting in person.

(12) Prosperity Building Materials Co. Ltd (Prosperity), represented by Mr Chow Sik Lun of Messrs LCP Lawyers.

Affected residents

(13) Coalition of the Victims of Contaminated Drinking Water (Lee Pui Yi, Chong So Nga, and Liu Hui Ping) (the Coalition), represented by Mr Martin Lee, S.C., leading Mr Jeffrey Tam, Ms Senia Ng and Mr Chris Ng, on the instructions of Messrs Ho Tse Wai, Philip Li & Partners.

Ambit of the Material and Testimonies Received by the Commission

21. By orders made during the inquiry, the Commission required the parties set out in paragraph 20 above to produce to the Commission and on a continuing basis a range of material, including in particular witness statements and relevant documents/records. In consequence and as a result of their compliance with those orders, a huge amount of material had been made available to Counsel for the Commission, from which material relevant to the Commission in the discharge of its duties had been received by the Commission in its hearings.

22. The Commission also received witness statements, reports, and documents/records from the Government Laboratory, Department of Health, Wo Hing Manufacturing Company (Wo Hing), Construction Industry Council (CIC), Vocational Training Council (VTC), Hong Kong Plumbing and Sanitary Ware Trade Association (PSWTA), Hong Kong Institution of Engineers (HKIE), Hong Kong Institute of Architects (HKIA), and Hong Kong Housing Society.

23. Almost all witnesses who had testified orally had been referred to prior witness statements addressing the subject of their testimony. Generally, in their oral testimony, given under oath or affirmation, such witnesses acknowledged the prior statements, amended or qualified in such way as they wished to do, as being true to the best of their knowledge and belief. Similarly, witnesses whose evidence had been received as that of an expert had produced reports to the Commission which they had addressed in their oral testimony. A list of witnesses is at pages vi to xiv.

24. Throughout the proceedings, the Commission had posted on its website on a daily basis a transcript of each day's proceedings. Most of the witness statements received by the Commission had been read into the transcripts when the respective witnesses gave oral testimony.

II. THE CAUSES OF THE INCIDENTS

Adverse Effect of Lead

25. Professor David Bellinger was instructed by the Commission to provide expert opinion on (a) health effects of elevated blood lead level on human beings; (b) the internationally accepted guidelines on the content of lead in tap water and blood; (c) the evaluation of the guidelines and parameters in (b) above; (d) the adequacy and suitability of the reference values for blood lead level and the care plan by the HKSAR; and (e) the adequacy and suitability of the acceptance criteria laid down by WSD for heavy metals.

26. More is known about the adverse effects of lead on human health than about any other environmental chemical.

27. Lead impairs processes that are fundamental to many aspects of the way our bodies work. Chemically, lead is a divalent cation similar to calcium and interferes with a lot of the biological processes that depend upon calcium. Nerve cells in our brain which communicate with one another are dependent on calcium, so lead interferes with the communication between cells in the brain. Lead interferes not just the transmission of information, but also the laying down of the fine structure of the nervous system. It interferes with processes that are important in long-term memory and storage of information. So lead is both a developmental neurotoxicant and a functional neurotoxicant.

28. The blood-brain barrier within our body limits the size of molecules that can pass into the brain. In children, the blood-brain barrier is not so tight. Molecules such as lead can get into the brain more easily in young children than in adults. Further, children only receive one chance to develop their brain, and so lead should be prevented from interfering with the complex spatial and temporal choreography involved in putting a brain together, which involves billions of nerve cells that have to be in the right place at the right time in order for normal brain development. That explains why the central nervous system is more vulnerable in children. Once lead gets into the brain of children, it settles inside and has an easier time getting in than getting out.

29. Lead is often characterised as a "multi-media" pollutant because of the diverse ways in which human exposure can occur. The major classes of sources and pathways of exposure to inorganic lead (the form of lead in solder) include food, air, soil, paint and water, although exposure can also occur as a result of many other activities (e.g. use of contaminated herbal medicines). Once lead enters the body, its toxicity is the same regardless of the source and pathway through which exposure occurred.

30. The lead in a person's body resides in three major "pools" namely, bone, soft tissues and blood. Among adults approximately 90% of the total body burden is in mineralised tissues, such as bone. The lead accumulated in hard (cortical) bone might remain there for several decades, whereas the lead accumulated in more porous (trabecular) bone,

which is in greater contact with the circulatory system, might remain there for much less time. In children, lead in bone accounts for approximately 70% of the total body burden, and appears to move in and out of bone much more rapidly than it does in adults due to the rapid changes in bone turnover that occur during childhood. Most of the rest of an individual's body burden of lead is in soft tissues such as the brain, liver and kidneys. Only a small percentage, about 5%, is in blood.

31. Lead can be mobilised from mineralised tissues and re-introduced into blood by a variety of physiologic and pathophysiologic states that increase bone turnover, such as pregnancy and lactation.

32. Therefore, the blood lead level measured for an individual at any given time reflects the equilibrium between the individual's current exposure to "new" lead and the "legacy" lead from past exposure. The half-life of lead in blood is approximately 30 days. That however does not mean that an individual's blood lead level will fall by half in a month's time if major exposure sources and pathways are removed.

33. As pointed out by Professor Bellinger, three groups of human population are particularly vulnerable to lead exposure: children, pregnant women and lactating mothers.

Infants and Children under Six Years of Age

34. Humans of any age can be harmed by exposure to lead, but young children are considered to be the most vulnerable subgroup of the population, and the developing central nervous system is considered to be

the most vulnerable organ. Children with blood lead levels below 25 μg/dL (micrograms per decilitre) generally do not show any signs or symptoms that bring them to medical attention. However, children with blood lead elevation at such levels are at increased risk of a variety of cognitive and behavioural adversities that are persistent and affect many aspects of an individual's health and well-being.

35. There are independent studies which suggest that children with blood lead level of 0 μg/dL will, all other things being equal, have an IQ score about five points higher than children with blood lead level of 10 μg/dL. Early-life exposure produces persistent changes in brain structure and function.

36. According to Professor Bellinger, there is sufficient evidence to conclude that blood lead levels <5 μg/dL in children are associated with adverse neurological effects, including reduced intelligence, neuropsychological function, and academic achievements and increased incidence of attention-related and other problem behaviours.

Children and Teenagers between 6 and 18 Years

37. Scientific evidence also shows that the inverse associations between early-life lead exposure and neurodevelopment persist, though perhaps in somewhat weakened form, over this interval.

38. The evidence is sufficient for the association between blood lead level <10 μg/dL and decreased hearing, delayed puberty, and reduced postnatal growth.

39. A considerable body of evidence now exists in support of the hypothesis that greater lead exposure places a child at increased risk of meeting diagnostic criteria for Attention Deficit Hyperactivity Disorder (ADHD). Studies have also suggested that greater childhood lead exposure is associated with an increased propensity for violence and aggression.

40. Certain areas of the brain are more vulnerable to the effects of lead than other areas. One of the primary areas is the frontal lobe where the executive functions, such as the ability to do long-term planning and organisation, the ability to develop strategies and to adapt the strategies in the face of new information, and the ability to delay gratification, are situated. It is believed that children with too much lead are more prone to ADHD and behavioural problems because executive functions are the major underlying deficit of children with ADHD.

41. Lead is also particularly dangerous to a small area of the brain called the hippocampus where learning and memory take place. So children may have trouble keeping up in school, may get into behavioural difficulties, and may have increased propensity to aggression, because they cannot delay gratification due to the executive function impairment.

Pregnant Women

42. Certain physiologic changes associated with pregnancy, and with the progression of pregnancy, alter lead kinetics in complex ways. Lead crosses the placenta by the process of passive diffusion. As a

result, the concentration of lead in the umbilical cord blood of a neonate will be similar to the concentration of lead in maternal blood at delivery. In other words, the lead exposure of a foetus is essentially the same as that of the pregnant woman.

43. Studies have shown that a greater concentration of lead in maternal blood during pregnancy or in the cord blood is significantly associated with pregnancy hypertension and elevated blood pressure during pregnancy and delivery. Studies using lead isotopic ratios have also shown that a substantial fraction of the lead in the blood of a pregnant woman cannot be attributed to her current external exposure but reflects lead from past exposure that has been mobilised by the rapid turnover of bone that occurs during the second and third trimesters of pregnancy.

44. Many studies have evaluated lead exposure as a risk factor for outcomes such as length of gestation, birth weight, birth length, head circumference and congenital anomalies. Although significant associations have been reported, the evidence is however inconsistent.

Lactating Mothers

45. Bone turnover is greater during lactation than pregnancy and continues as long as an infant is nursing. As much as 5% of a woman's bone mass is mobilised during this period. Isotopic studies of the lead in breast milk indicate that at least some of the lead comes from maternal bone, and the concentration of lead in maternal bone is positively related

to the concentration of lead in breast milk. However, the concentration of lead in breast milk is low, comparable to that in the blood. Thus, this pathway of exposure likely contributes relatively little to an infant's lead exposure. Balancing the known benefits of breastfeeding and the slight risks of substantial lead exposure from breastfeeding, the United States Centres for Disease Control and Prevention (USCDC) encourages mothers with a blood lead level ≤40 μg/dL to breastfeed.

46. Water however can be a very important pathway of lead exposure for infants who consume formula made up with water that contains lead.

Lead Concentration and Blood Lead Levels

47. Professor Bellinger also told us the development and evolution of the WHO guideline value in respect of lead.

48. In 1958, WHO recommended a maximum allowable lead concentration of 100 μg/L in water. This recommendation was health-based. In 1963, it was reduced to 50 μg/L. In the first edition of the Guidelines published in 1984, a health-based guideline value of 50 μg/L again was recommended. In its 1993 edition, the guideline value was lowered to 10 μg/L.

49. In 2011, the guideline value of 10 μg/L was evaluated and retained. However, it was designated as "provisional" on the basis of treatment performance and analytical achievability.

50. Further details concerning the history and development of lead's guideline value will be discussed when we come to Professor Fawell's evidence. It is sufficient to say at this juncture, that both experts in their evidence stated quite clearly that over the years, the guideline value had changed from health-based to non-health-based.

51. Professor Bellinger pointed out that as far as the U.S.A. was concerned, the allowable concentration of lead in water was established under the Safe Drinking Water Act 1974. Until 1991, the limit had been 50 μg/L.

52. After the passage of the Lead and Copper Rule in 1991, the allowable concentration was lowered to 15 μg/L. Usually, lead does not enter water at the source but as a result of corrosion of plumbing materials in the distribution system, and typically those materials are close to the point of consumption. This is particularly the case in the U.S.A. where lead water pipes are prevalent. Therefore, the allowable concentration of 15 μg/L is regarded as an action level that warrants further follow-up by the authorities. If the lead concentration of more than 10% of the tap water samples collected exceeds the 15 μg/L level, the water supplier is required to take steps to reduce exposure, including adopting the treatment technique established by the United States Environmental Protection Agency (USEPA) to reduce the corrosivity of water which aggravates the leaching of lead from the distribution system.

53. As for blood lead level, WHO at present identifies 10 μg/dL as the upper limit. It is considered that the absence of a threshold for lead

toxicity means that no level of exposure is safe (thus "tolerable").

54. USCDC identified 10 μg/dL as an "action level" in 1991. The current consensus in the U.S.A. is that there is no "safe" blood lead concentration below which adverse effects do not occur. In 2012, USCDC abandoned the concept of an "action level", substituting for it a "reference level". Reference level is defined solely on a statistical basis and is no longer a health-based value, and its purpose is simply to identify children who are the most exposed.

55. As stated by USCDC, because of the absence of an identified threshold for adverse effects, it could not specify "an allowable exposure level, level of concern, or by other bright line intended to connote a safe or unsafe level of exposure".

56. Having examined the blood lead levels of individual residents from the affected estates, Professor Bellinger noted that there was a decline in their blood lead levels between their baseline and follow-up blood test after measures had been introduced to reduce their exposure to lead in their drinking water. An average decrease of 13-14% was seen in pregnant women whereas an average decline of 30% was seen in other individuals.

57. Professor Bellinger came to the view that there was a positive relationship between the level of lead in water and the blood lead level of individual residents and that it was not necessary to conduct any isotopic analysis of blood samples to identify the origin of lead.

58. Professor Bellinger was of the opinion that the acceptance criteria laid down by WSD in respect of lead (≤ 10 µg/L), cadmium (≤ 3 µg/L), chromium (≤ 50 µg/L) and nickel (≤ 70 µg/L) were based on sound reasoning. In short, these values followed the Guidelines.

59. As to the care plan adopted by the Department of Health, Professor Bellinger told us that because of the multiplicity of sources and pathways of lead exposure, there might be sources and pathways other than water that contributed to an individual's continued blood lead elevation. For blood lead levels at 44 µg/dL and below, the interventions would be environmental investigation and assessment. An environment investigation and assessment would necessary involve consideration of lead hazards in an individual's home environment (paint, food, hobbies, use of folk medicines, children's toys, etc.), outside activities (soil, proximity to lead-emitting point sources), and any other environments in which an individual spent substantial time (e.g. school, day care centre, workplace). Apart from that, there is unfortunately not much else to offer.

60. Continued follow-up blood lead testing for individuals whose blood lead concentration remains above the age-appropriate reference value is very important. The use of chelation is counter-productive in children with blood lead level below 44 µg/dL because it chelates not only lead but chemicals such as calcium and zinc. There is some renal toxicity, so it is not performed below 45 µg/dL. Given the blood lead level of the affected children, Professor Bellinger was of the view that it would be unlikely for them to show signs or symptoms of lead toxicity

and that any shift in terms of mean level of performance would be unnoticeably minor.

61. Professor Bellinger concluded that lead served no biological purpose in the body. There was no "safe" level of lead, as adverse effects in different organ systems, particularly the central nervous system, had been observed at blood lead levels less than 5 μg/dL. Therefore, the ideal blood lead concentration for a human would be 0 μg/dL.

62. The many sources and pathways of lead exposure complicate the path to achieving this goal. Removing one pathway and source may produce only a modest reduction in blood lead level. That lead is an accumulative toxicant stored in multiple pools in the body besides blood introduces an additional complication.

63. The data available demonstrating an average reduction of approximately 30% in the blood lead levels of residents of the affected PRH estates following interruption of the water pathway suggested that lead in the drinking water was, indeed, contributing to the exposure of the residents. And Professor Bellinger was satisfied that the general components of the care plan proposed for residents by the Department of Health were appropriate.

Independent Investigation

64. Following the incidents, Professor Lee was instructed to:

(a) conduct, if necessary, independent investigation on behalf of the Commission to ascertain the factual sources of excess lead found in drinking water in PRH; and

(b) evaluate the methodologies and review and verify the findings of the Task Force.

65. Between July and September 2015, WSD collected a number of drinking water samples in the PRH estates of Hong Kong. 106 samples in 11 estates were found to exceed the WHO provisional guideline value of 10 μg/L. In addition, the Task Force also conducted an investigation into the causes of excess lead. It concluded, in October 2015, that the main cause of the excess lead was the use of leaded solder in the construction of the fresh water supply plumbing system.

66. As explained by Professor Lee, the lead concentration of drinking water at the consumer tap in a PRH estate building depended on a complex myriad of factors including: the time of consumption and prior use, the sources of lead in the water supply system, the pipe material and chemical properties of the water, detailed plumbing arrangements, and the age of the building. Different methods of sampling the same household supply would also give different results. There was currently no universally accepted method for sampling lead in drinking water; the appropriate method depended on the particular purpose for which sampling was carried out.

67. The lead concentration measured by WSD on the 1,325 drinking water samples in the 11 affected estates were all based on

"fully-flushed" samples (i.e. for each flat a 250mL sample was taken after flushing the tap for 2-5 minutes). While this sampling method provided a measure of general water quality of the bulk water supply, it did not reflect the actual and sometimes high lead concentrations to which the residents were exposed. Such data did not provide an estimate of the mean lead concentration used for drinking and cooking, nor an adequate basis for assessment of health risks.

68. Professor Lee added that unlike other countries, lead pipes were not used in the water supply system of Hong Kong. The deposition, release and transport of any lead introduced into the highly compact labyrinth of water supply system in a PRH estate building was a unique feature that had previously not been studied. In view of the enormous scale of the problem and the paucity of data, he resorted to the use of a computational fluid dynamics (CFD) model to assist with the data interpretation.

69. When water tap was not in use, say overnight, the water in the supply chain of a particular flat would have been stagnant. Lead deposits would be released into the water through chemical reaction and molecular diffusion. The lead concentration in the system would also increase with time. The distribution of the dissolved lead along the supply chain both during stagnation and after opening the tap could be obtained through the CFD modelling. The aim was to provide an indirect check on the lead leaching rates measured by Professor Lee's team and the Task Force, and to gain more insights into the causes and possible mitigation measures against risks of drinking lead-contaminated

water in PRH estate flats in Hong Kong.

70. Given the inadequacies of the "fully-flushed" method, Professor Lee and his team designed a field sampling programme and implemented it during 2 to 22 December 2015. The aim was to provide an independent data set for identification of the causes of lead contamination and to provide a basis for assessment of health risk. The sampling covered 36 buildings in the 11 affected estates and seven buildings in six selected unaffected estates: Shui Chuen O Estate, Yee Ming Estate, Choi Tak Estate, Kwai Chung Estate, Un Chau Estate Phase 5 and Sau Mau Ping South Estate. In each building, three flats at upper, middle and lower levels were randomly selected by HD. In total, 129 flats were sampled.

71. For each flat, a total of five samples were taken from the kitchen tap with the water continuously flowing: a "first-draw" sample and four subsequent samples at 20 second intervals. The sampling was carried out in the early morning between 6:30 and 9:00 am and the residents were informed by HD's staff to flush the kitchen and wash basin taps the night before for five minutes before going to bed, and not to use the kitchen tap afterwards before the sampling. The tap flow rate was also measured.

72. More detailed sampling was carried out in three vacant flats of three estates. The aim was to study how lead concentration at the kitchen tap varied with time in relation to water stagnation in the water supply chain of the individual flat. This would provide a systematic

data set for comparison of different sampling methods, for assessment of health risks, and for calibration and validation of the CFD model. For these flats, two additional sampling taps were installed with the assistance of WSD and HD: one at the water meter position for the flat and one at the entry location to the flat.

73. As explained by Professor Lee, any sources of lead introduced into the drinking water supply system would affect the lead concentration at the consumer tap. It is logical that we should first examine the quality of Hong Kong's raw water supply. The data kept by WSD for Muk Wu Pumping Station between April and July 2015 indicated the presence of very low level of lead in raw Dongjiang water. Muk Wu Pumping Station is the first waterworks facility where raw Dongjiang water enters Hong Kong. The level of lead was between undetectable and 1.8 μg/L. The data from the WSD treatment plants for the same period indicated the absence of lead in treated water.

74. Since WSD's measurements indicated the absence of any lead contamination in the supply line to each building, the roof tank and the down pipe, the focus of Professor Lee's investigation was on the release, accumulation, and transport of the lead in the branch water supply chain from the down pipe to the individual flats on each floor.

75. The tests conducted by WSD soon after the incidents indicated that the quality of drinking water before it travelled down from the roof tank of the affected estates was not compromised. There was no evidence of any problems with the quality of water distributed from the

WSD treatment plants to the connection points. As such, attention was focused on the quality of water in the inside service.

76. The result of the independent sampling revealed that 47.2% of the first-draw samples collected by Professor Lee's team had excess lead, as compared with 8.0% of the fully-flushed samples collected by WSD from the affected estates.

77. Two characteristic patterns of lead concentration's variation with time were observed. In about 37% of the cases in which lead was detected, the maximum concentration was observed in the first-draw sample. In other cases (around 63%), the maximum concentration was detected in the second sample at t=20 sec. This second pattern was mostly found in flats completed in or after 2010. The delayed peak concentration was usually found in flats with higher lead contamination, and probably reflected the relative location or the origin of the lead source (i.e. whether the lead originated from the meter room, corridor, or inside the flat).

78. While general patterns could be discerned, the sampling also indicated occasional samples that would not follow any general trend. Such outliers were rare but reflected the complexity of the problem once lead sources were introduced into the water supply chain.

79. The detailed data from the three vacant flats pointed to the sources of lead in the water supply chain of the flats. The sampling showed significant lead concentrations measured at the water meter

positions as well as at the locations of first entry to the flats. This meant most of the lead contamination came in the pipe network in the meter room, and along the corridor leading to the flat. This was consistent with the findings reported by the Task Force. It was clear that the elbows and joints contributed significantly to the lead contamination.

80. Based on a holistic assessment of the collective WSD and HKUST data, and the CFD modelling, Professor Lee concluded that the main cause of the excess lead found in drinking water of PRH estates was due to the leaching of significant lead deposits in the pipe joints and fittings (e.g. tees, elbows, valves, meters). From a soldering demonstration seen by Professor Lee and the WSD data, he came to the view that leaded soldering material could be introduced into the pipe joints due to over use of leaded solder and/or poor workmanship.

Review of Task Force Findings

81. Regarding the Task Force's findings, Professor Lee opined that WSD and the Government Laboratory had carried out a thorough and substantial investigation within the time and other constraints. In particular, the dismantling and chemical analysis of the key components of the water supply chains of three representative flats, i.e. two at Kai Ching and one at Kwai Luen, was a sensible and practical step.

82. Professor Lee told us that the direct measurements by the Task Force on the lead content and leaching rates of pipe sections, joints (elbows, sockets, tees) and fittings (meters, valves, taps) provided

valuable data to unravel the causes of excess lead. Given the mass of lead deposited in the components of the water supply chain, it could be roughly estimated that it could take as long as 5 to 10 years for most of the lead mass to be leached into the water, especially for the pipe joints.

83. The use of the isotopic analysis by the Task Force to ascertain the correlation between lead in water and the lead in the solder joints was judged by Professor Lee to be reasonable and valid.

84. Measurements by the Task Force on pipe joints in the flat in Hung Hei House of Hung Fuk Estate, where stainless steel pipes with mechanical joints and copper pipes with lead-free solder joints were used, showed the absence of lead. The pipe joints and fittings in these flats were otherwise similar to flats in the affected estates. This control experiment provided solid evidence that the leaded solder joints should be the main cause of excess lead in drinking water and the relative insignificant lead contribution of copper alloy fittings.

85. Professor Lee concluded that based on the average kitchen tap flow rate of 0.26 L/s, turning on the tap for 2-5 minutes (say, 3 minutes) would cover a supply chain pipe length of over 100 metres. Assuming a typical pipe length of around 20 metres, this would translate to more than "5 plumbing volumes". Hence WSD's sampling method would essentially produce fully-flushed samples according to generally accepted definitions. WSD's sampling would not give the maximum or average lead exposure levels of the consumers. While the independent planned sampling and analysis of lead contamination of 43 buildings in 17 PRH

estates conducted by Professor Lee had confirmed the main Task Force findings, the more detailed sampling had resulted in a more accurate assessment of the extent of lead contamination in the different estates and buildings. Lead contamination in the densely populated PRH estates seemed to be dominated by leaded solder deposits in the numerous joints of the water supply chain from the down pipe to the individual flats. The lead concentration at the kitchen tap varied with time in a complex manner possibly due to the random nature of the lead deposits in the system.

86. Both the sampling data and CFD results indicated that lead concentration in most cases dropped rapidly within 30-60 seconds. A flushing time in the order of half to one minute therefore appeared to be adequate for guarding against risks of lead contamination.

87. Having listened carefully to Professor Lee's evidence, we have no hesitation in accepting Professor Lee's conclusion: leaded solder joints were the main cause of excess lead in drinking water. Although some of the copper alloy components did contain lead in excess of their permissible limit, their contributions to the overall lead concentration were limited and insignificant for the purpose of the present inquiry.

Sampling Protocol

88. Following the incidents, HD sought the assistance of WSD to conduct water testing on all the PRH estates. In our view, the foremost important matter that both HD and WSD had to decide at the time was the purpose and objective of the testing. Only after the purpose and

objective had been set could an appropriate sampling protocol be designed and implemented.

89. In our view, the purpose and objective from the perspective of HD or the residents ought to be very simple and straightforward: to see if the drinking water had been affected or contaminated by the presence of lead. There was simply no point in testing the water quality as supplied, i.e. the water quality at the connection point of the lot boundary, for there was no suggestion the water mains had been contaminated.

90. In his first statement to the Commission dated 26 October 2015, Mr Chan Kin Man, Chief Waterworks Chemist of WSD, said:

> "**Taking of samples by WSD**
>
> 4. Since the discovery of lead in drinking water, WSD has taken samples of Plumbing Materials and water samples for testing in two separate contexts.
>
> (a) To assist the Housing Department ("HD") to take water samples and samples of Plumbing Materials for examination by the Government Laboratory (except plumbing materials of Kai Ching Estate which was sampled and tested by a laboratory engaged by the HD) in order *to identify which public rental housing estates/developments are affected*; and
>
> (b) Separately, the Task Force of WSD arranged sampling and testing for its own investigations." [*emphasis added*]

91. It was in the context of "discovery of lead in drinking water" that WSD decided to take water sample "in order to identify which public rental housing estates/developments are affected". In other words, the purpose was to investigate the extent of excess lead problem in PRH estates.

92. The decision on which PRH estate was to be identified as an affected estate was a crucial one since it would have a direct bearing on whether the Government would make available remedial measures, including blood lead level testing; provision of standpipes; supply of bottled water; installation of temporary water points; provision of filters; and replacement of pipes to the residents. So long as one water sample exceeded the provisional guideline value for lead, the whole estate would be classified by the Government as an affected estate.

93. The sampling protocol adopted at the time and indeed throughout the remaining months of 2015 when conducting the same test for other PRH estates was based on WSD's sampling procedure as set out in its own sampling manual:

> "7.1.3.2 Turn the tap on at maximum flow and let the water to flow for a minimum of 2 minutes (preferably about 5 minutes when sampling for trace metal analysis) in order to flush the interior of the nozzle and to free the service pipe of stagnant water. The period of flushing time required depends on the length of the service pipes or sample lines, type of sampling tap, water turnaround time of the system, on-site water quality data such as the level of residual chlorine, or follow instruction given by Waterworks Chemist."

94. WSD claimed that its sampling procedure was established with reference to ISO 5667-5:2006 which stated as follows:

> "6.4.1 **General**
>
> Depending on the objectives of the monitoring programme, it should be decided whether samples are required from faucets as they are found, whether samples should be collected after cleaning, disinfecting and flushing of the faucets, or whether samples are required before and

after such cleaning, disinfection and flushing. Whether or not faucets are cleaned, disinfected or flushed prior to sample collection depends on the sampling purpose. *If the effects of materials on water quality are being investigated, then the initial draw-off should be sampled.* Samples may also be taken after a specified period of stagnation to provide information on the rate at which materials affect water quality or the maximum likely effect. *If the quality of the water as supplied to premises is to be checked, then the faucets should be cleaned and flushed at a uniform rate for 2 min to 3 min or longer if necessary to achieve constant temperature before samples are collected.* The faucets should be cleaned, disinfected and flushed if samples are to be collected for microbiological analysis. Faucets should be left flowing at a steady rate during sampling." [*emphasis added*]

95. We find it difficult to appreciate WSD's sampling protocol. ISO 5667-5:2006 states that if one wants to find out the effects of materials on water quality, one should sample the initial draw-off. Our reading is that WSD should have taken initial draw-off samples in order to assess the lead contamination in the present incidents. Flushing the interior of the nozzle for such a long period of time may exclude any metal contamination caused by the terminal fittings, so that one can find out the true value of trace metal in water as supplied. Both the freeing of service pipe of stagnant water and the achievement of constant temperature aimed at one goal: the water sampled came from the water mains.

96. Professor Lee and Professor Fawell expressed their concerns and published their preliminary joint expert report on 12 November 2015. Throughout the inquiry, WSD insisted that a flushed sample would provide a representative sample of the average quality of drinking water. This proposition was rejected in the preliminary joint report. The two

experts expressed their disapproval of the sampling protocol used by WSD and stated that "data from fully-flushed samples are not likely to be representative of the extent of lead exposure". Professor Fawell further elaborated in his own report that "typically first-draw water will have a much higher concentration of lead but this may not reflect the concentrations of lead in water ingested in normal use. Equally, flushed samples would be expected to underestimate the concentration of lead in water ingested in normal use."

97. Professor Fawell told us that testing water at source might be helpful for most of the parameters that one was measuring in drinking water for quality. But for parameters that were influenced by the internal plumbing system or from the point where the supply came into a particular building or property or to the tap, that was not the case. Professor Fawell said at the hearing that :

> "We are looking at the guidelines for metals particularly…the concentration may change as a consequence of the internal distribution system, the internal plumbing system, or may arise completely from that system. Then you need to take into account how that will work within that system. So looking at the water before it arrives, basically, at the tap, which is what you are basically doing, will tell you about all the other parameters. It will also tell you whether those particular metals are present in the water coming through, and in fact nickel is an example. You do find some nickel which is present in the raw water, before treatment…but it doesn't tell you exactly how much will be coming from the internal plumbing…"

98. Since we had a situation where the inside service was a possible source, testing flushed samples alone could not help us identify the contamination fully. Also, in the case of lead, where we did not

have a health-based guideline value, WSD should not be looking at exposure with the WHO provisional guideline value as the benchmark. What WSD should have been looking for was to identify whether and how much lead was present in our drinking water, how much of it was coming from the inside service, and to minimise the level of exposure.

99. The explanation given by Director of Water Supplies at the hearing that the water samples taken were for general water quality compliance purpose whereas on the other hand, the samples of plumbing materials taken and tested by the Task Force were for investigation was tenuous and unconvincing. Surely there was only one objective at the time.

100. In essence, the sampling protocol adopted by WSD was insufficient for the purpose of identifying which PRH estates were affected by lead contamination in the drinking water. It only served the purpose of checking the water quality as supplied and carried no value in investigating the lead contamination that took place in the inside service. The two to five minutes flushing inevitably would free the service pipe of stagnant water and consequentially, most if not all lead contamination. The result now is that no one can say with any degree of certainty which PRH estates are not exposed to the potential risk of any lead contamination in drinking water.

101. Although Professor Lee pointed out in his report that "regardless of the method of sampling, the 'affected estates' and the 'unaffected estates' are largely confirmed", one has to bear in mind that

Professor Lee only conducted test on six unaffected estates, given the constraints on time and resource. Anyone suggesting that all "unaffected estates" are confirmed by the report of Professor Lee to be truly unaffected is simply taking those words out of their proper context.

102. Mr Chan Kin Man in his fourth statement dated 4 December 2015 and indeed during the hearing attempted to persuade us that the purpose at the time and throughout 2015 was to check the water quality to ensure compliance with the WHO provisional guideline value in respect of lead.

103. Mr Chan Kin Man said in his fourth statement:

> " 11. Where the purpose is to check water quality to ensure compliance with WHO Guidelines, the current sampling methodology of WSD is to take a sample to match as closely as possible the average quality of water routinely consumed and to ascertain its compliance with the WHO's guideline values and provisional guideline values ("PGV"). The "guideline values" represent the concentration of constituents in drinking water that will not result in any significant health risk to a consumer weighing 60 kg over a lifetime consumption of 2 litres per day for 70 years. (See Part 8.2 of the Guidelines.) "Provisional guideline values" are established based on, inter alia, the practical level of treatment performance or analytical achievability. They are not meant to be mandatory limits ..."

104. First of all, there is no mention of any concept of "average quality of water routinely consumed" in either the ISO standard or the Guidelines. Secondly, in our view, the pattern for consumption of drinking water varies from household to household. Even according to the interim finding of a survey commissioned by WSD in December 2015,

6.5% households used their first-draw water for cooking and drinking. This is not a small percentage. Besides, many households were vacant after the morning consumption of water for cleaning, brushing and showering. By the time household members returned home from work or school, water would have been stagnant in their pipes for some time. Should there be lead in the plumbing system, it could have leached into the water.

105. Further, we are not entirely sure if Mr Chan Kin Man, when questioned, really understood the conceptual subtlety between “guideline value” and “provisional guideline value” although he did mention the terms in his statements. As pointed out by Professor Fawell, a guideline value only normally represents the concentration of a chemical constituent in drinking water that will not result in any significant health risk. Lead unfortunately does not fall into this “normally” category and is one of the few exceptions to which only a provisional guideline value is given.

106. Once WSD announced its sampling protocol in July 2015, it had become the subject of debates and criticisms. As early as the first Task Force meeting on 17 July 2015, members of the Task Force expressed to WSD that “different procedures to collect water samples would affect the testing results of lead content. Flushing test and stagnation test ought to be conducted at different time intervals to address the controversy over the procedures of taking water samples”. Mr Chan Kin Man, a member of the Task Force, was present in the meeting.

107. Mr Chan Kin Man must be aware of the differing views over sampling protocol. We noted that on 21 July 2015 he made enquiry with the Drinking Water Inspectorate in the U.K. Reply from the Drinking Water Inspectorate was clear and that "first-draw" sample was required for regulatory compliance sampling.

108. At the Task Force meeting on 26 August 2015, Dr Chan Hon Fai, Chairman of the Advisory Committee on Water Resources and Quality of Water Supplies and a member of the Task Force presented a paper entitled "Proposed Mitigation of Lead Contamination in Tap Water". The paper set out various sampling protocols used by different jurisdictions. Save and except Queensland, Australia where lead testing is not required for drinking water, other countries require some kind of unflushed stagnant samples.

109. It was most unfortunate that good and sound advice given at the time or at any time had been brushed aside. WSD insisted on its own sampling protocol.

110. HKIE subsequently conducted a similar exercise. It too listed out different sampling protocols from other jurisdictions. After examining WSD's sampling protocol, HKIE made the following comments:

> "323. On the other hand, the TF[Task Force of HKIE] opined WSD Water Sampling Procedure was biased towards measuring the water quality as supplied to the premises and ignored the effects of plumbing materials, including any possible lead solder, on drinking water quality.
>
> 324. If the purpose of water sampling is for identifying the presence of

> lead solder and non-complaint valves and fittings in the plumbing installations, then initial draw-off water samples should be used."

111. We accept there is no universal sampling protocol but as Professor Fawell said:

> "…Where the sample is to be taken from a consumer's tap, the water actually sampled is likely to represent the water as supplied from the public water supply distribution system, or at least the water in the roof storage tank and down pipe, and does not fully reflect the water in the internal distribution system that has been in contact with the associated plumbing after the meter for an extended period of time. While this is appropriate for examining the water quality parameters that will not be affected by the internal distribution system, it is not suitable to ascertain the concentration of parameters that will change as a result of contact with or which arise wholly from the internal distribution system… "

112. In his fourth statement, Mr Chan Kin Man actually mentioned that both unflushed and flushed samples should be taken on some occasions, e.g. discolouration:

> "7. For the purpose of determining the cause of contamination of the distribution system or handling customer complaints, for example on discoloration of water quality, both unflushed and flushed samples before the water meter or at consumer taps will be taken by WSD for investigation to identify the source of the water quality problem."

113. We believe that testing of lead in drinking water in the context of the present incidents should not be different from testing of discolouration i.e. excess iron in drinking water. We do not understand why iron, which is an essential element to our body and where the Guidelines do not see the need to give a guideline value, was treated much more seriously than lead.

Conspiracy Theory

114. It was alleged by Counsel on behalf of the Coalition that the evidence given by Government officials pointed to a conspiracy on the part of the Government in not wanting to know the full extent of the problem because they suggested that the more estates being categorised as affected estates, the higher the cost the Government would incur.

115. They argued that the Government deliberately used flushed samples for testing, which might not have reflected the worst lead concentration in the drinking water possibly consumed by the residents. They also argued that the Government deliberately took 10 μg/L, an unrealistically high value in the circumstances of Hong Kong, as the benchmark. They also questioned whether the Chief Secretary for Administration, who chaired an interdepartmental meeting on follow-up measures, was involved in the above decisions.

116. As explained by Professor Fawell in his expert report, the guideline values for chemical contaminants provided a basis for assessing the risks to health from drinking water but WHO indicated that local circumstances should always be taken into account in setting national standards and recommended that individual guideline values should be considered in the appropriate context. We agree that given the historical background that lead pipes have not been in use for a long time, Hong Kong can adopt a benchmark a lot less than 10 μg/L. As stated in last chapter, we also agree that WSD should not have collected and tested flushed samples alone to identify the lead contamination of drinking

water in PRH estates. However, we do not accept the Government at or above the bureau level deliberately adopted the above measures in order to limit the scope of the problem. The fact that once a single flat was affected, the whole estate would be classified as an affected estate was a cautious one, given for example in the U.S.A. where the authorities will be required to take steps to reduce exposure only if the lead concentration of more than 10% of the samples collected exceeds the action level of 15 μg/L.

117. Throughout the inquiry, the Commission had been granted unrestricted access to Government documents. Not only that, as pointed out by Professor Fawell in his expert report, he was able too to access all the information he requested and all his questions were answered openly by HD and WSD officials.

118. The decision to adopt 10 μg/L as the benchmark at the time, in our view, was not entirely unreasonable as somehow a line had to be drawn. However, whether 10 μg/L is a suitable benchmark for Hong Kong in the light of its local circumstances is questionable. Regarding the decision of Director of Water Supplies to sample only flushed water, we believe that Mr Chan Kin Man played a dominating role.

119. The incumbent Director of Water Supplies might not have sufficient expertise himself in water science, hence a more thorough understanding of the Guidelines, but as a senior Government official, he should have appreciated the flaws in the flushed sample method. WSD had been given numerous opportunities to revise its sampling protocol,

unfortunately WSD insisted. It is difficult not to form the impression that there was indeed a predetermined mindset among the directorate staff to hang on to what the department had done.

120. The Chief Secretary for Administration might be made aware of the provisional guideline value or even the methodology, we however doubt that she would participate in making technical decisions of this kind. There is little evidence to substantiate the allegation of the Coalition.

121. One may justifiably attack WSD of being defensive and rigid. We however do not accept the Government has deliberately tried to downplay the incidents by adopting the flushed sample method and 10 μg/L as the benchmark.

III. <u>THE PRESENT REGULATORY AND MONITORING SYSTEM – WATER</u>

122. Term (b) of the Terms of Reference requires us to review and evaluate the adequacy of the present regulatory and monitoring system in respect of drinking water in Hong Kong. In our view, there are two aspects within the existing system that merit our examination: the first aspect involving the role played by WA and WSD in the assurance of the quality of drinking water within the existing water regulatory regime, and the second aspect involving the role played by HA and HD and other stakeholders in the construction of PRH estates. For the purpose of this inquiry, HA/HD and WA/WSD are used interchangeably. In this chapter, we are going to first look at the role played by WA and WSD.

The Existing Water Regulatory and Monitoring Regime

123. The existing water regulatory and monitoring regime in Hong Kong and the powers and responsibilities of WA and WSD are governed by WWO and the Waterworks Regulation (Cap. 102A) (WWR).

124. Relevant provisions of WWO and WWR include :

(1) Section 3 of WWO provides that:

> "3. Control of waterworks –
>
> (1) Subject to subsection (2), the Water Authority shall have the custody and control of the waterworks and of all water herein."

Waterworks means "any property occupied, used or maintained by WA for the purpose of this Ordinance and any gathering ground".

(2) Section 7 of WWO provides that:

" 7. Approval of consumer and agent

(1) The Water Authority may approve, as the consumer of a fire service or inside service in any premises, any person who –

(a) occupies the premises; or

(b) is responsible for the management of the premises or any part thereof; and

(c) gives an undertaking in, such form as the Water Authority may specify, -

(i) to pay any charge due in respect of the fire service or inside service; and

(ii) to accept responsibility for the custody and maintenance of the fire service or inside service and the custody of any meter pertaining to the fire service or inside service."

(3) Regulation 7 of WWR provides that :

" 7. Responsibility to keep inside service clean –

(1) Subject to subregulation (2), a consumer shall be responsible for keeping an inside service clean."

Inside service means "the pipes and fittings in premises, and any pipes and fittings between the premises and a connection to the main, (other than the pipes and fittings forming part of a fire service) which are used or are intended to be used for the purpose of a supply".

125. In very broad terms, one can say that WA is responsible for the custody and control of the waterworks while consumers are responsible for the custody and maintenance of the inside service. The three provisions stated above refer only to the custody and control of waterworks and water, custody and maintenance as well as cleanliness of pipes and fittings. Nowhere in WWO and WWR is the responsibility over the quality of our drinking water specifically mentioned.

126. Throughout the hearing, WSD emphasised repeatedly that it was only responsible for the quality of water up to the connection point presumably because it had complete control over the waterworks, and more importantly, all water inside the waterworks. Beyond the connection point, WSD said that it was the responsibility of the consumers. WSD's position was also reflected in one Government leaflet "Hong Kong's Water Supply/Reducing Lead in Drinking Water":

> " Water pipes that join the WSD's water mains to the connection point at the lot boundary are maintained by the WSD. The communal service including the service pipes from the building's lot boundary to the building as well as those communal pipes inside the building are maintained by the agent (usually the property management agent or the owners' committees). The inside service of a flat or property is maintained by the property owner."

127. Although it is not expressly stated, we believe the rationale behind the requirement for cleanliness on the part of the consumer, after reading both WWO and WWR in their proper context, must be for the prevention of possible contamination of the water mains. To require a consumer to ensure the safety of water on his own is simply unreasonable. Safety and cleanliness are two different concepts. As to who has the

responsibility over the quality of our drinking water, the existing statutory regime is unclear.

128. Not only that, under the existing statutory regimes, neither WWO nor WWR specifies any standards or requirements on the quality of drinking water, although the Chief Executive in Council may under section 37(1)(a) of WWO make regulations for "the quality and type of a supply".

129. That however does not mean that WSD has no control or responsibility over the quality of our drinking water. Water quality is monitored and controlled by a number of measures:

(1) WSD has pledged to supply water through its waterworks in full compliance with the Guidelines to its consumers up to the connection point at the lot boundaries;

(2) WSD has developed for implementation starting from 2006 the Water Safety Plans (WSPs) to ensure the safety of water from source to tap;

(3) Beyond the connection point, WSD has implemented a number of sub-measures to monitor and control the construction of the inside service. These sub-measures include:

(i) requiring that all pipes and fittings are of the British Standard;

(ii) licensing of plumbers and requiring the engagement of LPs to carry out work on the inside service;

(iii) requiring confirmation by Authorised Persons (APs) that the pipes and fittings used are in full compliance with WWO and WWR standards and requirements;

(iv) inspection and approval of inside service upon completion by WSD; and

(v) requiring that the results of water samples tested comply with specified standards; and

(4) The existing statutory regime confers on WA the following powers:

(i) to refuse to connect or reconnect inside service to the main if the inside service is not approved (section 8 of WWO);

(ii) to restrict or suspend a supply in order to inspect, test or remove any part of the inside service (section 9 of WWO);

(iii) to disconnect an inside service if the inside service does not, in the opinion of WA, comply with the provisions of WWO (section 10 of WWO);

(iv) no person shall construct and install inside service except with the permission in writing of WA (section 14 of WWO);

(v) where permission is required to construct an inside service, applications for such permission, accompanied by plans, specifications and other information as required, must be made to WA (regulation 5 of WWR);

(vi) no pipe of fittings forming part of an inside service shall be used or covered up until it has been inspected and approved by WA (regulation 6 of WWR);

(vii) every pipe or fitting shall be of the British Standard and WA has the power to test any pipe or fitting to ascertain if it complies with the British Standard (regulation 20 of WWR); and

(viii) WA has the power to require any pipe or fitting, before it is installed or used, to be tested (regulation 21 of WWR).

130. Theoretically, with all these measures in place, the quality of our drinking water should be adequately safeguarded. So what has gone wrong? Let us examine those measures one by one.

The First Measure: the Water Supplies Department's Pledge

131. Bearing in mind that Hong Kong does not have any statutory standard on water quality, it is important to first examine the pledge made by WSD which, although not having any legal effect, clearly sets the framework for and underpins most of WSD's policies and practices in relation to water quality. WSD prides itself on having achieved the pledge since 1994.

132. Following the incidents, the Government, undoubtedly with input from WSD, published the "Hong Kong's Water Supply/Reducing Lead in Drinking Water" leaflet advising the public on how to minimise the risk of exposure to lead in drinking water.

133. In the leaflet, the public were informed of the fact that the quality of drinking water supplied by WSD fully conformed to the WHO Guidelines. The public were further informed that WHO produced international norms on water quality and human health in the form of guidelines that were to be used as the basis for regulation and standard and that among others, the guideline values of lead, cadmium, nickel and chromium set by the Guidelines had been adopted as standards for Hong Kong.

134. Further, the public were told that the guideline values represented the concentration of constituents in drinking water that would not result in any significant health risk to a person weighing 60 kg over a lifetime consumption of two litres per day for 70 years. Citizens of Hong Kong would be protected if the concentration on any chemical constituents in the drinking water fell below the respective WHO guideline values.

<u>The Guidelines</u>

135. WHO developed the Guidelines which are revised on a regular basis. The first edition was published in 1984. The second and third editions were published in 1993 and 2004 respectively. The current

edition, i.e. the fourth one, was published in 2011. Lead has been mentioned in all of the editions.

136. When the Guidelines were first published in 1984, they superseded the International Standards for Drinking Water. The change from Standards to Guidelines was in recognition that the WHO Guidelines had no legal effect and there was a need for member states to develop their own legally enforceable drinking water standards.

137. It is stated in the current edition of the Guidelines that:

> " The Guidelines are intended to support the development and implementation of risk management strategies that will ensure the safety of drinking-water supplies through the control of hazardous constituents of water. These strategies may include national or regional standards developed from the scientific basis provided in the Guidelines. The Guidelines describe reasonable minimum requirements of safe practice to protect the health of consumers and derive numerical "guideline values" for constituents of water or indicators of water quality. When defining mandatory limits, it is preferable to consider the Guidelines in the context of local or national environmental, social, economic and cultural conditions. The Guidelines should also be part of an overall health protection strategy that includes sanitation and other strategies, such as managing food contamination. This strategy would also normally be incorporated into a legislative and regulatory framework that adapts the Guidelines to address local requirements and circumstances…
>
> …The Guidelines provide a scientific point of departure for national authorities to develop drinking-water regulations and standards appropriate for the national situation. In developing standards and regulations, care should be taken to ensure that scarce resources are not unnecessarily diverted to the development of standards and the monitoring of substances of relatively minor importance to public health. The approach followed in these Guidelines is intended to lead to national standards and regulations that can be readily implemented and enforced and are protective of public health...

> …Approaches that may work in one country or region will not necessarily transfer to other countries or regions. It is essential that each country review its needs and capacities in developing a regulatory framework…"

138. Rather than adapting the Guidelines to address our local requirements and circumstances, WSD simply adopted the Guidelines in its entirety as our standards. As pointed out by Professor Fawell, the guideline values for chemical contaminants in the Guidelines provided a basis for assessing the risk to health from drinking water, but WHO indicated that local circumstances should be taken into account in setting national standard and recommended that individual guideline value should be considered in the proper context.

139. In Hong Kong, lead pipes have been restricted for use since 1890. Section 16 of WWO's 1890 edition stated:

> "16. Lead pipes will only be permitted in new services when the water which passes through them *cannot be used for drinking or cooking* (down-pipes to water closets or overflow pipes from cisterns, for example). Provided always that owners of premises which are now provided with lead-services will not be compelled to remove them unless in the opinion of the Water Authority they are too weak, or otherwise defective." [*emphasis added*]

140. More than a century ago, our forefather was fully aware of the harmful effect of lead in drinking and cooking. In 1938, the use of lead pipes was effectively prohibited by regulation 11 of the then WWR:

> "(5) Lead pipes will not be permitted for the conveyance of water supplied from water works."

141. As mentioned in paragraph 179 below, the use of leaded solder was disallowed after 1987 by virtue of an amendment to BS 864-2:1983.

142. Given the absence of lead in our treated water and the prohibition against the use of lead pipes and leaded solder, lead should not normally be found in our drinking water. According to Professor Fawell, "any Hong Kong standard, developed from the Guidelines, would be a lot less than 10 μg/L", and 5 μg/L, in his view, could be an easily achievable standard for Hong Kong.

<u>The Provisional Guideline Value of Lead</u>

143. For each chemical constituent, WHO has prepared a background document which evaluates the risks for human health from exposure. A guideline value normally represents the concentration of a constituent that does not result in any significant risk to health over a lifetime consumption. In addition, a number of provisional guideline values have been established on the practical level of treatment performance and analytical achievability. In these cases, the provisional guideline value is higher than the calculated health-based value.

144. As pointed out by Professor Fawell, these provisional guideline values were set at a higher value than would be the case for a strictly health-based value because of practical consideration. Lead is one example. It is appropriate to try and achieve as low concentration as possible within the constraints of cost and practicality.

145. In respect of lead, the following passages were mentioned in the WHO background document –

> " In 1986, JECFA (Joint Food and Agriculture Organisation of the United Nations / World Health Organisation Expert Committee on Food

Additives) established a provisional tolerable weekly intake (PTWI) of 25μg of lead per kilogram of body weight (equivalent to 3.5 μg/kg of body weight per day) for infants and children, which took account of the fact that lead is a cumulative poison, so that any increase in the body burden of lead should be avoided. The PTWI was based on metabolic studies in infants showing that a mean daily intake of 3-4 μg/kg of body weight was not associated with an increase in blood lead levels or in the body burden of lead, whereas an intake of 5 μg/kg of body weight or more resulted in lead retention. This PTWI was reconfirmed by JECFA in 1993 and extended to all age groups.

In the second and third editions of the Guidelines, a guideline value of 0.01 mg/L was derived on the assumption of a 50% allocation of the PTWI to drinking-water for a 5 kg bottle-fed infant consuming 0.75 litre of drinking-water per day. As infants were considered to be the most sensitive subgroup for the population, this guideline value was thought to also be protective for other age groups.

JECFA re-evaluated lead in 2010, finding that exposure to lead is associated with a wide range of effects, including various neurodevelopmental effects, mortality, impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes. Impaired neurodevelopment in children is generally associated with lower blood lead concentrations than the other effects, the weight of evidence is greater for neurodevelopmental effects than for other health effects and the results across studies are more consistent than those for other effects. For adults, the adverse effect associated with lowest blood lead concentrations for which the weight of evidence is greatest and most consistent is a lead-associated increase in systolic blood pressure. JECFA concluded that the effects on neurodevelopment and systolic blood pressure provided the appropriate bases for dose-response analyses.

Based on the dose-response analyses, JECFA estimated that the previously established PTWI of 25 μg/kg of body weight is associated with a decrease of at least 3 IQ points in children and an increase in systolic blood pressure of approximately 3 mmHg (0.4 kPa) in adults. These changes are important when viewed as shift in the distribution of IQ or blood pressure within a population. JECFA therefore concluded that the PTWI could no longer be considered health protective, and it was withdrawn.

Because the dose-response analyses do not provide any indication of a threshold for the key effects of lead, JECFA concluded that it was not possible to establish a new PTWI that would be considered to be health protective. JECFA reaffirmed that because of the neurodevelopmental effects, fetuses, infants and children are the subgroups that are most sensitive to lead.

There remain uncertainties associated with the epidemiology, which relate to very low blood lead levels and end-points that are affected by many factors. Nevertheless, because lead exposure arises from a range of sources, of which water is frequently a minor one, and as it is extremely difficult to achieve a concentration lower than 10 µg/L by central conditioning, such as phosphate dosing, the guideline value is maintained at 10 µg/L but is designated as provisional on the basis of treatment performance and analytical achievability."

146. Some of the above mentioned passages found their way into the Chemical Fact Sheet of the Guidelines. In addition, the following passages were mentioned in the Chemical Fact Sheet too:

"***Lead***

Lead is used principally in the production of lead-acid batteries, solder and alloys. The organolead compounds tetraethyl and tetramethyl lead have also been used extensively as antiknock and lubricating agents in petrol, although their use for these purposes in many countries has largely been phased out. Owing to the decreasing use of lead-containing additives in petrol and of lead-containing solder in the food processing industry, concentrations in air and food are declining; in most countries, lead levels in blood are also declining unless there are specific sources, such as dust from leaded paint or household recycling of lead-containing materials. Lead is rarely present in tap water as a result of its dissolution from natural sources; rather, its presence is primarily from corrosive water effects on household plumbing systems containing lead in pipes, solder, fittings or the service connections to homes. The amount of lead

> dissolved from the plumbing system depends on several factors, including pH, temperature, water hardness and standing time of the water, with soft, acidic water being the most plumbosolvent. Free chlorine residuals in drinking-water tend to form more insoluble lead-containing sediments, whereas chloramine residuals may form more soluble sediments in lead pipe.
>
> …
>
> It needs to be recognized that lead is exceptional compared with other chemical hazards, in that most lead in drinking-water arises from plumbing in buildings, and the remedy consists principally of removing plumbing and fittings containing lead, which requires much time and money. It is therefore emphasized that all other practical measures to reduce total exposure to lead, including corrosion control, should be implemented."

147. In short, the nature of the guideline value for lead has changed and it is no longer "health-based". There is no safe threshold for lead and lead was given a provisional guideline value of 10 μg/L on the basis of treatment performance and analytical achievability.

148. Amongst the four chemical constituents mentioned in the Government's leaflet, nickel and cadmium were given guideline values whereas chromium and lead were given provisional guideline values. In the case of chromium, a provisional guideline value of 50 μg/L was given because of uncertainties in the toxicological database. There were no adequate toxicity studies available to provide a basis for NOAEL, i.e. no-observed-adverse-effect-level.

149. Because of the fact that only provisional guideline values were given to lead and chromium, it was therefore incorrect to state in the

leaflet that drinking water with concentration of these two chemical contaminants up to the respective provisional guideline values would not result in any significant health risk to any person who consumed two litres of the drinking water per day over a lifetime of 70 years. It is clear that achieving a concentration level of 10 μg/L does not mean that there will not be any adverse effects on health. In the case of lead, it should be avoided as much as possible. Professor Fawell advised that WSD should revisit its pledge and "not set the wrong goal".

150. In our view, there were misunderstandings by WSD regarding (a) the use of the Guidelines, without taking local circumstances into account, as standards for Hong Kong, (b) the adoption of 10 μg/L as the standard for lead concentration in the drinking water of Hong Kong, and (c) the use and interpretation of provisional guideline values as "health-based" values.

The Second Measure: Water Safety Plans

151. In the 2004 edition of the Guidelines, WHO first introduced the concept of WSPs. The rationale behind its introduction was explained by Professor Fawell in his report:

> "35. The Guidelines have evolved over time and in 2004 introduced the concept of the Guidelines as a framework for safe drinking water. It was recognised that assuring safe drinking water requires more than simply measuring microbial indicators and standards for individual chemicals in the water as supplied (often termed end of pipe monitoring). The concept of water safety plans was introduced in order to encourage a proactive preventive approach to managing risks to drinking water from the catchment to the point at which consumers receive their drinking water, frequently referred to as the source to tap approach."

152. Following its pledge and the source-to-tap approach, WSD produced its first WSP in March 2006. WSD's first Water Safety Plan – General Plan stated as follows:

"**1. Vision, Missions and Values of Water Supplies Department**

Vision

To excel in satisfying customers' needs for the provision of quality water services.

Missions

To provide a reliable and adequate supply of wholesome potable water and seawater to our customers in the most cost-effective way…

2. Preambles

…

2.2 The WHO considers the application of a preventive WSP as an effective means to assure the quality of drinking water for the protection of public health. *A WSP systematically assesses risks throughout a drinking water supply system from the source through treatment to customers' taps and identify the control measures and operational monitoring that can manage* and *minimise the risks to public health.* The comprehensive strategy for drinking water quality management based on quality and risks involves understanding of the entire water supply system, the hazards and events that can compromise drinking water quality, and the preventive measures and operational control necessary for assuring a safe and reliable drinking water supply.

2.3 *The Water Supplies Department (WSD) is committed to providing a safe, clean and reliable drinking water supply to Hong Kong.*

…

5. Water Safe Plan (WSP)

5.1 General

5.1.1 The WSP for the WSD is the central component of the safe drinking water framework. It is guided by the health-based targets set out by the DH[Department of Health] and overseen by drinking water quality and public health surveillance. *The development and implementation of WSP will control and minimise the risks of contamination and ensure that the treated water supply will present a negligible risk to public health* and are acceptable to customers.

5.1.2 Based on a multi-barrier approach, *the WSP provides an integrated system of procedures and processes that collectively prevent or reduce the contamination of drinking water from source to tap in order to reduce risk to public health.*

5.2 Objectives of WSP

5.2.1 The primary objectives of the WSP are set out as follows:

(i) The prevention of contamination of source waters;
(ii) The reduction or removal of contamination through treatment processes to meet water quality targets; and
(iii) *The prevention of contamination during storage, distribution and handling of drinking water.*

…

5.9 Customer Services

5.9.1 *Significant adverse health effects may be associated with the poor design, incorrect installation*, alteration, inadequate maintenance and servicing *of plumbing systems in buildings*. The piped distribution of drinking water within a building must be controlled to prevent microbial and chemical contamination of drinking water. *The Customer Services Branch (CSB) of the WSD plays a key role in ensuring the safety of drinking water at customers' taps*. The detailed roles and responsibilities of CSB are set out in Annex 4.

5.9.2 *The CSB shall enforce appropriate policies, procedures and practices and relevant Waterworks Ordinance (WWO) and Waterworks Regulations (WWR) to prevent degradation of drinking water quality within buildings beyond the connection points.*

5.9.3 The CSB shall prescribe the nature, size and quality of the pipes and fittings of the inside service and the manner of the construction or installation of an inside service by means of Hong Kong Waterworks Standard Requirements and Circular Letters.

5.9.4 The CSB shall vet plumbing proposals and inspect the inside service upon completion of construction, installation or alteration of inside service.

5.9.5 The CSB shall maintain a list of qualified plumbers and require construction, installation, maintenance, alteration, repair or removal of inside service to be carried out by licensed plumbers in accordance with relevant statutory requirements." [*emphasis added*]

153. Paragraph 1.1 of Annex 4 to the 2006 General Plan described the roles and responsibilities of Customer Services Branch of WSD, among others, as follows –

> "1.1 Apart from account-related matters and other services for customers, the *Customer Services Branch (CSB) is responsible for undertaking measures and practices to ensure the quality and the safety of drinking water supply to customers beyond the connection points.*" [*emphasis added*]

154. It can be seen from the above that WSD unequivocally assumed responsibility over the quality and safety of our drinking water beyond connection point, contrary to what we have been told repeatedly throughout this inquiry. WSD went further to say that the plan aimed to

provide wholesome potable water, minimise risks of contamination and ensure that treated water would present negligible risk to public health. The plan also mentioned the important role played by the CSB in ensuring the safety of drinking water at the consumer tap, knowing that significant adverse health effects might be associated with the poor design and incorrect installation of plumbing systems.

155. In 2011, the second edition of the WSP was published. The same pledge and provisions were repeated.

156. After the incidents, instead of undergoing an in-depth review for improvement, Director of Water Supplies, in September 2015, retracted his department's responsibility by making the following amendments to the 2011 WSP:

(a) Paragraph 2.2 – deleting "customers' taps" and substituting it with "customers";

(b) Paragraph 5.1.2 – deleting "from source to tap" and substituting it with "from source to distribution";

(c) Paragraph 5.2.1 – deleting "The prevention of contamination during storage, distribution and handling of drinking water" and substituting it with "The prevention of contamination during storage, distribution and supply of drinking water"; and

(d) Paragraph 5.9.1 – deleting "plays key role in ensuring the safety of drinking water at customer's taps" and substituting it with "playing a regulatory role in controlling inside service to safeguard water quality."

157. Difficult ahead the task may be, the people of Hong Kong must be disappointed at WSD's shirking its responsibility. The unilateral retraction of responsibility by Director of Water Supplies also indicated to us that the WSP was prepared, as pointed out by Professor Fawell, with negligible input from outsiders.

158. According to the Guidelines, key steps of any WSP should include the following: (1) undertake a hazard assessment and risk characterisation to identify and understand how hazards can enter into the water supply; (2) identify control measures to control the risks; (3) define monitoring of control measures; (4) establish procedures to verify that the WSP is working effectively and will meet the health-based targets; (5) develop supporting programmes such as standard operating procedure; (6) prepare management procedures (including corrective actions) for unforeseen incident or emergency situation; and (7) establish documentation and communication procedures.

159. To translate the concept into a proper WSP, lead should be identified as an important parameter during the hazard and risk assessment phase of the WSP. The choice of sampling points should reflect whether the parameter is likely to change between the treatment works and the tap. Substances that are introduced from materials in the distribution, such as lead, should be monitored close to or at the tap to reflect the worst case. Sampling frequency should reflect the variability

of the concentration of a parameter over time. Once the hazard assessment and risk characterisation phase is completed, control measures should be identified.

160. Control measures are barriers to risks. As to control measures, the Guidelines recommended that chemicals and materials in contact with drinking water should be of an appropriate quality to prevent contamination of water by chemicals leaching in significant quantities from the materials. There are a number of approval systems in place in different countries (the National Science Foundation in the U.S.A., the Water Regulations Advisory Scheme in the U.K. etc.) and these can form the basis of assuring the suitability of chemicals and materials more widely. By specifying the use of British Standard, Hong Kong has in place the structure to take advantage of these systems.

161. As pointed out by Professor Fawell, no system would be effective unless there was enforcement of the rules. Operational monitoring such as sample submission and approval, central purchasing, visual checking upon delivery to site, submission of delivery notes and invoices, inspection of lead-free solder used during installation stage should be established and put in place.

162. Verification is required to provide reassurance that WSPs are effective and water systems as a whole operate safely. Verification of control measures such as conducting check on the presence of lead at pipe joint using X-Ray fluorescent analyser and testing water quality are also crucial. Verification can also take the form of auditing WSPs.

External audit by independent outsider will be an added advantage.

163. Appropriate construction and maintenance procedures are also required to ensure that the safety and quality of drinking water is not compromised by the design and during maintenance.

164. Management procedures, which form a key part of WSPs, if clearly laid out and understood, underpin the delivery of safe water from source to tap. Management procedures, such as procedure for sample submission, procedure for material inspection during delivery and construction, procedure for final inspection on completion, are important. HA's Specification Library is one good example of laying down management procedures.

165. Effective management procedures should define actions to be taken during normal operational conditions, and in specific incident situations and unforeseen situations. Management procedures should also be documented alongside system assessment, monitory plans, communication protocol, as well as supporting programmes such as training programmes for worker to appreciate the health hazards of lead, and for site quality assurance staff to operate X-Ray fluorescent analyser. For emergency situation, communication protocol must be prepared to, for instance, convey information on preventive measures to the public (e.g. flushing the water before drinking and cooking).

166. The documented management procedures should ensure that when any part of the system has a problem, that problem will be rectified

in due time to prevent any unnecessary risk to consumers. The existing WSP in relation to inside service only contains a skeleton of action required, without any details.

167. In this case, none of the responsible parties including WSD had carried out any basic checks despite Hong Kong had procedures in place to ensure that inappropriate materials would not be installed. Although HA specified in its contractual arrangements that lead-free solder should be used, there also needed to be an active process by which checks would be made so that the requirements were being met. Significant responsibility also lied with the main contractors, the sub-contractors and LPs to conduct checks.

168. The undenying truth is that WSD had never undertaken any systematic hazard assessment or risk characterisation regarding lead despite the fact that it had ample opportunities to do so:

(1) In March 1998, PSWTA issued a circular to its members, reminding them to pay attention to the use of lead-free solder in end-feed capillary fittings. When asked at the hearing, WSD said that they did not know about this circular.

(2) The 1999 incident in Scotland where leaded solder was found to be used in newly constructed houses. The lead level reached 1920 μg/L, 40 times over the legal limit of 50 μg/L at the time. We were told since the incident did not cause any major reporting, WSD was not aware of it. In our view, the illegal use of leaded solder in Scotland did not cause any major reporting was hardly surprising given

the fact that that was more or less an old issue. Notwithstanding that, one point clearly stood out – the use of leaded solder had not ceased to be a problem. It continued to pose challenges to water regulatory agencies.

(3) ACQWS was set up in 2000 to advise on water quality with Director of Water Supplies as vice chairman and a representative from HD as member. The ACQWS paper No. 7 was discussed in one of its meetings in January 2001.

Paragraphs 8 and 9 of the paper provided as follows:

"Current Practice Elsewhere in the World on How to Ensure Quality of Water in Buildings

8. The problem of water quality in buildings is not unique to Hong Kong. A literature research of publications and through the internet has been conducted. The situation in the United Kingdom, United States of America, Canada and Singapore has been briefly reviewed.

9. In the UK and USA, the *most common problem is the presence of lead in water since during their development stage, lead pipes and lead-soldered copper pipes were widely used*. The problem has to be addressed by dosing inhibiting chemical additives during the water supply treatment process to suppress ionization of lead and by re-plumbing. These countries also have …" [*emphasis added*]

We were told that the italicised words were no more than introductory and passing remarks. The focus at the time was the discolouration of water caused by rusty pipes. The words did not attract the attention of HD's staff. The involvement of HD on this aspect will be further discussed in the next chapter.

In our view, this may at best be an excuse for HD, but it certainly should not be an excuse for WSD which was supposedly to be the leading authority of water quality in Hong Kong. We were however told by Director of Water Supplies that as lead pipe and leaded solder had been banned in 1938 and 1987 respectively in Hong Kong, it was considered that the risk of presence of lead in water in the U.K. and U.S.A. had no application to Hong Kong.

We do not find his explanation convincing, after all leaded solder was prohibited from use in potable water system as early as 1987 in the UK too. Further, one also should not overlook the objective as set out in the preamble of the paper which was to "set out possible strategies for enhancing the entire water supply system such that Hong Kong citizens can have confidence in drinking high quality water directly from their taps". It was on this premise that members' advice was sought. Throughout the inquiry, the mentality adopted by WSD was plain and simple: WSD had nothing to do with the use of leaded solder and it was HD's problem.

It is disappointing that WSD tended to adopt a defensive mentality not only on sampling protocol but on almost any issues. It is complacency manifested from a different angle.

(4) In 2002, in view of its plan for expanding the use of copper pipes in future construction projects, HD sought comments from WSD on "the selection of piping materials". WSD reverted with no comments to HD's proposal. There was no mention in WSD's reply of any potential risks to the safety of drinking water as a result of the proposed alternative arrangements.

(5) The minutes of meeting of the "Working Party on Licensed Plumber" in 2004 showed that concerns had been raised by Mr Paul Ho Key Wei, a representative and an engineer from WSD, regarding the use of lead-free soldering material in pipe connection. In another meeting held in 2006, the issue of on-site testing for lead was mentioned.

(6) Two articles "The Development of Lead Free Copper Alloys for use in Drinking Water Applications in the European Union" and "Lead Free Water Supply System" were published between 2014 and 2015 by PSWTA. These publications were distributed at their 2014 and 2015 annual dinners which Director and Deputy Director of Water Supplies attended. Indeed, the subject of leaching of lead from solder was noted by a researcher long before. We learnt that as early as 1987, a research student from the University of Hong Kong published a thesis entitled "An assessment of the effects of lead exposure on Hong Kong school children". In its conclusion, it was mentioned that "[a]lso the increase in use of copper pipings in domestic water supply system should be carefully monitored

because the leaching of lead from the solders has been reported to be the source of undue lead absorption".

169. Counsel for the Commission pointed out that it might be tempting to simply query why the aforesaid events were not caught by WSD's radar screen and seized upon as opportunities to address possible hazards of lead in drinking water, this might nevertheless involve too much application of hindsight and overlook the proper context of each event. A more fundamental issue is the apparent lack of a system within WSD to assess the potential risks in drinking water from a public health perspective. Had an assessment of these contaminants from pipes and fittings been conducted, chances are that measures would have been put in place to control and monitor the relevant potential risks. Other key steps included in the WSP could well be properly established.

170. Apart from the lack of systematic hazard assessment and risk characterisation regarding lead, Professor Fawell also pointed out a number of inadequacies in the WSPs prepared by WSD.

171. These inadequacies included:

(1) the preparation appeared to be top down with no clear indication of how the WSD teams worked, which was an important part of the process;

(2) the extent of engagement of external stakeholders was unclear given the involvement of external stakeholders was key in ensuring full understanding of what WSPs were and their role in assuring safe drinking water. Had HA (a stakeholder) become or been made more aware of

the risk, the present incident might well have been avoided. In fact evidence revealed that all the WSPs were no more than internal documents kept by WSD;

(3) lack of an overarching team that linked up with external stakeholders on a day-to-day basis to ensure consistency;

(4) lack of a more systematic understanding of the possible hazards and risks from Dongjiang River, given its importance as a source;

(5) distribution system management plans did not appear to be well developed;

(6) lack of external audit to identify improvements; and

(7) absence of reassessment of the monitoring regimes.

172. We have no hesitation in accepting Professor Fawell's observations which we found convincing, objective and fair. Professor Fawell also gave his opinion on the way forwards. We shall deal with that in our recommendations.

The Third Measure: **Control of Construction of Inside Service**

173. Under this heading, there are a number of sub-measures, the first being compliance with British Standard.

<u>British Standard of Pipes and Fittings</u>

174. WWO gives "fitting" a wide definition. It covers any material, including solder, which is used in the inside service.

175. WWR stipulates that every pipe or fitting shall be of the British Standard. British Standard is defined under regulation 2 of WWR to mean "the latest revised edition of a specification issued by The British Standards Institution".

176. Part 1 of Schedule 2 of WWR sets out all the British Standards which apply to any pipe or fitting installed or intended to be installed in any inside service.

177. Paragraph 17 of Part 1 of Schedule 2 states as follows –

> "Capillary fittings or compression fittings shall comply with BS864, part 2 for capillary and compression fittings of copper and copper alloy and compression fittings for pipes laid under the ground shall be Type B."

178. BS 864-2:1983 laid down requirements for capillary and compression fittings for use with copper tubes. When first published in 1983, solder used for making capillary joints was required to be at least equivalent to grades C and G of BS 219:1977. Grades C and G of BS 219:1977 at the time permitted the use of over 50% of lead in the chemical composition of solder.

179. The use of over 50% of lead in the chemical composition of solder was tightened in 1987. By an amendment in 1987 to BS 864-2:1983, solder used for making capillary joints was changed to one of lead-free grades of soft solder specified in Table 17 for potable water applications. For general applications, Grade G continued to be

permitted. In the case of potable water application, only 0.1% of lead in the chemical composition of the solder was permitted. BS 219:1977 was similarly amended in 1987.

180. In 1993, BS EN 29453:1994 was published to supersede BS 219:1977. In 2006, BS EN ISO 9453:2006 was published to supersede BS EN 29453:1994 which was then withdrawn. Despite these changes, the maximum permissible chemical composition for lead in soft solder remained to be 0.1%. In 2014, BS EN ISO 9453:2014 was published to supersede BS EN ISO 9453:2006 and it reduced the maximum permissible chemical composition for lead to 0.07%.

181. In 1998, BS EN 1254-1:1998 and BS EN 1254-2:1998 were published to supersede BS 864-2:1983, which was declared obsolescent. Soldering alloys with lead and brazing alloys with cadmium were not permitted in installations for water for human consumption under Table 6 of BS EN 1254-1:1998.

182. Up to this moment, BS EN 1254-1:1998 remains to be the current British Standard governing fittings with ends for capillary soldering or capillary brazing to copper tubes.

183. Reading BS EN 1254-1:1998 and BS EN ISO 9453:2014 together, the current specification for maximum permissible chemical composition for lead in soft solder is set at 0.07%.

184. Despite all these technical developments in British Standards, BS 864-2:1983 continues to be the standard specified in WWR. One

can immediately see that WWR is seriously out of date.

185. We were constantly reminded throughout the hearing by the senior management of WSD that, given the definition of "BS" in WWR as "the latest revised edition of a specification issued by the British Standards Institution", it was unnecessary to update the regulations because the definition had, by default, taken care of all these latest changes.

186. With respect, we disagree.

187. "BS" as defined means not the latest edition but the latest *revised* edition. In Chinese, it says "最新修訂版". "Latest revised edition" simply means the latest amended edition. As such, BS EN 1254-1:1998 is not the latest revised edition of BS 864-2:1983. It is a new British Standard; the former has superseded the latter.

188. Ordinances and regulations require constant update. Its importance was highlighted in one memo prepared by WSD back in January 1990. In a set of Drafting Instructions prepared on behalf of Director of Water Supplies, the following passages were mentioned:

> " **<u>Introduction</u>**
>
> 1. Over the years, a considerable number of irregularities in the Waterworks Ordinance and Regulations have become apparent which are due to either technical references being out of date or additions being necessary to strengthen particular sections to facilitate enforcement and clarify interpretation. A review has been made of the Ordinance and certain amendments have been identified to be necessary. It is therefore intended to amend the relevant Ordinance and Regulations with a view to

removing the irregularities accordingly.

<u>Background</u>

2. The technical references quoted in the Waterworks Regulations were based on information available in the early seventies. With the advancement in technology and the development of British Standard Specifications, some of the technical references have become obsolete or inadequate. New pipe materials have also been made available for use in water supply systems and obsolete pipe materials are being phased out. The existing Regulations are not yet wholly updated in this respect.

…

(B) <u>Detailed Instructions</u>

4. Detailed instructions are tabulated in the schedule attached –

Ordinance/ Regulations	Proposed Amendments	Remarks
Second Schedule. Part I	…	…
	To delete para. 14.	B.S. 66 and 99 has been withdrawn.
	To replace "B.S. 864, part 2 and 3" in para. 17 by "B.S. 864 part 2".	B.S. 864 part 3 is not the appropriate B.S. for copper tubes fittings.
	To include unplasticised P.V.C. pipes and polybutylene pipes in para. 1(3) as alternative pipe materials for fresh water inside services.	Unplasticised P.V.C. and polybutylene are now accepted pipe materials."

189. As pointed out by HKIE in its report "Study of Lead in Drinking Water in Public Housing Estates" submitted to this Commission, apart from BS 864-2:1983, save and except three, the British Standards

mentioned in the Annex to Form WWO 46 are outdated.

190. HKIE was of the view that "for engineering specification, it is imperative to ensure obsolete standards shall not be specified" and "the lapse of WSD failing to replace those obsolete specification by current standards was a very serious matter, considering a few of them had already expired for over a decade".

191. Explanation given during the hearing for not amending WWR was that WSD would not insist on strict and immediate compliance with the latest British Standard. WSD would exercise its discretion either to allow the industry a grace period to catch up with the change or because the amendment was of a minor nature.

192. One can see the practical need of a grace period for the industry, it however inevitably creates considerable legal uncertainty. It is hardly ideal in Hong Kong for we pride ourselves on the rule of law. Unfettered discretion may unfortunately lead to misuse of executive power. This situation is also unhelpful because sections 14(3) and (4) of WWO create a criminal offence if the construction of inside service is not carried out in such manner as may be prescribed and the quality of the pipes and fittings of the inside service is not as prescribed.

193. Whatever justifications WSD may have, in the case of the use of lead-free solder, we have not seen, up to this juncture, any notice or circular issued by WSD notifying the industry or the public of the effective change of requirement in the maximum permissible lead content

in soft solder from over 50% to 0.1% or from 0.1% to 0.07%. These changes are very substantial changes and a "grace period" of 18 years in our view is totally unacceptable.

The Engagement of Licensed Plumbers

194. Plumbers play a key role in managing risks by ensuring compliance with applicable standards and codes. Plumbers have to ensure that water systems are intact and that intrusion of microbial and chemical contaminants is minimised.

195. Under regulation 32A of WWR, plumber's licences may be issued by WA.

196. Before 1992, examinations of LPs were administered by WSD. Since October 1992, any persons who hold a Craft Certificate in Plumbing and Pipefitting issued by VTC after 1987 or equivalent, plus a Certificate in Plumbing Services (Hong Kong) issued by VTC or an equivalent qualification may apply for a plumber's licence. The focus of the plumbing courses offered by VTC is to equip its students with the necessary skills and knowledge to become LPs. The use of lead-free solder is one among many subjects taught by VTC.

197. The plumber's licence is renewed annually. Apart from paying the necessary fees and collecting the licence in person at a specified office annually, there is no requirement for continuous training to ensure their knowledge is up to date.

198. As such, there is no way of knowing whether the existing LPs actually possess the necessary skills and knowledge expected of them in today's ever increasing complex plumbing environment. This is highly unsatisfactory.

199. Under the existing statutory regime, LPs are given unique responsibilities. Sections 14(1) and 15 of WWO provide as follows –

> "**14. Construction, etc., of fire services and inside services**
>
> (1) Subject to subsection (2), no person shall, except with the permission in writing of the Water Authority, construct, install, alter or remove a fire service or inside service.
>
> …
>
> **15. Construction, etc. by licensed plumbers**
>
> (1) Subject to subsection (2), no fire service or inside service shall be constructed, installed, maintained, altered, repaired or removed by a person other than a licensed plumber or a public officer authorized by the Water Authority.
>
> (2) Alterations or repairs to a fire service or inside service which are, in the opinion of the Water Authority, of a minor nature, or the rewashering of a tap, may be carried out by a person other than a licensed plumber or a public officer authorized by the Water Authority.
>
> (3) Subject to subsection (2), any person who –
>
> (a) contravenes subsection (1); or
>
> (b) employs or permits a person other than a licensed plumber or a public officer authorized by the Water Authority to construct, install, maintain, alter, repair or remove a fire service or inside service,
>
> shall be guilty of an offence. "

200. One controversy arose during the hearing was whether the law required LPs to construct inside service by themselves, with the exception

of works which were of minor nature.

201. This issue cannot be described as unimportant or purely academic because as pointed out by Professor Lee, poor workmanship was one factor which contributed to the present incidents. Further, LPs were regarded as the gatekeeper by WSD. However, the position of WSD on this issue was ambiguous and could hardly be described as reassuring.

202. At the beginning of the hearing, WSD relied on the WSD Circular Letter No. 2/90 dated 4 September 1990 to support its position. It provides that :

> "**Need for Plumbing Work to be Carried out**
> **<u>by Licensed Plumbers</u>**
>
> There have been instance where licensed plumbers withdraw from the plumbing work of a project and ask other person to take over the work without notifying the Water Authority.
>
> I like to remind you that you should not hand over the plumbing work for which you have signed Waterworks Form 'G' to any other person so as deem to transfer the responsibility for supervising the work unless the person to take over is himself a licensed plumber and has obtained the approval of the Water Authority through submission of a fresh Waterworks Form 'G'.
>
> So long as you remain to be the licensed plumber of a particular job for which you have signed Waterworks Form 'G', you *may employ workers* who are not necessarily licensed plumbers *to assist* you in carrying out the work. But under no circumstances should you use your licence to enable non-licensed persons to undertake plumbing work without *involving* yourself *in the supervision of the work*." [e*mphasis added*]

203. WSD relied essentially on the statements "may employ workers to assist" and "involving in the supervision of the work" to justify that LPs would not need to construct inside service by themselves. On what

legal basis WSD could say that, we have not been provided with any answer.

204. When the senior management of WSD came to take the stand, we were informed that it was a matter of policy that LPs were not required to carry out plumbing works personally on the ground that such had been a long established practice; to require LPs to construct inside service themselves was unworkable and practically impossible; and so long as the plumbing works were supervised by LPs, that would be sufficient.

205. When questioned further as to whether supervision entailed the physical presence of LPs, we were told by Director of Water Supplies that it was unnecessary. When the same question was put to Deputy Director of Water Supplies, his answer was simply "he [the LP] is responsible".

206. When Assistant Director, Mr Lam Ching Man, came to testify, he sought to contrast the language with the wordings in statutory provisions of other professions, such as electrical workers and gas installations workers, where the laws imposed a personal obligation on them to carry out the works.

207. We do not find the use of the analogy helpful. The wordings of section 15 of WWO are plain and simple. It is difficult to see how, as a matter of statutory construction, words can be read into the current provision to allow inside service to be constructed by a person other than a LP or by others under the supervision of a LP.

208. The 1990 Drafting Instructions mentioned earlier did not just highlight the need for correcting technical irregularities. It went on to examine the role of LPs:

> "3. Apart from attempting those proposed amendments which are either simple ones to keep the Waterworks Ordinance and Regulations in pace with the latest development of pipe materials and British Standards or minor in nature without introducing much change to the prevailing policy, opportunity is taken to incorporate a few amendments which aim at strengthening the enforcements or particular sections of the Ordinance and Regulations. These are explained below:
>
> (a) …
> (b) …
> (c) Control is becoming too loose over those persons who are deemed to be a licensed plumber under Regulation 38."

209. In WWO's 1938 edition, "LP" meant "any person or persons or corporate body licensed by the water authority to construct, alter or repair inside on fire services." It was not a statutory requirement to employ LP to construct inside service. Section 10 of WWO's 1938 edition stated that "any consumer *may* arrange with a LP to construct an inside service in premises for the supply of water from waterworks". [*emphasis added*]

210. WWO's 1938 edition was repealed by WWO's 1974 edition. LP was given a new definition to mean a person licensed under WWO and a person deemed under WWO to be a LP. The present section 15 was also introduced into WWO in this 1974 edition. WWO's 1974 edition imposed for the first time a mandatory requirement to employ LPs.

211. During 1990, there were issues with LPs. The same Drafting Instructions summarised the problem faced by WSD at the time:

"**Licensed Plumbers**

It is required by Section 15(1) of the Waterworks Ordinance Cap. 102, that work associated with the construction, installation, maintenance, alteration, repair or removal of inside and fire services *must be* undertaken by Licensed Plumbers.

The licensing of plumbers is done by the Director of Water Supplies according to Waterworks Regulation 34(1). This is done by a written examination and an oral interview to test the knowledge of the applicant in relation to the work and the provisions of the Ordinance. Licences are renewed annually upon the satisfaction of the Director and the payment of a fee.

An earlier version of the Waterworks Regulations (i.e. Reg. 10(2) of the Ordinance No. 20 of 1938) allowed firms which employed Licensed Plumbers to be issued with licences. This was found difficult to control because the individual holding the licence might leave the firm any time thus giving rise to possible situations under which the firm might be allowed to carry out works without the employment of a Licensed Plumber.

In view of the above, a revision was made in the Ordinance 1974 to the effect that firms were no longer issued with licences but Regulation 38(1) stipulates that any person (instead of a firm) who carries on business of plumbing and employs a Licensed Plumber, shall be deemed to be a Licensed Plumber. This enables the proprietor of a firm to undertake works connected with inside and fire services for the purpose of the Waterworks Ordinance as long as he employs a Licensed Plumber. Such a person is required by Regulation 38(2) to submit to the Director of Water Supplies, the name of every licensed plumber employed by him within 14 days after the end of every year.

However, it is now found that there are administrative problems in implementing this mainly because there is practically little change in the situation by allowing a person instead of a firm, to employ a Licensed Plumber for the purpose of carrying out plumbing business and the same difficulty in control as described in the third paragraph above is also experienced.

An assignment (no. 36/78) was done by the Corruption Prevention Department in 1978 on the Licensing of Plumbers. The report drew attention to the anomalies which exist in relation to this regulation and proposed that the legislation be updated. The case has been carefully reviewed and it is considered that there is no real need to retain Regulation 38 and it *would be a better arrangement to make it a strict requirement that all plumbing work must be carried out by a Licensed Plumber as stipulated in Section 15(1) of the Waterworks Ordinance*.

It is proposed to delete Regulation 38 altogether for reasons stated above and to amend the interpretation of "licensed plumber" in Section 2 accordingly." [*emphasis added*]

212. Regulation 38 was indeed repealed in 1992.

213. WSD also took the view that allowing only LPs to carry out plumbing works personally would contradict the provisions of the Construction Workers Registration Ordinance (Cap. 583) (CWRO) which provides for the registration of skilled and semi-skilled construction workers and the regulation of construction workers personally carrying out construction work. Plumbing is one of designated trades regulated by CWRO. We note the seeming contradictions between WWO and CWRO. This in our view could well be a case whereby the operation of the two ordinances had simply slipped the mind of the draftsman.

214. We recognise that the industry will encounter serious practical difficulties if LPs are required to carry out all the plumbing works by themselves. However, one should not use that as an excuse either to read words into otherwise a clear and unambiguous statutory provision.

The remedy of course is to amend the current WWO.

215. For the purpose of this inquiry, we accept that it would not be necessary for us to come to a definitive conclusion on the legal interpretation of the relevant provisions. What is obvious is that there is a huge gap between the language of law and the industry practice permitted by WSD. That is highly undesirable not only for that discrepancy in itself but because criminal sanctions are attached to section 15 of WWO. Criminal laws require a high degree of certainty.

216. After the incidents, WSD issued Circular Letter 4/2015 which stated as follows –

> "For the avoidance of doubt, all plumbing works using soldering for connecting copper pipes shall have the permission of the Water Authority and shall be carried out by a licensed plumber in accordance with section 14 and 15 of Waterworks Ordinance (Cap. 102)."

217. On any objective reading, one gets the impression that it mandated soldering works to be carried out by LPs personally. Had workers other than LPs all along been permitted to carry out the soldering work, there was no need for any "avoidance of doubt". However, soon after the circular was issued, given inquiries from the industry, WSD posted onto its website the following clarification:

> " According to the Circular, please clarify whether all solder joints must be carried out by licensed plumber.
>
> Under the Waterworks Ordinance, construct, install, maintain, alter, repair and remove of fire service and inside service shall be carried out by licensed plumber. The licensed plumber can be assisted by workers when needed. However he should involve in supervision of the plumbing works."

218. In our view, the clarification did not clarify anything. It seems LPs were still required to do the soldering works. Only when needed, LPs might be assisted by workers. Be that as it may, this again demonstrated to us all the uncertainty and confusion that permeated within WSD as to the exact duty and responsibility of LPs.

219. Some of the responsibilities assigned to LPs include (a) the certification of pipes and fittings installed or intended to be installed, including those as listed on the Annex to Form WWO 46 and those not listed, are as prescribed by WWR; (b) the listing of the proposed pipes and fittings intended to be used in the plumbing works (Annex to Form WWO 46); and (c) application made to WA for final inspection.

220. Most of the above involve paper work only.

221. The three LPs responsible for the affected estates had been called to testify in this inquiry. None of them attended any of the VTC courses for they were qualified in the 1970s and 1980s.

222. Leaving aside their knowledge on the use of lead-free solder, it is clear that none of them involved themselves personally in the construction of the inside service. In the case of Mr Ng Hak Ming, who impressed upon us as the most knowledgeable and conscientious one amongst the three, performed no more than an administrative and supervisory role. As to another LP, Mr Lam Tak Sum, his role was essentially limited to attending the final inspection and affixing his signature onto various WSD documents. Regarding Mr Cheung Tat

Yam, for reasons stated later, we simply do not believe his evidence.

223. Even if it was accepted that a LP could be assisted by workers when needed, there was no requirement by WSD on how the LP should carry out or be involved in material inspection at site or inspection of workmanship of his workers. A LP can at present, theoretically sign up for a number of building projects at any given times. In the case of Kai Ching, only one LP was engaged for the plumbing works of over 5,000 housing apartments. It is doubtful how well the LP could divide his time to supervise plumbing works of such scale.

224. WSD hardly conducted any random check apart from mandatory inspections required of WWO. It was submitted on behalf of WSD that this might just amount to "a further layer of sporadic checks". We do not agree. Even on final inspection, there was no mandatory requirement that LPs must be present. LPs might appoint a representative to be present although there would be penalty points attached. This was further complicated by the loose "supervision" concept permitted by WSD where LPs could remotely supervise the plumbing works.

225. As pointed out by Professor Fawell, having a pool of specialists looking specifically after the plumbing aspects in building projects was commendable, but it was necessary that these people were equipped with the proper knowledge, including knowledge as to the health aspect of their responsibilities, and would display professionalism in their work.

226. In our view, the LP system needs to be strengthened and improved.

Confirmation by Authorised Person

227. One of the sub-measures to control the construction of the inside service involves the engagement of professional service of APs, who are qualified and registered professionals (architects / engineer / surveyor) as defined under the Buildings Ordinance (Cap. 123). Due to the complexity of plumbing works, WA has imposed on APs the responsibility of ensuring compliance with WWO and WWR since 1982. In the construction of PRH projects, although it is exempt from the control of the Buildings Ordinance, Chief Architects (CAs) of HD are tasked to mirror the role of APs. CAs are responsible for the overall design of buildings and they need to have an understanding of the operation of and requirements associated with water supply systems.

228. Under the Building (Administration) Regulations (Cap. 123A), APs are required to submit to the Building Authority a certificate regarding water supply connection to be issued by WA upon completion of a new building. Section 21(6) of the Buildings Ordinance provides that for buildings to which a supply of water is required to be connected for any purpose, the Building Authority may refuse to issue an occupation permit when it is not satisfied that connection of water supply has been duly made to the building by WA.

229. APs have since 1987 been required to comply with the following requirements and fill in a number of different forms:

(a) AP of a developer is required to make enquiry with WA about the availability of water supply (Form WWO 132 Part I);

(b) AP and LP are required to apply jointly to WA for permission to commence plumbing works (Form WWO 46 Parts I and II). This involves AP and LP giving the following certification:

> "We hereby notify that the plumbing works detailed above … will be commenced on … We CERTIFY that the pipes and fittings installed/intended to be installed, including those as listed on the attached Annex to this Form and those not listed, are as prescribed by the Waterworks Regulations.";

(c) AP and LP are required to list out the proposed pipes and fittings intended to be installed in the plumbing works (Annex to Form WWO 46);

(d) after completion, AP and LP are required to apply jointly for inspection by WA for approval of their works; and

(e) upon approval and after cleansing and disinfection of the inside service, AP is required to apply to WA for issuance of "Certificate regarding water supply connection" (Form WWO 132 Part II). AP is required to confirm that the pipes and fittings used in the project are in full compliance with waterworks standard and requirements.

230. In 1995, HKIA confirmed again the appropriateness in appointing APs as persons responsible for submitting plumbing proposals and supervising plumbing installation for building projects. Apart from

the confirmation, HKIA replied to WSD as follows:

> "Members of our Institute that have qualified for the List 1 of the Authorized Persons would have acquired the basic knowledge of design and installation of plumbing system in their university education and professional training. They would have supervised periodically the carrying out of plumbing installation as part of their inspection duties on building works."

231. Both the certification mentioned in paragraph 229 and the response given by HKIA confer upon architects very important responsibilities. It is, in our view, not open for them to claim "lack of awareness" or "inadequate awareness" as an excuse.

232. APs seemingly are given an onerous task. However in reality, all APs from HD told us that they expected LPs to perform their duties under WWO and WWR. All that they had done were no more than putting down their signatures alongside LPs'.

233. It was submitted by Counsel for HA that one should not treat APs the same as LPs or WSD for they had no statutory role to play under the existing regulatory regime on water quality. We agree. But the undisputed fact is that APs are required to put down their signatures on various WSD documents to undertake certain obligations. They are therefore liable under those undertakings. In fact, HA admitted its CAs' failure in one background paper sent to us (see paragraphs 300 and 301 below).

234. In essence, WSD relied on LPs and APs for statutory compliance. APs relied on LPs because LPs were regarded as

specialists and had statutory duty to perform. LPs in turn relied on WSD's final inspection. The whole process ended up in a failing circle.

235. The involvement and co-operation of other stakeholders such as LPs and APs are important. However, given its extensive powers under the law, we are of the view that the ultimate responsibility in ensuring water quality falls firmly on WSD. WSD cannot simply rely on the hope that other stakeholders will perform their tasks properly, and confine itself comfortably to certain functionality tests. As we now know, the use of leaded solder was introduced into the inside service during the construction stage of the building projects, which has proved that WSD's regulatory approach did not work.

<u>Final Inspection upon Completion</u>

236. What are the responsibilities of WSD during the construction stage of any building projects? Its responsibilities or regulatory role as perceived were encapsulated in the witness statement of Mr Cheung Yip Kui, Senior Engineer of the Customer Services Branch:

> " 5. The supply of safe drinking water from the inside service is dependent on effective collaboration amongst various stakeholders, each of which has a distinct role to play. Apart from WA, the relevant stakeholders include developers. Authorized Persons ("AP"), building contractors, plumbing subcontractors and licensed plumbers ("LP"). The role of WA in relation to inspection and approval of the inside service is to be understood in this context where there has been a long standing quality control and site supervision system during the construction process undertaken by the various stakeholders. Together with AP and LP's certification that the use and installation of pipes and fittings in the inside service are compliant, the system provides a reasonable and manageable safeguard against the use of non-compliant materials such as leaded

solder…

6. Taking into account the quality control and site supervision system already in place, the focus of WA's inspection is on prevention of misuse and wastage of water and pollution of the government water supply. *In practice, the inspections carried out by WA emphasize on checking the plumbing system, including the sizes, configuration and alignment/position of pipes, fittings and meters, against the approved plumbing drawings as well as the materials as listed in the Annex to Form WWO 46 submitted previously by the AP and L*P...

13. The inspection and approval of plumbing works in relation to the inside services of the Affected Estates were carried out by WSD staff in the Customer Services Division of the Customer Services Branch whilst the collection and testing of water samples at the connection points were conducted by WSD staff in the Water Science Division of the Development Branch except for Tung Wui Estate and Choi Fook Estate (Phase 1), which were conducted by the HOKLAS accredited laboratories." [*emphasis added*]

237. In essence, after delegating all the duties and responsibilities to APs and LPs during the construction stage, the responsibilities or regulatory role of WSD are confined to final inspection after the completion of the building projects. We note the requirement for interim inspection, but in the present case since all the pipes were not covered, interim inspection was inapplicable. In any event the final inspection, as explained later, focused exclusively on functionality, and on the prevention of misuse and wastage of water and pollution of the Government's water supply. Prior to the incidents, no checking was conducted on the chemical composition of any plumbing materials. Solder and joints were not included in WSD's checklist. In fact, solder was not included as one of the items required to be listed on the Annex to Form WWO 46 at the very beginning of the building project. Note 7 of

the Annex stated that:

> "All pipes used/intended to be used are required to be reported in the Annex. For fittings, only draw-off taps, stop valves, gate valves, ball valves and combination fittings need to be reported…"

238. The inclusion of taps, valves and fittings, i.e. terminal fittings, was again to serve the purposes of functionality and prevention of water leakage. In explaining why no thought was apparently given to the health risks posed by pipes and fittings, Deputy Director of Water Supplies told us that such risks would have been alleviated had there been strict compliance with British Standards and all the specifications under the contracts. As pointed out by Counsel for the Commission, this is not a satisfactory answer, given the same could be said about the functional risks.

Test of Water Sample at Final Inspection

239. The purpose of testing water samples during final inspection was again not for identifying non-compliant material used in inside service but to guard against contamination of the Government's water supply by any newly constructed inside service. This is reinforced by the fact that WA only required water samples to be taken near each connection point from the newly constructed inside service before effecting water supply.

240. Prior to July 2015, water samples were taken to test against eight parameters. These parameters were pH at 25˚C, turbidity, colour, conductivity at 25˚C, residual free chlorine, E.coli, total Coliforms and

heterotrophic plate counts.

241. pH was tested to ensure the inside service had been thoroughly flushed and that there were no excessive disinfectants present which would affect the acceptability of water. Turbidity was tested for suspended or colloidal particles in water; high turbidity would provide protection against microorganisms. Colour was tested for the presence of coloured substances which would affect the acceptability of water. Conductivity was tested for cross connection between fresh and salt water supply system. Residual free chlorine was tested for the effectiveness of disinfection. E.coli was tested for faecal contamination. Total Coliform and heterotrophic plate counts were tested for cleanliness and integrity of the system and the potential presence of biofilm which covered a wider range of microorganisms. The overall objective was focused on any indication of possible contamination of WSD's water mains and not on the safety of water eventually consumed at tap. The testing of the eight parameters was also not related to compliance with the Guidelines.

242. In explaining why lead was not included, WSD relied on the WHO's publication: "Chemical Safety of Drinking-water: Assessing Priorities for Risk Management" which provided, among others, that:

(a) Generally, lead was not a high priority for routine monitoring programmes, but possible risks posed by lead in drinking-water should be assessed;

(b) Unless there was strong evidence that particular chemicals were currently found or would be found in the near future, at levels that might compromise the health of a significant proportion of the population, the inclusion of those chemicals in drinking-water monitoring programme would not be justified, particularly where resources were limited;

(c) Lead could also be present if leaded solder was used in the installation of copper piping. A control measure in this case would normally be to avoid the use of leaded solders for applications involving drinking-water. Chemical monitoring of drinking-water was not normally considered to be appropriate and the most suitable method of management was by product specification, as indicated above for other materials; and

(d) When found in drinking-water, lead usually arose from lead pipes and leaded solder, mostly from plumbing in buildings. Monitoring was quite difficult and would require samples to be taken at the tap. Assessing the presence of lead pipes, or the ability of the water to dissolve lead, would be the most appropriate management approaches. Monitoring would only be considered if significant resources were available.

243. As told by Professor Fawell, preventing the contamination of water by chemicals through material control and regulation was a much more cost-effective approach and that one should not be tempted to apply 20/20 hindsight.

244. We agree with that approach. Indeed, under regulation 21 of WWR, WA may require any pipe or fitting, before it is installed or used, to be tested. However, in practice, we were told that no test had ever been conducted by WSD on the plumbing materials used in the construction of inside service.

245. After the incidents, four more chemicals, namely lead, cadmium, chromium and nickel, were added to the testing parameters of WSD. As pointed out by Professor Fawell repeatedly in his report, the sampling protocol used by WSD was incapable of achieving the intended objective of testing the extent of chemical contamination that happened within the inside system. An appropriate sampling protocol should be devised. In addition, as suggested by Professor Fawell, it would be useful to add copper, antimony and zinc to the list of metals to be tested. Copper can be leached from copper piping and is known to cause acute gastric irritation when the concentration exceeds about 2 mg/L. Copper is only a problem in new copper plumbing system. Antimony is seen at taps in Europe, so it would be prudent to collect some data as well. Zinc may be released from galvanised pipes and can cause problems with the acceptability at concentrations above 3 mg/L.

The Fourth Measure: Powers Conferred onto the Water Authority

246. As to all the powers conferred (listed in paragraph 129(4)) onto WA for the purpose of ensuring compliance of plumbing materials, we have heard very little evidence as to how they are implemented at the operational level. We have not heard any evidence, in particular,

regarding the use of the power under regulations 20 and 21 of WWR respectively to ascertain if any pipe or fitting complies with the British Standard and require any pipe or fitting, before it is installed or used, to be tested. We know that WSD only has chemical, biological and radiological testing facilities within the Water Services Division, there however is no material testing facility for any plumbing materials. We doubt if these two particular provisions have ever been applied in the past.

IV. THE PRESENT REGULATORY AND MONITORING SYSTEM – CONSTRUCTION OF PUBLIC RENTAL HOUSING ESTATES

247. Let us now look at the role of HA and HD. Theoretically, HA could have prevented the present incidents from happening if its control measures in place, in particular, the requirement for lead-free solder, were working properly.

The Hong Kong Housing Authority

248. HA is the statutory body established in April 1973 under the Housing Ordinance to develop and implement Hong Kong's public housing programme, with a mandate to help low income families in need to gain access to affordable housing. The Secretary for Transport and Housing assumes the office of Chairman of HA, while Director of Housing assumes that of Vice-chairman. Six standing committees have been formed under the Housing Ordinance to formulate, administer and oversee policies in specific areas.

249. HA is not part of the Government and is subject to statutory requirements such as those in WWO which are applicable to private property developers. Although HA is exempt from the Buildings Ordinance which governs the planning, design and construction of buildings, it however submits building proposals for vetting and approval by the Independent Checking Unit which reports directly to the Permanent Secretary for Transport and Housing (Housing) and mirrors

the same functions of the Building Authority under the Buildings Ordinance.

250. HD is the executive arm of HA, staffed mostly by civil servants. It is headed by Director of Housing. Under the office of Director of Housing, there are four divisions, namely the Development and Construction Division, Estate Management Division, Strategy Division and Corporate Services Division. Similar to other organisations, HD has undergone organisational changes at different time and stages. Different divisions may have different names and functions in different periods of time. For the purpose of this inquiry and to simplify matters, their current names will be used throughout the report.

251. The Development and Construction Division is responsible for the production of new public housing units, which include all aspects of project management and production work covering the initial site search and feasibility studies, planning, design and construction management. The Development and Construction Division is also responsible for establishing operational policies on procurement, design, construction, quality performance assessment, research and development, safety and environmental management for public housing development in Hong Kong.

252. The Development and Construction Division is headed by a Deputy Director who is supported by four Assistant Directors and 25 Chief Professionals, including CAs, Chief Building Services Engineers (CBSEs), Chief Civil Engineers, Chief Geotechnical Engineers,

Chief Planning Officers, Chief Quantity Surveyors, and Chief Structural Engineers. At present, the establishment of the Development and Construction Division including non-directorate staff is 2,497.

253. After the incidents, Chairman of HA set up the Review Committee to carry out a full review on HA's quality control and monitoring mechanism at different stages of public housing construction. The Review Committee comprised HA members of different professional background.

254. The Review Committee submitted an interim report on 6 October 2015 and the final report in January 2016.

255. The Review Committee concluded that:

(a) there were inadequacies in the past mechanism, at the regulatory and industry-wide level, for ensuring the quality of drinking water supplied to PRH estates;

(b) there had been "inadequate awareness" of the stakeholders in the construction industry on the use of leaded soldering materials and their consequences on the quality of drinking water;

(c) the main contractors, well aware of the contractual requirements to use lead-free solder, failed to put in place sufficient quality control and supervision to fulfil their contractual obligations; and

(d) there were inadequacies in HA's past quality control mechanism which had been geared towards known issues about safety and quality of fresh water but not on the presence of lead (or other heavy metals) in the fresh water supply system or in the water, and had not targeted soldering materials as a high risk item.

256. As pointed out by Counsel for the Commission, "lack of awareness" had become a hackneyed phrase in the investigation of the present incidents. We shall examine the validity of this explanation by tracing the development of the use of copper pipes in PRH projects over the years.

Use of Copper Pipes

257. Galvanised steel pipes were used in PRH estates before 1994. Since they caused discolouration in drinking water, unplasticised polyvinyl chloride lined galvanised steel pipes (uPVC-lined pipes) were introduced as replacement in HA's buildings after 1994. Contamination by metals was therefore not new albeit in the case of discolouration, only the aesthetic quality of the drinking water had been affected.

258. In January 1999, at one internal meeting of the Liaison Group on Construction Quality (LGCQ), a forum for exchange of views between the Development and Construction Division and the Estate Management Division on construction quality, materials and technical standards, the Estate Management Division started discussions comparing the use of copper pipes, uPVC-lined pipes and ductile iron pipes for re-plumbing work. The proposal was made against the background that copper pipes had gained popularity in private developments and become more readily

available on the market. Information was then passed to a CBSE of the Development and Construction Division in February 1999 for further study.

259. A number of meetings followed. A report which summarised the advantages and disadvantages of the use of copper pipes and uPVC-lined pipes was prepared. At a LGCQ meeting in February 2001, the use of copper pipes was recommended as an alternative for galvanised steel pipes.

260. Separately, around that time, the subject of water quality in buildings was also discussed at WSD's ACQWS. ACQWS comprised members from different sectors including academics, professionals and officials from related Government departments. Since its inception in 2000, its membership has always included a representative of HD.

261. Mr Wong Bay, then Assistant Director of Estate Management Division and Co-Chairman of LGCQ, represented HD on ACQWS between 2000 and 2007. However, during this period, he had not raised any matters of ACQWS, in particular the problem associated with the use of leaded solder, for discussion at any LGCQ meetings.

262. The ACQWS Paper No. 7 entitled "Quality of Water in Buildings" was prepared by WSD in January 2001. It was stated in paragraph 6 by way of background that in 1998 WSD commissioned a consultancy study to look into the quality of fresh water supply in 120 randomly selected residential buildings less than 10 years old. The

study found that a small percentage of these buildings had discoloured water problems and the causes were mainly the rusting of the internal plumbing system or poor maintenance of their water tanks and water pumps.

263. Paragraphs 8 and 9 of the Paper (which are quoted in paragraph 168(3) above) stated the overseas problem that lead pipes and lead-soldered copper pipes were widely used.

264. Mr Wong Bay explained that the focus of ACQWS at that time was on the quality of water supplied from Dongjiang, the discolouration and turbidity due to rusty pipes and the poor maintenance of plumbing systems in Hong Kong. The contents of paragraphs 8 and 9 of the Paper were not discussed in any detail by ACQWS. He did not report the reference in paragraphs 8 and 9 of the Paper to HD as his focus at that time was to consider means to tackle the problems of discolouration and turbidity from an estate management perspective.

265. Matters have to be judged in their context. One of the solutions to the problem of discolouration and turbidity was to find suitable alternative piping materials. Mr Wong Bay happened to be the only person who sat in both LGCQ and ACQWS. He was the link between the two bodies. In our view, this was one hit-or-miss golden opportunity for HA to recognise the threat and risk of leaded solder being used.

266. ACQWS allowed stakeholders of different backgrounds to work together for the meaningful purpose of ensuring the quality and safety of drinking water in Hong Kong. We expected that HA, as the developer of PRH estates in Hong Kong, would play a major role in the committee. As pointed out by Counsel for the Commission, Mr Wong Bay's evidence at the hearing did not give people confidence in the effectiveness of HA's participation in ACQWS:

(a) If HA had in mind an overriding objective to take care of the health risks in drinking water, it should have discussed (and continued to discuss) with its representative in ACQWS on matters such as what contribution HA could make to the committee; what main areas HA should focus on in the discussions of the committee; and what particular areas discussed in ACQWS should the representative bring back to HA for follow-up actions, etc.;

(b) Although Mr Wong Bay did give evidence on the areas discussed in ACQWS which he had apparently focused and followed up on, there was no evidence which could show the considerations of HA in prioritising the issues, and its coordination/communication with the representative on such issues, which might have led to the outcomes as mentioned above; and

(c) ACQWS was supposed to provide a good channel for every stakeholder to express its views on how to improve the quality of our drinking water. In fact, the papers prepared by ACQWS on various aspects of drinking quality in Hong Kong were generally well-researched and informative. HA should have designated staff to read and consider such papers in order to find out what they would pay heed to in future projects and policies.

Development of Specifications for Copper Pipes and Fittings

267. In early 2002, a working group was set up in HD to look into the use of alternative materials in cold water supply installation. As copper pipes had then been widely used in the building industry, the working group considered that there would be benefit to use copper pipes as an alternative to galvanised steel pipes to enhance price competition.

268. A team of building services professionals led by Mr Ng Tat Kwan, then Senior Building Services Engineer, was given the responsibility for the drafting of the specifications whereas a quantity surveyor took responsibility for the necessary changes in tender and contract documentation.

269. With the requirements of WWO, WWR and relevant British Standards in mind, Mr Ng Tat Kwan and his team started to draft various specifications associated with the use of copper pipes and fittings.

270. According to Mr Ng Tat Kwan, he and his team soon realised that BS 864-2:1983 for capillary and compression fittings of copper, as prescribed in paragraph 17 of Part 1 Schedule 2 of WWR, had already become obsolete and been superseded by BS EN 1254-1:1998.

271. Unlike BS 864-2:1983 which contained a table (Table 17) setting out the chemical compositions, including maximum permissible lead content of soft solders for use with potable water, BS EN 1254-1:1998 does not have a similar table. Paragraph 4.2.2 of BS EN 1254-1:1998 only deals with fittings with built-in or integral solder materials and states that "leaded solders shall not be used for manufacture of integral solder ring fittings".

272. Table 6 of BS EN 1254-1:1998 focuses mainly on the maximum temperature and pressure for different kinds of soldering and brazing materials. There is, however, a footnote under Table 6, which specifies the requirement that "soldering alloys with lead and brazing alloys with cadmium are not permitted in installations for water for human consumption". An inescapable and irresistible inference of this footnote must be that leaded solders are detrimental to human health.

273. Due to the inconspicuousness of the footnote and hence the requirement, Mr Ng Tat Kwan and his team decided to make it clear and draft a dedicated specification clause setting out all the requirements:

"**Soldering Alloys for Copper and Copper Alloy Capillary Fittings**

(a) Soldering alloys shall comply with the specifications as listed in EN1254 part 1 table 6 section II & III;

(b) The use of integral solder fittings is permitted provided they comply with EN1254 part 1;

(c) Only lead-free category solders shall be used;

(d) Copper oxide and dirt shall be removed from pipe spigot and fitting socket prior to the application of soldering flux;

(e) Only a non-corrosive type of flux, recommended by the solder alloy manufacturer shall be used. Flux should be applied sparsely and with excess removed prior to heating;

(f) Soldered pipe joints shall be cleaned with a damp cloth on completion to remove flux residues."

274. As Mr Ng Tat Kwan further explained at the hearing, the use of lead-free solder was not new. The General Specification for Building 1993 Edition, issued by the Architectural Services Department, had already required that solder for joining potable water pipes should be lead-free and conform to BS 864-2:1983 Table 17.

275. The newly drafted specifications for copper pipe and fittings were widely circulated among senior officers of HD, including Project Directors, Project Managers, CAs, CBSEs, Chief Civil Engineers, Chief Geotechnical Engineers, Chief Quality Surveyors etc., for review. Only minor suggestions were received and incorporated into the specifications.

276. The Hong Kong Construction Association (HKCA) was also consulted. In one bi-monthly liaison meeting held in July 2002 between HD and HKCA, the use of copper pipes in future HA projects was mentioned. HD also agreed to forward preliminary draft specifications and design layout drawings to HKCA for comment. The reply from the HKCA indicated that it had no comment regarding the materials stipulated in the draft specifications.

277. A paper on the "Use of Alternative Piping Material for Cold Water Supply Installations in HA Buildings" was then prepared and submitted to the Assistant Director/Development for clearance before

submission to the Development and Construction Management Board of HD for approval. The use of copper pipes and fittings was finally approved on 23 July 2002 for implementation with the following two specific new specifications:

> "**SUP 1.M178.N Soldering Alloys for Copper and Copper Alloy Capillary Fittings**
>
> (a) Soldering alloys: complying with BS EN 1254 Part 1 Table 6 Sections II & III;
>
> (b) The use of integral solder fittings is permitted provided they comply with BS EN 1254 Part 1;
>
> (c) Use only lead-free category solders;
>
> (d) Use only a non-corrosive type of the flux that is recommended by the solder alloy manufacturer.
>
> **SUP 1.W450.N Jointing Copper Pipework by soldering**
>
> (a) Remove copper oxide and dirt from pipe spigot and fitting socket prior to the application of soldering flux;
>
> (b) Apply flux sparsely and remove excess flux prior to heating;
>
> (c) Clean pipe joints with a damp cloth on completion to remove flux residues."

278. Given the above historical context, it appears clear to us that Mr Ng Tat Kwan and his team were fully aware of the risk of using leaded solder. They decided to go one step further by emphasising in the specification the "use" of "only lead-free category solders" and the "use" of "only a non-corrosive type of flux that is recommended by the solder alloy manufacturer". Flux is a chemical cleaning agent to facilitate the process of soldering. Nowhere in BS EN 1254-1:1998 is the requirement of flux mentioned. As such, the inclusion of

non-corrosive type of flux in the specifications indicated to us that Mr Ng Tat Kwan and his team had perused and researched widely showing their understanding of not only the soldering process but the associated technical matters involved. A separate specification for joining copper pipes by soldering was also prepared.

279. Implicit in demanding the use of only lead-free category of solder, HA, no doubt, was aware of the various non-lead-free category solders available on the market. To put the matter beyond doubt, BS 864-2:1983 and BS EN 1254-1:1998 actually listed out some of the different categories of solder.

280. Given the unequivocal wordings of all the specifications, HA, as an entity, must be clearly aware of the hazardous nature of leaded solder.

281. Furthermore, apart from copper pipes, uPVC-lined pipes were also at the time allowed to be used as an alternative to galvanised steel pipes. It is noted that the specification in relation to the use of uPVC-lined pipes were even more stringent than those proposed for copper pipes. Samples of uPVC-lined pipes and fittings together with catalogues and job references and many other documents had to be submitted for inspection. Copy of ISO 9000 series certification for the manufacturing plant was also required to be submitted for inspection too.

282. It was also stipulated that the uPVC lining to pipes and fittings should be suitable for use in potable water system and comply with

BS 6920 with respect to the effect on water quality. Corrosion resistance test was one of the quality tests required. For example, the concentration of dissolved iron in the water should be less than 200 μg/L after the pipes' being used for three months.

283. The requirements for suitable lining in uPVC-lined pipes indicated to us that HA was fully aware of the risk of possible contamination from materials used during the construction of the inside service.

284. HA sought to justify its "lack of awareness" by emphasising that solder materials were sundry items similar to tying wire, bolts and nuts. However, even if a particular kind of material is regarded as a sundry item in terms of its nature and use, it does not necessarily follow that such an item is insignificant and/or does not need to be subject to constant or random checking or testing. Materials like tile adhesive, tile grout, and emulsion paints may be seen as sundry items, but they have been subject to HA's "On-site Delivery Verification" mechanism.

The Construction Industry

285. As pointed out by Mr Ng Tat Kwan in paragraph 274 that the use of leaded solder was a prevalent issue, we have reasons to believe that all along the industry has general awareness of the hazardous nature of leaded solder.

The Hong Kong Construction Association

286. As stated above, HKCA was consulted prior to the introduction

of the use of copper pipes. It ought to have knowledge about the requirement of the use of lead-free solder.

<u>The Hong Kong Plumbing and Sanitary Ware Trade Association</u>

287. PSWTA found it necessary as early as in 1998 to issue a circular to its members, reminding them of the use of lead-free solder in end-feed capillary fitting. It knew.

<u>The Construction Industry Council</u>

288. Mr Li Cheung On, Trade Test Superintendent of CIC, told us that when he was teaching the basic craft course in plumbing and pipe fitting between 1996 and 2014, students were taught to use lead-free solder wire for capillary fitting. He had mentioned to his students that all materials used for fresh water supply system had to be lead-free.

<u>The Vocational Training Council</u>

289. In the 1996 Craft Certificate in Plumbing and Pipefitting course offered by VTC, students were taught to identify lead-tin solders, their melting points and the use of flux. In 2001, students were taught the different classification and melting temperature of solders, reasons for using flux and procedures in soldering. Although the use of lead-free grade solder was not specifically mentioned in the course scheme, instructors in practical classes always used lead-free grade solder for demonstration. In its examination papers in 2002/2003, students were tested on the toxic effect of lead.

290. Mr Chan Tze Kin, an instructor of VTC Craft Certificate course told us that he had always taught his students to use lead-free solder since he started teaching the course in 2001. He also adopted the use of one video produced by the Copper Development Centre in his lectures. In this video, it was clearly stated that lead-free solder should be used for potable water system.

291. Mr Leung Man joined VTC as an instructor in 1987. When students were taught about soldering, he introduced to his students the use of lead-free as well as lead-containing solders. Students were reminded that in the case of drinking water, lead-free solder ought to be used because lead was harmful.

292. The teaching of using lead-free soldering materials was discussed in one liaison meeting between VTC and WSD in December 2004. A representative from VTC informed Mr Paul Ho Key Wei, an engineer of WSD, that all students had been taught to use lead-free soldering material in workshop practice.

293. Mr Ho told us that around 2004, there was an increase of applications from suppliers for the use of copper pipes and fittings in inside service. He therefore took the opportunity of the liaison meeting to remind VTC of the need to teach students to use lead-free solder.

294. In our view, the construction industry as a whole was or ought to be aware of the risk of using leaded solder. However, given the breadth and depth of the industry and the number of individuals involved,

we are not surprised that some individuals may genuinely not know, some do not want to know and some pretend not to know, the risk of using leaded solder.

Risk Assessment by the Hong Kong Housing Authority

295. Once potential hazards have been identified, it is important to conduct risk assessment. It was stated in WHO's Water Safety in Buildings, 2011 Edition:

> "Once potential hazards and hazardous events have been identified, the levels of risk need to be assessed so that priorities for risk management can be established. Risk assessments need to consider the likelihood and severity of hazards and hazardous events in the context of exposure (type, extent and frequency) and the vulnerability of those exposed.
>
> Although many hazards may threaten water quality, not all will represent a high risk. The aim should be to distinguish between high and low risks so that attention can be focused on mitigating risks that are more likely to cause harm."

296. Unfortunately, upon the hazard having been identified, HA failed to conduct any risk assessment. HA's explanation was that prior to the incidents, there was a general belief or assumption within the industry that lead-free solders had always been used and that such materials should be safe. However, in the absence of any risk assessment, there was simply little basis for HA to form such belief or assumption.

297. According to one memo dated 8 February 2002, then CA (Design and Standard) asked Mr Leung Sai Chi, then CBSE to whom

Mr Ng Tat Kwan reported, to consider quality test for copper pipes and fittings similar to that for uPVC-lined galvanised steel pipes and fittings. Mr Leung however decided that since relevant standards had been specified, tests for other purpose were not envisaged. When Mr Leung was asked in the hearing on how HA could ensure the use of lead-free solder, his answer was "up to the project teams". We are disappointed with his answer. Given the professional expertise one would expect from a building services engineer, surely it was up to him to decide. In our view, there is a disconnection in HA between setting the specifications and their subsequent implementation.

298. It seems no thought had been given by HA on how to ensure or monitor compliance with the lead-free solder requirement. Without any specific risk assessment, HA failed to put in place control or mitigating measures to eliminate any of the risk posed by the use of leaded solder. As pointed out by Professor Fawell:

> "I find the statements that the HA were unaware of the issue of lead rather difficult to understand in view of the HA's specific requirement for using unleaded solder and low lead fittings. This implies that little thought was being applied to the contract. Rather, standard terms were being applied without understanding the reason for their inclusion."

299. All that HA hoped for was that the main contractors would follow the terms and conditions of the contracts, in particular the specifications, entered between the parties.

300. In August 2015, at the request of the Commission, HA provided a background paper to explain the past mechanism implemented

by HA in ensuring the safety and quality of fresh water supply in PRH estates. It comprised 18 major steps at four different stages:

(1) At the Design Stage, HD's CA serving AP's role of a public housing project submitted Form WWO 132 Part 1 to WSD to apply for confirmation/certificate of water supply availability.

(2) HD's project team prepared plumbing drawings and specifications in compliance with statutory requirements.

(3) Upon receipt of WSD's confirmation pursuant to step 1 above, HD's project team submitted two sets of plumbing drawings to WSD for approval.

(4) WSD approved the plumbing proposal via a written memorandum, with comments, if any.

(5) At the Tender Stage, HD's project team prepared tender drawings and specifications for tendering of the building contract (i.e. the contract with the main contractor).

(6) HD's project team issued tenders for building contract.

(7) At the Construction Stage, after the contract had been awarded, the main contractor might sublet part of the works to a domestic plumbing

subcontractor for execution of plumbing installation works. The domestic subcontractor would appoint a LP to take charge of the works.

(8) HD's CA serving AP's role of the project, as well as LP's, jointly signed and submitted Form WWO 46 Part I to notify WSD of the commencement date and the scope of plumbing works to be carried out, and to certify that the pipes and fittings intended to be installed (including those listed in the Annex to the Form and those not listed) were as prescribed by WWR.

(9) The main contractor (with his domestic subcontractor) submitted plumbing materials to the Contract Manager, namely a CA of HD, for approval.

(10) WSD completed Form WWO 46 Part III to indicate its acceptance of the plumbing details, and gave permission for LP to proceed with the plumbing works as detailed in Part I and in the Annex.

(11) The main contractor (with his domestic subcontractor) proceeded with the plumbing installation works on site.

(12) The main contractor, as required, gave continuous supervision, provided all necessary superintendence and executed the works in

accordance with the contract to the satisfaction of the Contract Manager.

(13) The AP and/or his representatives gave periodical supervision and made such inspection as necessary to ensure that the works would meet specified requirements.

(14) During Completion Stage, the main contractor cleansed and disinfected fresh water inside service.

(15) & (16) The AP confirmed that the works were in compliance with WWR, and applied to WSD for connection of water supply by completing Form WWO 132 Part II. At the same time, LP notified WSD of the completion of plumbing works, and requested for final inspection and approval by completing Form WWO 46 Part IV, which was also signed by AP.

(17) After steps 14 to 16 above, WSD would collect water samples from water connection points for testing and analysis. Water samples would be tested against the eight parameters namely pH, colour turbidity, conductivity, free residual chlorine, E.coli, total coliforms and heterotrophic plate count.

(18) Upon obtaining satisfactory testing results, WSD issued the certificate for water supply connection.

301. In this background paper, HA frankly admitted that the major cause of the incidents was the use of non-conforming solder materials for the joining of copper pipes which had escaped all stakeholders' attention at step 11, 12, 13, 15, 16 and 17.

302. The main contract between HA and the main contractors followed the requirements of the Government of Hong Kong General Conditions of Contract for Building Works 1993 Edition. The new specifications on the use of solder in paragraph 277 above became part of HA's Specification Library in 2002. HA's Specification Library 2004 or 2008 Edition, depending on the year of construction, formed part of the main contract.

303. For all the building projects including the 11 affected estates, the following standard specifications for plumbing installation in the building contracts were adopted (a) PLU1-Water Supply; and (b) PLU2-Sanitary Appliance. The main contractors were required under PLU1.G020.4 to comply with all statutory regulations and relevant standards including WWO, WWR, Hong Kong Waterworks Standard Requirement for Plumbing Installations in Buildings, Circular Letters issued by WSD, and relevant sections of appropriate British Standards on materials and workmanship.

304. It was specified under Clause PLU1.M160.4 (2004 edition) and PLU1.M160.5 (2008 edition) that only lead-free category solders could be used as soldering alloys for copper and copper alloy capillary fittings.

305. At all material times, HA implemented a process whereby samples of various materials would need to be submitted by the main contractors for HA's approval. In relation to most of the materials for sanitary appliances under PLU2 of the Specification Library, samples would need to be submitted.

306. For PLU1 materials, with only a few exceptions such as pipe brackets and anchors, draw-off taps, ball float valves for flushing cisterns, and uPVC-lined pipes, the main contractor would only need to submit type test reports/certificates issued by laboratories for verification of compliance by HA. It was unnecessary for samples of solder to be submitted to HA for approval.

307. However, as a matter of practice, in respect of each of the 11 affected estates, all the four involved main contractors had submitted a sample of FRY 99C lead-free grade solder wire, together with the relevant catalogue, test report and job reference to HA for approval. The act of submission by the main contractors and the acceptance by HA of the samples indicated that both parties knew very well the importance that only lead-free solder should be used for the drinking water system.

308. Following the "On-site Delivery Verification" mechanism, the staff of HD would verify and check the materials listed under Form No. 6210, upon their delivery to the construction site. Such a mechanism involved both "Document Check" and "Materials Check". However, solder was not covered by this verification mechanism of HA.

309. HD had a Site Inspection Team which comprised various ranks of Site Staff (namely Senior Clerk of Works, Clerk of Works, Assistant Clerk of Works and Works Supervisor) who were responsible for the day-to-day inspection of works and materials on site in accordance with the Architectural Site Inspection Guide.

310. Further, the Architectural Site Inspection Guide contained provisions regarding different categories of inspection during the course of the construction process (namely, Category A: 100%, Category B: 10%, and Category C: Random), which were usually conducted after the materials had already been applied to the works.

311. Again, solder was not subject to any of the above categories of inspection. In the circumstances, even if solder had been subject to the above inspection process, HD's Site Inspection Team would not have been able to identify whether the solder already applied and consumed was lead-free or complied with the contractual specifications unless they conducted on-site testing via, for example, X-Ray fluorescent analyser for each housing project.

312. We accept that it would be impracticable to expect any party to check, verify or inspect each kind of the numerous materials, in construction projects, given the constraints of time and resources. It is nevertheless, important to examine the steps taken by HA (and the rationale behind) in devising the checking and inspection system to assess if there have been any underlying flaws or deficiencies in HA's material monitoring system.

313. HA claimed that it adopted a "risk-based approach for quality control". However, no systematic risk assessment was carried out in 2002 when HA decided to allow the main contractors the choice of using copper pipes for fresh water plumbing installation. The choice of materials to be set out in Form No. 6210 was apparently based on two factors: (a) whether sample submissions were required for the materials under the contractual specifications; and (b) whether there had been previous incidents which would alert the industry (including HA) to the risk relating to the issue of compliance.

314. As pointed out by Counsel for the Commission, the fact that nothing had gone wrong before was not a reliable guide, because taken to a logical extreme, it would mean that one had to wait for something to go wrong for the first time before taking any monitoring or preventive measure.

315. As remarked by Professor Fawell at the hearing, if HA was not aware of the rationale behind its own specifications, it would not be in a position to monitor compliance by ensuring that the contractor would have in place the appropriate steps. HA's evidence showed that it completely relied on the main contractors to ensure that only the approved solder would be delivered and used on the site.

316. In our view, it was unsafe for HA to have such an idealistic assumption, without going through a proper risk assessment process, which in turn resulted in the glaring absence of a supervisory and monitoring system for solder.

317. Given its total reliance on the main contractors, HA simply did not know what solder was actually delivered to the site. Further, had HA requested for copies of the delivery notes of solder, they could have possibly detected the presence of non-compliant materials on-site, and perhaps prevented the present incidents.

318. Similar to WSD, there had been a systemic failure within HA as to the use of solder in the construction of the inside service. The process for the construction of the whole water supply system should be carefully re-examined. Introduction of a WSP for PRH estates may well be one of the answers since key steps involved in a WSP will take care of most, if not all, of the quality issues. As a matter of fact, HA has already introduced a number of control measures, procedures for operational monitoring and procedures for verification of control measures into its latest quality assurance programme. These measures are in line with the key steps in a WSP.

319. As pointed out in "Water Safety in Buildings" published by WHO in March 2011, "Development of WSPs should not be considered as overwhelming or too complicated. The aim is straightforward: to ensure consistent supply of safe water to consumers. To a large extent, WSPs document established good practice, and the most important step is getting started."

The Main Contractors

320. Evidence was received from witnesses called by the four main contractors. These witnesses told us their involvement during the

construction of the 11 affected estates. They also told us their knowledge, or lack of knowledge, on the required use of lead-free solder. As expected, their evidence varied a great deal, depending on their scope of work and past experience.

321. Despite all the differences, there is no doubt that each of the four main contractors was contractually bound by the terms of the main contract to comply with the lead-free solder specification. All four main contractors understood that and did not deny their responsibilities in ensuring the correct solder being used. Not only did they accept their responsibilities, they further admitted that there were shortcomings in their quality assurance procedures. In our view, they all acted sensibly and responsibly and co-operated fully with the Commission throughout the inquiry. The Commission also noted the remedial measures they undertook after the incidents.

322. All four main contractors had engaged plumbing subcontractors to undertake the plumbing works, and included in their plumbing subcontracts similar, if not identical, provisions for the use of lead-free solder. In essence, they passed their obligations under the main contracts onto the plumbing subcontractors in the form of "back-to-back" contracts.

323. Apart from labour, all the plumbing subcontractors involved in this inquiry, depending on the terms of the contract, were required under their respective plumbing sub-contracts to procure and bear the cost of some of the plumbing materials to be used in the projects. Golden Day

and Ho Biu Kee were required to provide all plumbing materials including pipes and fittings, whereas Wing Hing and Hang Lee were only required to provide sundry items. In all cases, they procured their own solder. Solder had been described as "sundry items", "metal fittings" or "small hardware items".

324. All four main contractors required their plumbing subcontractors to submit solder samples for approval by HA. In all the 11 affected estates, FRY 99C lead-free solder was submitted. All samples were supplied by Prosperity:

	Dates of submission and approval
Ching Ho	2/11/2007; 4/6/2007; 13/11/2007
Yan On	15/1/2009; 2/2/2009
Lower Ngau Tau Kok	5/11/2009; 1/10/2009
Shek Kip Mei	31/5/2010; 3/6/2010
Choi Fook	7/8/2008; 13/8/2008
Hung Hom	23/1/2009; 5/2/2009
Kai Ching	5/9/2011; 30/9/2011
Kwai Luen	18/2/2013; 20/5/2013
Tung Wui	13/12/2010; 23/12/2010
Wing Cheong	2/12/2011; 9/12/2011
Un Chau	Record unavailable

325. The evidence presented to the Commission showed that the four main contractors had taken steps to notify their subcontractors upon obtaining HA's approval. China State, for instance, produced a memo dated 3 October 2011 which was issued to Ho Biu Kee in respect of Kai Ching, notifying the latter that FRY 99C lead-free solder wire was approved. There was a similar memo dated 11 February 2009 issued to Golden Day in respect of Hung Hom. China State explained that it was their standard procedure for notifying subcontractors of sample approval.

326. Similarly, Shui On produced an email dated 3 June 2013 which was addressed to Mr Leung Wai Kin of Ho Biu Kee and attached with it a "material approval letter".

327. As regards Paul Y, it was explained that notification of sample approval would be effected by the company's site agent by email and by memo delivered to Golden Day. Neither of these documents was retrieved and produced at the inquiry, but Golden Day confirmed that such notification would be made by Paul Y.

328. Yau Lee and Ming Hop are sister companies. Yau Lee subcontracted the plumbing works to Ming Hop but the actual installation was further subcontracted to Wing Hing and Hang Lee. Apart from providing labour, Mr Mok Hoi Kwong of Wing Hing and Mr Siu Kin Wong of Hang Lee were responsible for procuring solder.

329. After sample approval, it appears that the four main contractors had taken no further steps to ensure that the solder actually procured and

used on their construction sites conformed to the approved sample.

330. In all cases, when solder arrived at site, it was the plumbing subcontractors who took delivery of it. It emerged from the evidence that the main contractors either had no system in place to inspect or verify incoming solder, or had not followed their system of control.

331. In the case of China State, solder was not required in either its Project Quality/Management Plans or Standard Operating Procedure for checking upon delivery. Yet under the Standard Operating Procedure, there was a requirement that even if a material was not listed therein, a sampling ratio had to be determined for conducting sampling check. China State admitted that there was no consideration or discussion for including solder in these plans.

332. In the case of Shui On, although its Project Quality Plan set out as many as 96 types of materials and the different levels of inspection upon delivery, inspection for solder was not required under the plan and, indeed, no thought was given to checking solder when formulating the plan.

333. In the case of Paul Y, its Project Quality Plan covered materials procured by the company only and required no checking of materials procured by its plumbing subcontractors.

334. In the case of Yau Lee, the company's internal guidelines required submission of delivery records from subcontractors and checking to see if the materials delivered had been approved. In case of

non-compliance, it would notify the subcontractor to return the materials. The guidelines required adherence to the above steps even for materials not specifically listed therein. Yau Lee accepted that the guidelines had not been followed insofar as solder was concerned.

335. As with witnesses of HA, it was a prevalent saying amongst personnel of the main contractors and plumbing subcontractors that solder was considered a "minor", "cost-insignificant' and "consumable" item in the plumbing industry. This could explain why solder did not feature at all in the design or implementation of the guidelines and project management plans of the main contractors.

336. In determining what was to be verified and/or inspected on site, the main contractors were also influenced by the emphasis (or lack thereof) placed by HA on different materials. Paul Y, for instance, said the level of supervision and inspection set out in its Project Quality Plan depended to a large extent on the importance and risks attached to the item of material in question by HA as expressed via their specifications and testing requirements. China State also relied on the fact that solder was not a specific item which HA required to be checked upon delivery in its Form No. 6210. This is in spite of the fact that the main contractors were supposed to have their own independent systems and procedures for material monitoring and supervision.

337. The main contractors also appeared to have placed complete reliance on the plumbing subcontractors to procure and use the correct type of solder. None of them had the practice of asking for delivery

records for verification. Paul Y, for instance, said it would only undertake a "high-level supervisory role" in overseeing and monitoring the works of the plumbing subcontractors, and would rely on the latter to comply with the law. Such trust turned out to be misplaced.

338. During the inquiry, the attention of the Commission was drawn to a common practice at construction sites, namely the submission of a "gate entry permit". The purpose of the "gate entry permit" was to notify the main contractor's frontline staff what materials were going to be delivered in advance, such that logistical and storage arrangements could be made. Again, when it came to sundry items, subcontractors were not required to specify the precise detail such as brand, type, quantity, etc. of the items on the "gate entry permit".

339. In the context of solder, given the lead-free requirement and the almost impossibility in identification once solder had been used in the plumbing system, a mechanism of sample submission and assurance of its subsequent use is vital. The measures adopted by HA after the incidents, in our view, are comprehensive and commendable. If followed strictly, similar incidents would likely be avoided.

340. However, the mechanism can minimise the risk of non-compliance only if there is a proper system to (a) ensure that all relevant parties know about the approved sample and the need for conformity of procured materials to the sample and (b) monitor compliance by the parties. The sample approval process cannot be treated as a formality. One relatively simple but effective step to take

under such a system is to request the plumbing subcontractors to provide delivery records. Had this been done, the use of non-compliant solder would likely have been detected.

341. Earlier we have mentioned WSD's reliance on LP and AP at paragraph 234 above for statutory compliance. Both WWO and WWR did not impose on main contractors any statutory duties. They were not required to notify WSD of the commencement date and the scope of plumbing work to be carried out. They were also not required to apply to WSD for final connection of water supply after completion of plumbing work. Given that main contractors played a key role in the construction of PRH estates, the present arrangement was certainly unsatisfactory.

342. Having reviewed all the evidence, we are satisfied that the four main contractors involved did not intentionally use any leaded solder in any of their building projects. There was simply no benefit for them to do so. Nonetheless, they failed to fulfil their contractual obligations under the main contracts. It was also unreasonable for the exclusion of main contractors from the statutory compliance process.

The Plumbing Subcontractors

343. The Commission has heard evidence from four plumbing subcontractors.

(1) Wing Hing Plumbing Drainage

Mr Mok Hoi Kwong

344. Mr Mok is the sole proprietor of Wing Hing. Mr Mok joined the plumbing industry in 1979. Wing Hing was set up in 1994 and became Yau Lee's plumbing subcontractor in 1995. Mr Mok obtained his equivalent CIC Trade Test Certification in plumbing in 1998. Wing Hing was the plumbing subcontractor for Yau Lee's PRH projects namely Un Chau, Ching Ho, Yan On, Lower Ngau Tau Kok and Shek Kip Mei.

345. For Ching Ho, the original plumbing subcontractor was Sum Kee. Wing Hing was called in to replace Sum Kee midway.

346. In respect of all five housing estates, Wing Hing was responsible for the procurement of sundry items such as solder but had never been instructed by Yau Lee / Ming Hop to purchase a particular brand with any specification. Mr Mok stated that he could not recall if Wing Hing had been asked to provide or had provided on its own initiative sample of solder to Ming Hop. Neither was Mr Mok able to recall if FRY 99C lead-free solder had been provided to Ming Hop or Yau Lee. He also had no idea what amounted to "meeting the requirement of Housing Department" as stated in his contract with Ming Hop. Had he known in advance that lead-free solder was required, he would certainly have followed that specification.

347. At different stages of the project development, HA required main contractors to put up timber mock-up flats and sample flats. Mr

Mok said that Wing Hing had used tin strips for joining the pipes both at the timber mock-up flats and sample flats. As far as he knew, tin strips had been commonly used for joining copper pipes.

348. During the construction of the five housing estates, Wing Hing used tin strips. On occasions when tin strips were out of stock, tin wires would be used. Mr Mok claimed that he was not at all aware that solder might contain lead. To his understanding, no plumbing workers in his trade possessed such knowledge. Tin strips were used because they were convenient and had a lower melting point.

349. Mr Mok told us that he did not know the price difference between tin strips and tin wires. He believed the use of tin strips, though cheaper, would not save costs because of higher wastage : workers would have to dispose of the last hand-held portion of the tin strips towards the end of the soldering process to avoid getting burnt.

350. Wing Hing procured tin strips from two suppliers, Prosperity and Wo Hing. Prosperity was the supplier for Un Chau, Ching Ho and Yan On. Wo Hing was the supplier for Lower Ngau Tau Kok and Shek Kip Mei.

351. When ordering, Wing Hing simply asked for tin strips. If tin strips were out of stock, the supplier would suggest tin wires as alternative. The only information asked of from the supplier was quantity and delivery address. There was no need to provide any information regarding brand name, model number or purpose of use.

352. Prosperity and Wo Hing supplied similar tin strips which were bundled into batches without outer packaging or brand name. Tin wires, in the form of reels, however were contained in boxes from the original manufacturer.

353. When tin strips were delivered to construction site, either Mr Mok or his workers would pay cash for the goods and sign on the delivery note. Invoice would be issued by the supplier. Most of these invoices had been lost or misplaced.

Findings

354. We do not believe what Mr Mok told us about his lack of knowledge is true.

355. Mr Ng Hak Ming told us that for projects prior to Un Chau, solder was procured by Ming Hop rather than the plumbing subcontractor. He had told Mr Mok that FRY 99C lead-free solder had to be used in the plumbing works.

356. As regards Ching Ho, Mr Ng Hak Ming testified that he had visited the site together with Mr Mok when Wing Hing took over the project. He had informed Mr Mok that FRY 99C lead-free solder which had been already procured by Sum Kee was required by HA. According to the record produced by Prosperity, all the solders ordered by Wing Hing for Ching Ho from June 2008 to 2 September 2009 was FRY 99C lead-free solder. We also do not accept that Prosperity would, as Mr Mok told us, suggest the use of FRY 99C lead-free solder as replacement

when tin strips were out of stock. Mr Chow Ka Ping of Prosperity told us that the out-of-stock situation was not common. Procurement staff of Ho Biu Kee also told us that in case of out of stock, Prosperity would simply inform them of the situation.

357. Yau Lee's site agent for Yan On, Mr Chau Chi Wai, testified that Mr Mok had personally handed a sample of FRY 99C lead-free solder to him for sample submission to HA. He remembered that he had personally chased up Mr Mok for the sample.

358. In respect of a separate HA project at Anderson Road, Yau Lee's Architectural Quality Control Coordinator (AQCC), Mr Leo Tam Sin Ting, testified that Mr Mok had personally delivered to him a sample of FRY 99C lead-free solder for submission to HA. Mr Ching Chi Fai, Ming Hop's Senior Engineer, said he was the one calling Mr Mok to submit a sample solder compliant with HA's requirement. Mr Ching recalled that he had also informed Mr Mok of the subsequent approval by HA in July 2013.

359. Mr Ching Chi Fai further testified that, during the construction of Lower Ngau Tau Kok, he had contacted Mr Mok for a soldering demonstration in the sample flat as requested by HA. He did not specifically mention the lead-free requirement. Yet on that occasion, FRY 99C lead-free solder was used.

360. The invoice produced by Prosperity showed that 20 reels of FRY 99C lead-free solder had been delivered to Un Chau. The invoice

was addressed to Mr Mok. Delivery notes signed by Mr Mok showed the delivery of 110 reels to FRY 99C lead-free solder to Ching Ho between June and August 2008. These were all cash-on-delivery sales.

361. Given the fact that (a) Mr Mok became a registered skilled worker in 1998 and his extensive experience in HA's projects; (b) by his own admission, he had submitted FRY 99C lead-free solder as sample to HA for at least the Anderson Road project; and (c) his name and signature were on various invoices and delivery notes of solder, it appears to us that Mr Mok was at all material times aware that FRY 99C lead-free solder was the type of solder approved by HA for the PRH projects.

362. There was significant price difference between FRY 99C lead-free solder and tin strips. Pound for pound, tin strips cost about 40% less than lead-free solder. In our view, there were enough financial incentives for Mr Mok to use the cheaper solder given the competitiveness in pricing over public building projects.

(2) Hang Lee Engineering Company

Mr Siu Kin Wong

363. Mr Siu is the proprietor of Hang Lee which was set up in 2002. Mr Siu joined the plumbing industry in the 1980s. Similar to Mr Mok Hoi Kwong, Mr Siu obtained his equivalent CIC Trade Test Certification in plumbing in 2000.

364. In respect of Choi Fook, Yau Lee was the main contractor whereas Ming Hop was the subcontractor. Hang Lee was the plumbing sub-subcontractor. Clause 78 of the plumbing contract required Hang Lee to procure sundry items, including solder, at its own costs. According to Mr Siu, Ming Hop had never suggested which particular brand or place to purchase those items. The project commenced in 2007 and was completed in 2010.

365. According to Mr Siu, Hang Lee procured tin strips from Prosperity. The tin strips were about two feet long each and flat in shape. They were used in the construction of the timber mock-up flat and sample flat too. Mr Siu stated that prior to the incidents, he had never come across FRY 99C lead-free solder. Nor was he aware that solder might contain lead. To his understanding, workers in the plumbing trade did not possess any knowledge as to whether tin strips might contain lead. He was not familiar with any plumbing standards such as British Standard.

366. Hang Lee ordered tin strips from Prosperity. As tin strips were inexpensive items, Hang Lee had never found it necessary to negotiate price. When ordering, Mr Siu said there was no need to inform staff of Prosperity any brand name; he needed only to mention the quantity of "tin strips" required. After placing order, Prosperity would deliver the tin strips in rectangular boxes to the site. As tin strips arrived in the form of strip, workers needed not cut them into smaller sections.

367. Choi Fook was Hang Lee's first project. Mr Siu said that he did not expect to make any profit; he simply hoped to gain experience as a subcontractor.

368. Mr Siu stressed that throughout all the years, tin strips had been used not only in Choi Fook, but also when he worked for other contractors. He had never seen "solder wire in a green reel" (i.e. FRY 99C lead-free solder, which is in the form of a reel with a green label).

Findings

369. We do not believe Mr Siu [redacted]

370. In response to Hang Lee's contentions, Yau Lee / Ming Hop initially produced photos taken during a soldering demonstration to HA at Choi Fook, one of which showed a man in a black and white striped top holding a reel of FRY 99C lead-free solder and a jar of flux. Mr Siu initially denied he had any knowledge of FRY 99C lead-free solder and that the man depicted in the photo was him, despite the contrary evidence of Mr Yee Yat Ming, Yau Lee's AQCC for Choi Fook.

371. Mr Yee worked for Yau Lee between December 2007 and May 2013 as AQCC at Choi Fook. During his employment with Yau Lee, Mr Yee only worked on this Choi Fook project.

372. According to Mr Yee, before the plumbing work was commenced, he had liaised with Ming Hop on sample submission to HA.

It was Mr Siu who personally passed him a sample of FRY 99C lead-free solder. Mr Yee remembered clearly that the lead-free solder sample came in with a green label and in a reel. Not knowing the past practice, Mr Yee had suggested to Mr Siu to submit, instead of the whole reel, only a section of the solder wire. That suggestion was rejected by Mr Siu, who explained that the whole reel had to be submitted for approval.

373. Mr Yee told us that he was fully aware of HA's specification on solder and even had exchanges with HD's Clerk of Work as to its requirement during its submission.

374. Mr Yee testified that on 27 March 2009, a demonstration on how to join copper pipes was conducted at one of the sample rooms at which Mr Siu was present. Photos depicting a worker holding FRY 99C lead-free solder wire were taken.

375. Although the face of the worker was not captured in those photos, Mr Yee however stressed that the worker indeed was Mr Siu based on the physique and the upper garment worn by the worker. To prove this point, another photo depicting Mr Siu wearing the same upper garment whilst attending a meeting was produced during the hearing.

376. We have no hesitation in accepting Mr Yee's evidence. He worked for Yau Lee on only one housing project. There is little room for confusion. He also has no apparent self-interest to serve for he is no longer an employee of Yau Lee.

377. Invoices produced by Prosperity showed that only tin strips had been delivered to Choi Fook. Again, they were all cash-on-delivery sales.

378. The CIC (formerly known as the Construction Industry Training Authority) has been responsible for training and holding trade tests for plumbing workers since 1995. According to the evidence of Mr Li Cheung On, Trade Test Superintendent of CIC, in the training offered by CIC, the knowledge of using lead-free solder was taught to student workers.

379. Completion of the CIC courses however is not mandatory for becoming a registered skilled or semi-skilled worker in the plumbing trade. A worker having sufficient work experience can become registered. Plumbing workers in HA building projects are mostly "skilled" or "semi-skilled" workers registered under CWRO. Although the written course outlines did not specify teaching content about the requirement for lead-free solder, instructors would communicate the same to the students. In conducting trade tests, lead-free solder would be provided to candidates. In other words, whether Mr Siu obtained his "skilled workers" qualification through attending course or through passing the trade test, either way, he must have been made aware that lead-free solder ought to be used for joining drinking water pipes.

380. It appears clear to us that Mr Siu was aware at all material times that FRY 99C lead-free solder was the solder which had been approved by HA and was the only brand of solder that could be used for

Choi Fook. Similar to Mr Mok, Mr Siu decided to use tin strips instead for financial gain.

(3) Golden Day Engineering Company Limited

(i) Mr Cheung Tat Yam

381. Mr Cheung is Managing Director of Golden Day which was established in about 1987. Golden Day was the plumbing subcontractor for Wing Cheong, Tung Wui and Hung Hom. It was responsible for both procurement of materials and provision of labour and submission of solder sample to HA for approval. Golden Day was aware of the lead-free solder specification as stipulated in HA's Specification Library 2004 and 2008 edition.

382. Mr Cheung also served as LP for all three building projects. He had been in the plumbing industry for over 40 years. He had been aware of the requirement of lead-free solder for at least eight to nine years, but he had never done any soldering work himself. He claimed that he did not know there was leaded solder on the market. Neither was he aware of the distinction between tin strips and tin wires. He was however aware of the harmful effect of lead.

(ii) Mr Yung Kwok Choi

383. Mr Yung was Project Manager and Director of Golden Day. He joined Golden Day in 2002. Among other duties, he was responsible for sample submission. All along only FRY 99C lead-free solder had

been submitted to HA for approval. Since solder was sundry items, he did not know whether there was leaded solder on the market. He also did not know the difference between tin strips and tin wires.

384. Once HA had granted approval for the solder sample, he would inform the same to his staff, Mr Wong Kam Man. Mr Wong would in turn inform Ms Lam Lai Ping and Ms Mok Wai Yin of the procurement department. According to Mr Yung, Mr Wong, Ms Lam and Ms Mok should know that only FRY 99C ought to be ordered and used in these building projects.

385. After the incidents, at the request of Paul Y, Mr Yung attended a meeting with its senior management on 16 July 2015. In the meeting, Paul Y requested Golden Day to provide proof that lead-free solder had been used in their projects the following day.

386. After the meeting, Mr Yung relayed over the phone the request of Paul Y to Ms Lam and asked Ms Lam to locate all relevant documents. On 17 July 2012, Mr Wong as instructed by Mr Yung emailed all the relevant documents, which had allegedly been located by Ms Lam, to Mr John Ma of Paul Y. Mr Yung told us that later in the day he returned to Golden Day, got hold of the same documents which were placed inside an envelope and personally delivered them to Paul Y. He claimed that he was not aware what documents were inside the envelope. His understanding was that all the documents were prepared for him by Ms Lam.

387. Mr Yung denied he had ever asked Ms Lam to forge any delivery notes. For personal reasons, Mr Yung left Golden Day in August 2015.

(iii) Ms Lam Lai King

388. Ms Lam joined Golden Day in 1988. Between 2002 and the first half of July 2015, she was also made a Director. After resigning as Director, she continued to be in the employ of Golden Day. Ms Lam was responsible for the company's human resources, office administration and procurement matters.

389. According to Ms Lam, although she was responsible for procurement, she had little knowledge about solder. She did not know the difference between tin strips and tin wires. Nor did she know that solder for joining drinking water pipes had to be lead-free.

390. When placing orders for solder, she would simply repeat the order as per the instruction of the person-in-charge of the site. If tin strips were requested, she would order tin strips. The same applied to tin wires.

391. As to documentation regarding the purchase of solder, Ms Lam told us that all had been discarded. She said that the practice of the company was that all documents after audit would be discarded for lack of space, despite the Inland Revenue Department's requirement for retaining the same for seven years.

392. Ms Lam's version of what happened on 16 July 2015 was different from Mr Yung's. Ms Lam testified that Mr Yung had called her to say that Paul Y had requested Golden Day to provide records on procurement of solder for Wing Cheong. After checking, she discovered some delivery notes of tin strips. Ms Lam called Mr Yung and told him the result. According to Ms Lam, Mr Yung stated that what he needed were delivery notes showing Prosperity had delivered lead-free solder wires to Wing Cheong. Mr Yung also hinted that if there were no such delivery notes, she should know what to do. She subsequently found four delivery notes on the tray and changed the content therein from tin strips to tin wires. She then called Mr Yung to confirm what she had done.

(iv) Mr Hui Wang San

393. Mr Hui was the foreman for Hung Hom and Wing Cheong. He was fully aware that lead-free solder should be used for joining potable water pipes but did not know that leaded solders were available on the market. When he placed order with either Ms Lam or Ms Mok, he would simply ask for tin strips. He did not know the difference between tin trips and tin wires. As far as he knew, tin strips did not contain lead.

(v) Mr Chau See Ming

394. Mr Chau was the foreman for Tung Wui. He did not know lead-free solder was required for joining potable water pipes. He was

not aware of the difference between tin strips and tin wires, and their respective compositions. He would only ask for tin strips when placing orders. He used FRY 99C lead-free solder once in relation to a private development project of Golden Day.

(vi) Mr Wong Kam Man

395. Mr Wong joined Golden Day in 1996. On occasions, he assisted Ms Lam and Ms Mok in receiving purchase orders from site foremen. Every time, he would just pass on their requests to the two ladies, who would then follow up with the suppliers. He recalled that the foremen normally asked for tin strips however, sometimes they asked for tin wires. He would relay whatever was ordered in exact wordings to Ms Lam or Ms Mok.

396. Prior to the incidents, Mr Wong was aware of the requirement to use lead-free solder in PRH projects. He however was not aware that there were leaded solders on the market. It was Mr Yung who submitted solder samples to the respective main contractors. Mr Yung would inform him once approval was obtained.

(vii) Ms Mok Wai Yin

397. Ms Mok joined Golden Day as a clerk in 1998. Part of her duties included material procurement. She did not know lead-free solder was required for joining fresh water pipes. When placing orders, she simply repeated the requests made by the site foremen Mr Hui and Mr Chau. She did not know whether the solder procured and used by

Golden Day contained lead. She had never seen FRY 99C lead-free solder.

Findings

398. We are not impressed with Mr Cheung's evidence. He tried to distance himself as far as possible from the present incidents.

399. Despite his extensive experience in the plumbing business, he told us that he had never done any soldering himself and had never known the difference between tin strips and tin wires. He only knew there was only one type of solder, that was FRY 99C lead-free solder.

400. When a reel of FRY 99C lead-free solder was shown to Mr Cheung, he told us that he did not understand the word "lead-free" because of his limited English capability. Yet, according to Mr Cheung, he was aware of HA's requirement for lead-free solder, and he knew the relevant specification as stipulated in both the 2004 and 2008 "The Hong Kong Housing Authority Specification Library", all written in English.

401. Mr Cheung informed us that he had no idea what was stated in the Form WWO 46 despite the fact that, as an LP, he had signed the same form many times for the past 30 years in respect of over 50 public housing projects.

402. In distancing himself, Mr Cheung told us that he had no idea who decided to submit sample of solder to HA. He had no idea how many Directors there were in Golden Day in July 2015. He had no idea

as to when Ms Lam resigned as Director and why his wife resigned after the incidents too. As to the other Co-Director Mr Yung, Mr Cheung was very reluctant to furnish any information too.

403. We were also told by various staff that Mr Cheung was on holiday in China, with no telephone connection, between 17 and 22 July 2015, while four delivery notes were being forged in his absence.

404. In the course of the inquiry, four delivery notes submitted by Golden Day to Paul Y after the discovery of excess lead in drinking water turned out to be forged. The forged documents showed the delivery of FRY 99C lead-free solder to Wing Cheong, and the authentic delivery notes showed the non-compliant "UK 50 lead flat tin strips" (transliteration of "英國 50 力扁錫條"). Ms Lam admitted to having forged the documents at the behest of Mr Yung.

405. When being questioned as to why he formed the view that the four forged delivery notes could not be genuine, Mr Cheung's answer was simply that he believed in Prosperity's record-keeping. In other words, the possibility of Prosperity's making a mistake had never been contemplated.

406. Golden Day was a very small company with five staff working at a 700-square-feet office and two at its construction sites. Mr Cheung's attempt to distance himself from his staff and what was happening to his company was unordinary. It was also strange that Mr Cheung did not bother to find out from his staff why the forged

documents had been made.

407. Mr Cheung's explanation as to when and why all the invoices and delivery notes regarding the purchase of sundry items had been discarded was unconvincing too. As to when records were discarded, three different versions had been put forwarded by him: (a) after payment was made; (b) one year after project completion; and (c) two years after maintenance period. As to why they were discarded, the answer given was simply there were too many of them. Apparently, no thought had ever been given to either scanning these invoices or delivery notes or computerising all the data. Documents were simply discarded irrespective of the Inland Revenue Department's requirement.

408. The invoice and delivery notes produced by Prosperity showed that Golden Day ordered one reel of FRY 99C lead-free solder as sample at the beginning of the Hung Hom project in March 2009. At the end of the project in March and April 2011, 100 reels of FRY 99C lead-free solder were again ordered. Between March 2009 and April 2011, 1045 pounds of leaded tin strips were purchased. From the usage pattern, we doubt if Mr Hui really did not know the difference between tin strips and tin wires and that he only ordered tin strips for use. In fact, we have strong reservation about the evidence given by the staff of Golden Day except Ms Mok.

409. After the incidents, when being asked by WSD as to why leaded solder was used in the projects, Mr Cheung simply replied "no explanation". He had hardly been forthcoming in our inquiry.

410. In respect of Tung Wui and Wing Cheong, Golden Day had ordered a total of 1,705 pounds leaded tin strips between June 2010 and March 2013 with no order of FRY 99C lead-free solder at all. Interestingly, Mr Chau told us that in another private development project of Golden Day, lead-free tin wires were delivered even if he had ordered tin strips.

411. We are not impressed by Mr Yung's evidence either. [redacted]

412. After the incidents, Mr Yung was called up by the senior management of Paul Y to provide records to prove that lead-free solder had been used. Yet according to his evidence, after relaying Paul Y's request to Ms Lam, he claimed that he had not asked Ms Lam for any answer. He did not even see what documents had been put inside the envelope before hand-delivered the same to Paul Y. Any sensible person would undoubtedly make sure that only the correct documents were being delivered, for it was not any trivial matter especially after the extensive media coverage of the incidents.

413. At the hearing, Mr Yung produced Whatsapp messages to demonstrate how Ms Lam informed him that the requested documents were ready. The same messages indicated to us that all the documents for Paul Y were prepared at the request of Mr Yung. In other words, the initiation came from Mr Yung. In our view, Mr Yung and Ms Lam must have had detail exchanges beforehand, and Mr Yung did not need to

check what was inside the envelope because he knew precisely what had been prepared for him by Ms Lam. On this aspect of the evidence, we believe what Ms Lam told us.

414. As to Ms Lam, [redacted]

415. Having said all that, we do not feel necessary to identify here the extent of involvement of all individuals. Suffice to say that most if not all the senior management of Golden Day knew full well about the use of leaded solder. We would in due course refer the matter to the appropriate law enforcement agency for follow up investigation.

(4) <u>Ho Biu Kee Construction Engineering Company Limited</u>

(i) Mr Ho Man Piu

416. Mr Ho Man Piu is Managing Director of Ho Biu Kee, which was set up in 1981. It has been active in the plumbing business, having completed over 126 public housing projects. Ho Biu Kee was the plumbing subcontractor for China State's two PRH projects, namely Kai Ching and Hung Hom. It was also the plumbing subcontractor for Shui On's Kwai Luen project.

417. Although plumbing was one of his business areas, Mr Ho said that he did not himself do any soldering of copper pipes as this was done by his staff. Thus, Mr Ho did not have any practical experience or knowledge in the type or brand of solder for joining of copper pipes.

418. Mr Ho did not know the requirement of using lead-free solder in the potable plumbing works prior to the present incidents. He did not know the requirement that lead should not be present in potable water system prior to July 2015. After all, the testing of water samples did not include lead or other heavy metals.

419. As solder was not included in the Bill of Quantities, Mr Ho considered it as a consumable and came to the belief that there was no specification for the same. Mr Ho strongly disagreed with any suggestion that cost saving was the prime objective for using the cheaper tin strips. Mr Ho held that the cost of solder was insignificant and he was more concerned about the efficiency and productivity of his workers.

420. For Blocks 3 and 4 of Kai Ching, the labour subcontractor was Mr Chan Sze Lam who engaged his own workers to work on branch pipes in the corridor of each floor, as well as external PVC pipes. Extra payment as incentive was devised if Mr Chan Sze Lam completed his work within or ahead of schedule. Other works (except the roof) in Blocks 3 and 4 were done by workers directly employed by Ho Biu Kee.

421. Mr Ho told us that after Kai Ching, Mr Chan Siu Wah was deployed to Lung Yat, another PRH project, where all plumbing works were done by workers of Ho Biu Kee. Records showed that only lead-free solder wires were ordered and used.

422. For Kwai Luen, after the incidents, Mr Ho said he asked Mr Wong Kwai Hung why he had ordered tin strips as well as tin wires. Mr Wong explained that as both materials were observed to have been used in Kai Ching, he just followed the same practice.

(ii) Mr Kevin Kwong Ka Fu

423. Mr Kevin Kwong Ka Fu, a quantity surveyor of Ho Biu Kee, obtained a Diploma in Building Studies from VTC. He was responsible for submission of materials, including solder, to HA through main contractors. He was aware of the lead-free requirement in the specification but did not know the rationale behind it. When preparing quotations for tender, Mr Kwong would allow approximately 5% of the total contract sum for sundry items which included solder. He would approach Mr Chow Ka Ping of Prosperity to obtain a sample of solder for submission. Every time, Mr Chow would provide FRY 99C lead-free solder and other supporting documents to him.

424. According to Mr Kwong, there was little communication between him and the staff of the purchasing department after obtaining HA's approval of the sample. Mr Kwong believed his colleagues in the purchasing department would approach Prosperity for FRY 99C lead-free

solder. Mr Kwong denied having told site supervisors of Kai Ching (Mr Wong Kwai Hung for Blocks 1 and 2; Mr Chan Sze Lam for Blocks 3 and 4 and Mr Fan Sau Pang for Blocks 5 and 6) about the use of different joining materials (soldering or silver brazing) for different diameters of copper pipes. These were, according to Mr Kwong, technical matters beyond his professional knowledge. Mr Kwong also did not telephone Mr Chan Siu Wah to tell him the same for Lung Yat.

(iii) Ms Wong Wai Ping

425. Ms Wong is Personal Assistant to Mr Ho. She has worked for Mr Ho since 1997. Ms Wong was not involved in any sample submission or site operation. She was not aware that solder for joining fresh water pipes ought to be lead-free. She also did not know that tin strips might contain lead.

426. Although Ms Wong oversaw the work of Ms Jess Chiu Wai Kuen (head of the purchasing department of Ho Biu Kee), she seldom did the purchasing herself. She assisted Ms Chiu and her colleagues in placing orders on some occasions.

427. Ms Wong denied that when tin strips were requested for Lung Yat by Mr Chan Siu Wah, she had requested him to amend his request to tin wires.

(iv) Mr Leung Wai Kin

428. Mr Leung was appointed Project Manager of Ho Biu Kee in

February 2012. He first got involved in Kai Ching in about mid 2012. At that time, Mr Leung was responsible for nine to ten building projects. Mr Leung told us that he was not involved in any minor details and did not know anything about the material submissions including that for solder.

429. Mr Leung further explained that he did not spend much time on each site as he had to look after many projects. His main role was to resolve issues raised by main contractors regarding site operation and progress of work. In essence, monitoring and supervision of works on site was left to the officers-in-charge.

430. Mr Leung said that the copper pipe works (except the roof) as well as PVC pipe works in Blocks 3 and 4 of Kai Ching had been subcontracted to Mr Chan Sze Lam. As far as he was aware, Mr Chan Siu Wah brought in Mr Chan Sze Lam.

431. Kai Ching was a big project then. It would have entailed a great deal of management if all works were carried out by Ho Biu Kee's direct labour. Based on Mr Leung's cost analysis, Mr Ho agreed to subcontract the works in Blocks 3 and 4 to Mr Chan Sze lam. As the amount of payment to Mr Chan Sze Lam depended on the progress of his work, there were incentives for Mr Chan Sze Lam and his workers to complete their work as speedily as possible.

(v) Mr Chan Siu Wah

432. Mr Chan stated that he did not know lead-free solder was

required for potable water pipes before July 2015. He also did not know how to differentiate lead-free solder from leaded solder.

433. Mr Chan maintained that he had been using tin strips all along and he had always put down tin strips on Ho Biu Kee's Material Request Forms. He was aware that solder delivered from Prosperity included reels of tin wires and boxes of tin strips, however, he did not know that HA had only approved "FRY 99C lead-free solder" but not tin strips.

434. Mr Chan was of view that when Prosperity did not have sufficient quantity of tin strips, tin wires would be delivered instead. Mr Chan maintained that he was not aware of the price difference between the two and he did not know whether Prosperity had informed any purchasing staff of Ho Biu Kee why tin wires were delivered.

435. For Lung Yat, Mr Chan said he had requested tin strips but reels of tin wires were delivered. A female staff of Ho Biu Kee asked him to amend his request form to tin wires. He however could not remember the identity of the lady and the reason behind for such a change.

(vi) Mr Wong Kwai Hung

436. Mr Wong had 20 years of experience in plumbing works. He held a full Trade Test Certificate in plumbing from the equivalent of CIC. Mr Wong had been working for Ho Biu Kee since 2003.

437. Mr Wong started to work at Kai Ching in April 2012 as the supervisor responsible for Blocks 1 and 2. The purchase of solder was arranged by Mr Chan Siu Wah, as the overall person-in-charge of Kai Ching project. Mr Chan Siu Wah ordered both tin strips and tin wires. Kai Ching was the first time that Mr Wong had used tin strips. To the best of Mr Wong's knowledge, Ho Biu Kee had not used tin strips in prior PRH projects.

438. Mr Wong was later put in charge of Kwai Luen. He was responsible for preparing Material Request Forms. He followed the same practice in Kai Ching and ordered both tin strips and tin wires. He used tin strips for copper pipes with a diameter of 15-42 mm, tin wires for copper pipes with a diameter of 50-67 mm and pressure-reducing valves, and silver brazing for copper pipes with a diameter of 70-100 mm. He reckoned that tin strips were easier to use because of their lower melting point. He also reckoned that tin wires should be used for pressure-reducing valves because of their higher melting point and greater strength.

439. Mr Wong did not know that solder was required to be approved by HA. He was not aware of the lead-free requirement for solder in potable water system. He also did not know that the tin strips used in Kai Ching and Kwai Luen might contain lead.

(vii) Ms Jess Chiu Wai Kuen

440. Ms Chiu was the head of the purchasing department of Ho Biu

Kee. Ms Chiu confirmed that she and other purchasing staff of Ho Biu Kee were not aware that tin strips might contain lead.

441. According to Ms Chiu, Mr Chan Siu Wah, the person-in-charge of Kai Ching, had requested both tin strips and tin wires. Ms Chiu acceded to his request and asked Prosperity to supply the same. According to Ms Chiu, Mr Wong Kwai Hung, the person-in-charge of Kwai Luen, also had made similar request for both tin strips and tin wires.

442. Ms Chiu denied having requested Mr Chan Siu Wah to amend his request from tin strips to tin wires in Lung Yat. As head of the purchasing department, she was not aware any of her staff had made such request too.

Findings

443. Unlike the evidence of other plumbing subcontractors, we do find Mr Ho's evidence believable. He appeared to be frank and forthcoming in giving his evidence. We do not believe either he or Ho Biu Kee as an entity had intentionally used leaded solder for financial gain. Having said that, we believe that Mr Chan Siu Wah had deliberately ordered leaded solder and permitted its use in Kai Ching. We are also satisfied that Mr Wong Kwai Hung had followed Mr Chan Siu Wah's practice and used leaded solder not only in Kai Ching but also in Kwai Luen.

444. We are unimpressed with Mr Chan Siu Wah's evidence. He tried very hard to disassociate himself from the present incidents by claiming that he knew little about the requirement of HA and the technical detail of his works. As the officer-in-charge, one of his primary responsibilities was to ensure that the progress of all plumbing works would meet the schedule. Once the progress was behind schedule, it is not difficult to contemplate that Mr Chan Siu Wah would need to consider ways and means to catch up. We note that in respect of Blocks 3 and 4, Mr Chan Sze Lam, a labour subcontractor, was recruited into the project by Mr Chan Siu Wah. Incentive was devised by Ho Biu Kee for Mr Chan Sze Lam to complete the job on or ahead of the schedule. As Kai Ching was the first project that Mr Chan Siu Wah was put in charge by Mr Ho, it defies common sense for Mr Chan Siu Wah to say that he was not concerned with the progress of the plumbing works or his performance in managing the project.

445. We also note that Mr Chan Siu Wah was dismissed by Ho Biu Kee for misappropriation of property from the company's construction site. In our view, he knew full well that workers preferred to use tin strips instead of tin wires as the former melted at a lower temperature and it could help speed up the soldering process. He had ordered both tin strips and tin wires for the project. Tin wires were used mainly for joining pressure reducing valves or pipes with a large diameter.

446. Invoices produced by Prosperity showed that between October 2011 and June 2012, both lead-free tin wires and leaded tin strips were ordered and delivered to Kai Ching. The pattern of purchase

tended to support Mr Wong Kwai Hung's testimony that different solders were used for pipes of different diameters, albeit not on any technical or scientific basis. However, it seems that this practice had been abandoned altogether soon after. Between June 2012 and January 2013, leaded tin strips were used exclusively at Kai Ching.

447. Mr Wong Kwai Hung brought this practice to Kwai Luen. Between April 2013 and March 2014 while he was the person-in-charge of Kwai Luen, save and except on one occasion, leaded tin strips were ordered and used throughout. The only occasion on which tin wires were ordered was the next day after FRY 99C lead-free solder was approved by HA on 3 June 2013. One box of 20 reels of lead-free solder and three boxes of leaded tin strips were ordered by Mr Wong Kwai Hung. This pattern of ordering demonstrated unequivocally to us that Mr Wong Kwai Hung was clear about the difference between the two. He knew lead-free solder ought to be used, but for the ease of work, he chose to ignore it.

448. We fully appreciate the limitation placed on us by virtue of section 3 of the Ordinance. All the above factual findings are made based on the evidence received pertaining to the issue of plumbing subcontractors' knowledge on the use of leaded solder. They are not intended to attach any bearing on any individuals, whether legal or natural persons, as to their civil or criminal responsibilities.

449. There is little point in our view to go further down the manpower hierarchy than the persons-in-charge of individual building

projects for we accept that workers simply used whatever had been provided to them. There is also little meaning to assess the misnomer given to tin strips and tin wires for we have found that all relevant persons responsible for ordering knew what exactly they were ordering. They knew what they should order, what they did order and what their workers were given.

450. In our view, in respect of the 11 affected estates, leaded solder was introduced into the plumbing system during their construction. Leaded solder was intentionally used with little regards to its adverse implication on human health and the contractual requirements imposed on them.

V. CONCLUSION

451. We are satisfied that leaded solder is the direct cause of excess lead found in drinking water in all the 11 affected PRH estates. This is a finding made by the WSD Task Force, accepted by Professor John Fawell and verified by Professor Joseph Lee in his independent investigation conducted on behalf of the Commission.

452. Arrays of literature and evidence presented to the Commission, including Professor David Bellinger's expert report, have pointed out the adverse effects of lead on human health. It is a known fact that children, pregnant women and lactating mothers are particularly vulnerable to the health effects of lead. However, given the relatively low blood lead levels of the residents, the general components of current care plan implemented by Department of Health are considered to be appropriate.

453. From the perspective of public health, lead in drinking water is not to be tolerated. Lead concentration in drinking water should always be kept as low as is feasible. Since lead does not normally come from the contamination of source water and that lead pipes and leaded solder have been prohibited from use in Hong Kong for decades, excess lead should not be found in our drinking water nowadays.

454. We have reviewed and evaluated the adequacy of the present regulatory and monitoring system in respect of drinking water in Hong Kong. Our findings pertaining to different involved parties are

summarised in the following paragraphs.

The Water Authority/Water Supplies Department

(a) Lack of clear responsibility over the quality of drinking water at the tap

455. Under the existing water supplies statutory regime, there are no clear statutory provisions as to who has responsibility over the quality of drinking water beyond connection point. The situation is further complicated by the fact that neither WWO nor WWR specifies any standards or requirements over quality of drinking water in Hong Kong. As a result, a number of regulatory and monitoring inadequacies arise.

456. WSD had throughout the hearing contended that it was only responsible for the quality of water up to the connection point. WSD further argued that since the consumers were responsible for the custody, maintenance and cleanliness of the inside service under the laws, it was therefore the consumers' responsibility regarding the water quality beyond the connection point.

457. We have reservation about WSD's contentions. In our view, safety and cleanliness are two different concepts. No doubt the responsibility for maintenance and cleanliness of inside service should rest with the consumers, but the undenying truth is that WSD ought to be the regulatory authority over the quality of drinking water across the territory.

458. Without any clear guidance and detailed stipulations on the responsibility of the consumers, it is simply unreasonable for WSD to expect and believe that the consumers would have the professional knowledge and expertise in ensuring the quality and safety of their own drinking water. Given the reluctance on the part of WSD in accepting this overarching responsibility, it is therefore not surprising to see that the present incidents escaped the attention of WSD.

(b) Inadequate understanding of the WHO guidelines and need for developing Hong Kong's own water quality standards and a comprehensive WSP

459. WSD adopted the WHO Guidelines in 1994. It was a welcome step for Hong Kong. However, WSD just stopped there and failed to appreciate that the Guidelines were intended to be a scientific point of departure for the development of our own water quality standards. To date, we still do not have our standards.

460. In 2004, WHO introduced the concept of WSPs in order to encourage a proactive preventive approach to managing risks to drinking water from the catchment to the point at which consumers receive their drinking water, i.e. the source-to-tap approach. WSD published the first WSP in 2006, pledging to adopt the Guidelines and the source-to-tap approach, and assumed responsibility over quality of drinking water throughout Hong Kong. The declared mission of WSD was to provide a reliable and adequate supply of wholesome potable water to the consumers of Hong Kong.

461. In practice, however, WSD failed to formulate or put in place a sound and effective WSP with clear engagement of external stakeholders. The current WSPs were prepared top down with little involvement of external stakeholders, such as developer, architect, main contractor, plumbing subcontractor and building manager. Besides, they were only in the form of a skeleton with little details and regarded as no more than internal documents by WSD. Worse still, WSD amended its 2011 WSP in September 2015 to retract its responsibility over quality of drinking water "from source to tap" to "from source to distribution".

462. In addition, we noticed that WSD failed to undergo any systematic hazard assessment and risk characterisation regarding lead or other chemical contaminants likely to be found in inside service, as required.

463. Lead pipes and leaded solder have been prohibited against their use in potable water supply system in Hong Kong since 1938 and 1987 respectively. Therefore, unlike the situation in other countries such as the U.S.A. and U.K., where lead pipes are common, the level of lead concentration in our drinking water should be low. Had WSD followed the Guidelines and developed our own drinking water standards, WSD would probably have adopted a lead guideline value lower than 10 μg/L for Hong Kong.

(c) Inadequate understanding of the meaning of the WHO provisional guideline value for lead

464. It appears that WSD failed to appreciate the conceptual subtlety between "guideline value" and "provisional guideline value" adopted by WHO. Lead was given a guideline value of 10 μg/L before 2011. It was a health-based value. As a result of further evaluation in 2011, WHO concluded that there was no safe threshold for lead, as adverse effects in different organ systems, particularly the central nervous system, had been observed at blood lead levels of less than 5μg/dL. The ideal blood lead concentration for human is 0μg/dL.

465. Although the guideline value of 10 μg/L was retained, WHO designated it as "provisional" on the basis of treatment performance and analytical achievability. In essence, the value had changed from health-based to non-health-based, and WSD should not be looking at exposure with the WHO guideline value as the benchmark. WSD seemingly failed to understand the difference in between. It is therefore no surprise for WSD to have adopted 10 μg/L without taking into account the local circumstances as required by WHO. This misunderstanding also contributed to its failure to adopt a proper sampling protocol to identify the extent of lead contamination in PRH estates.

(d) Failure to update legislation to keep up with changes in British Standards

466. WSD failed to update technical standards as stipulated in

WWO, WWR and the Form WWO 46 for years, which created unnecessary misunderstandings and confusion for the plumbing industry.

467. In respect of the use of solder, BS 864-2:1983 was superseded by BS EN 1254-1:1998 in 1998. The maximum permissible lead content in solder was reduced from over 50% in 1983 to 0.07% at present. Yet the same old British Standard still stays on our statute book. Except three, all British Standards on the Form WWO 46 are outdated. Explanations given by WSD were inconsistent with its past practice.

(e) Failure to uphold a robust LP regime

468. WSD failed to uphold the robustness of the LP regime, including the responsibilities, competency and working strength of the LPs. Under the existing statutory provisions, no inside service shall be constructed or installed by a person other than a LP. In reality, WSD permitted workers other than LPs to undertake plumbing works, provided those workers were supervised by LPs. Supervision however did not entail the physical presence of LPs. None of the three LPs called to testify personally performed any installation work.

469. The responsibility of LPs is an important issue because poor workmanship was one factor which contributed to the present incidents. There is a huge gap between the language of the law and the industry practice permitted by WSD.

470. WA as the licensing authority also failed to ensure the continued competency of LPs. Once plumber licences are issued, LPs

are not required to update their knowledge of the plumbing trade. There is also no restriction as to the number of projects that a LP may take at any given time. For instance, only one LP was engaged for the plumbing works of over 5,000 housing apartments in Kai Ching. It is difficult to imagine how well the LP could divide his time to supervise plumbing works of such scale.

(f) Failure to exercise its legal powers to ensure compliance by the trade

471. WWO and WWR confer on WSD a number of powers. For example, WSD can require (under regulations 20 and 21 of WWR) any pipes or fittings to be tested before installation. However, WSD does not have material testing facilities for any plumbing materials. We doubt if WSD has ever conducted any test or taken any enforcement action against LPs for failing to comply with these two statutory technical requirements.

472. WSD argued that any enforcement action in the form of random checks would amount to just a further layer of sporadic checks. Given this mindset, it is no wonder that WSD in its final inspection of newly constructed plumbing work focused exclusively on functionality without any regards to material safety and water quality.

473. Similarly, the purpose of taking water samples at final inspection, hence the determination of testing parameters, was targeted solely towards the prevention of possible contamination of the

Government's water supply. This practice was proved to be inadequate.

(g) Failure to adopt a proper sampling protocol

474. Regarding the decision of Director of Water Supplies to sample only flushed water, we believe that Chief Waterworks Chemist played a dominating role. This sampling protocol, however, was insufficient to ascertain the full extent of the problem of lead contamination in the drinking water of all PRH estates. Despite the numerous occasions on which good and sound advice was given to WSD, it was unfortunate that WSD insisted on using its own sampling protocol. As a result, nobody can say now with any degree of certainty the number of PRH estates that are truly unaffected by lead in drinking water.

The Hong Kong Housing Authority/Housing Department

475. Throughout the inquiry, HA repeatedly told us that there had been a lack of or inadequate awareness in HA on the use of leaded solder and its implications on the quality of drinking water. Our view is that HA, as an entity, was aware of the harmful effect of the use of leaded solder and its adverse implications on human health. This is borne out by the fact that HA had all along specified in its contracts the requirement of the use of lead-free category solder.

476. Besides, as a routine practice, HA's site staff had required sample submission of solder by main contractors. Evidence also showed that HA's site staff were familiar with the risks associated with lead. However, there was no effective mechanism whereby such

knowledge would be shared across divisions and with the senior management, resulting in the absence of a holistic assurance programme that could effectively prevent the use of non-lead-free solder.

477. HA failed to conduct any systematic risk assessment back in 2002 after HA decided to allow its main contractors to use copper pipes for fresh water plumbing installation, which in turn resulted in the glaring absence of an effective supervisory and monitoring system for solder. The attention of HA tended to focus on the functionality of the construction works, with insufficient emphasis on potential health risks which might arise.

478. HA failed to include solder as one of the items under its "On-site Delivery Verification" mechanism. No check was conducted when solder was delivered to site. Further, HD's Site Inspection Team which was responsible for quality assurance programme was also not required to check the use of solder under the Architectural Site Inspection Guide.

479. Consequentially, HA failed to ensure the solder used in joining copper pipes and fittings would conform to the approved sample. There had been a systemic failure within HA as to the use of solder in the construction of the inside service. HA appeared to rely heavily on document check in order to control the quality of the construction works undertaken by the main contractors. We accept that it is not practicable or cost-effective for HA to micromanage all its PRH projects, that does not however mean that HA should not put in place more effective

measures to forestall possible failure on the part of its main contractors in fulfilling their contractual obligations.

480. As the largest developer in Hong Kong, HA should always be vigilant to every possible health hazard associated to drinking water, with or without alerts from WSD.

Main Contractors

481. All four main contractors were well aware of HA's requirement on the use of lead-free solder, judging by the fact that they imposed the same requirement on their sub-contractors and arranged for the submission of the correct type of solder for approval. However, they all failed to put in place effective mechanisms to ensure that only the approved solder would be used by their subcontractors. The sample approval process turned out to be just a formality.

482. The situation was aggravated by the fact that under the existing regulatory regime, the main contractors did not have any role to play in the construction of inside service. For example, they were not featured in either Form WWO 46 or Form WWO 132.

483. No doubt all four main contractors failed to fulfil their contractual obligations with HA. We believe, however, that there was little incentive for them to deliberately use leaded solder for all the plumbing works. They suffered the consequence for not putting in place a proper system of supervision and mistakenly placing their entire trust in the subcontractors.

Plumbing Subcontractors and Licensed Plumbers

484. We are of the view that all plumbing subcontractors knew that only lead-free solder should be used in PRH projects. We believe that leaded solder was intentionally used or caused to be used by some subcontractors and/or their staff. Apart from financial incentive, there was attraction for some workers to use leaded solder which has a lower melting point.

485. The LPs are the plumbing specialists in Hong Kong. They are intended to be a pool of professionals, suitably qualified and have the competency and up-to-date knowledge to design, install and maintain plumbing systems. They also have a key role in managing risks and ensuring compliance with relevant statutory requirements and applicable standards. The reality however is that inside service has been rarely constructed by LPs themselves, or even by other workers in the presence or under the supervision of LPs. Some LPs play the role of no more than affixing their signatures on WSD documents.

486. All in all, what we have seen is a collective failure on the part of all stakeholders to guard against the use of non-compliant solder in the plumbing system. On the surface, there was in place a perfect multi-barrier checking system: HA specified in its contracts with the main contractors that only lead-free solder should be used; a similar provision was repeated in the contracts between the main contractors and their subcontractors; the main contractors even took the initiative of submitting solder sample to HA for approval which was actually not part

of the requirements; and WA had in place statutory requirements on building materials and demanded AP/LP certification before allowing water supply. In practice, however, this multi-barrier checking system turned out to be no more than a paper system in which every party transferred the duty of supervision to the other(s), resulting in a classic case of buck-passing. Trust was misplaced and in the end it was the residents who suffered the most.

VI. RECOMMENDATIONS

487. The following are measures we would recommend in order to prevent the recurrence of similar incidents in future –

(1) Given the inadequacy of the sampling protocol adopted by WSD and in order to put the minds of all PRH residents at ease, the Government should undertake to test the drinking water of all PRH estates again using an appropriate sampling protocol that would include the testing of stagnant water as well.

(2) Given the ever increasing complexity of modern buildings, the Government should, at the policy level, review the adequacy of the existing legislative framework and regulatory regime in safeguarding the safety and quality of drinking water in Hong Kong. The review should cover :

(i) the need for delineating the role of WA (as regulator of water quality) and the role of WSD (as water supplier); and

(ii) WSD's roles and responsibilities in effectively safeguarding the quality and safety of drinking water in Hong Kong, in particular whether its responsibilities are only confined to the quality of drinking water up to the connection points.

(3) The Government should set up an independent body to overlook the performance of WSD and water quality in Hong Kong generally. This body should be empowered to conduct independent inspections and auditing when necessary.

(4) We support WA/WSD's proposal to set up an international expert panel on water safety to provide expert advice to Hong Kong on matters including water quality standard, water quality regulatory and monitoring regime, water sampling protocol etc.

(5) WA/WSD should undertake a comprehensive study with a view to establishing the "Hong Kong Drinking Water Standards", taking into account overseas experience and practices.

(6) WA/WSD should define, preferably by way of legislation, the roles, involvements and responsibilities of other parties such as developers, contractors and APs who are in practice involved in the design, construction and maintenance of inside service but are currently not prescribed with any duties under WWO and WWR.

(7) With the involvement of all relevant stakeholders including experts, professionals of different related disciplines and the general public, WA/WSD should establish and implement a WSP for Hong Kong in general and WSPs specifically for other developments in Hong Kong (e.g. public and private housing

developments, hospitals, elderly homes, schools), with clear indication of :

(i) how to identify potential hazards and conduct risk assessment of contamination at different sections of the water distribution system, i.e. waterworks, communal service and inside service; and

(ii) the responsibilities of stakeholders at different sections of the water distribution system.

(8) WA/WSD should set out clearly, in the legislation or appropriate medium, the latest approved pipes and fittings as well as the latest standards for all plumbing material and components to be used in the construction of inside service, and update the same regularly and periodically.

(9) WA/WSD should devise and uphold a robust licensing / registration regime for parties responsible for plumbing installations, including to:

(i) define the duties of LPs under WWO, taking into account the relevant provisions of the Construction Workers Registration Ordinance (Cap. 583) (CWRO) which allows skilled workers to perform plumbing installations;

(ii) review the adequacy of the existing arrangement where an individual LP can be responsible for plumbing installations of any scale (e.g. up to thousands of household units) at any given time;

(iii) review the competency and manpower development of LPs, and consider the need for continuous professional education for LPs on a compulsory basis as part of the conditions for renewal of licences;

(iv) ensure that LPs and skilled plumbing workers under CWRO would be taught in their training, certification and professional development the potential causes and hazards of drinking water contaminations, and precautionary measures; and

(v) consider the need and feasibility to include other professionals (such as building services engineers) and specialised contractors (such as in the form of a registration system for plumbing contractors) in the design and construction of inside service.

(10) HA should review its control mechanism on the construction projects with emphasis not only on the functionality of the plumbing system but also the quality and safety of water.

(11) HA should equip its CA (Design and Standard) with necessary expertise on plumbing installations and strengthen its research capability to identify the existing

and emerging risks to the quality and safety of water in developing and managing PRH estates.

(12) HA should, in consultation with WSD, review all the materials to be used in the construction of PRH estates with a view to identifying the potential hazards and contamination in the drinking water, and revising the project specifications as necessary.

(13) HA should put in place a robust system to monitor the compliance of the plumbing installations with the project specifications by main contractors and their subcontractors.

(14) We support all the control measures put forward by the Review Committee regarding the purchase, use and testing of solder in the construction of all new PRH projects. It is important not to relegate these control measures into yet another document check exercise.

(15) HA should contribute proactively to the establishment of a WSP for PRH estates under (7) above.

(16) At all times and especially before the establishment of a WSP for PRH estates, HA should ensure all its staff, in particular all the CAs who are responsible for signing WWO certifications and documents, are aware of all the potential causes and hazards of drinking water contamination and precautionary measures.

(17) At all times and before WA/WSD has defined the specific roles of all involved parties, the developers and main contractors, when contracting out the plumbing work, should devise and execute an effective management plan for making sure that :

(i) only the approved/compliant materials would be used in plumbing installations; and

(ii) the plumbing work would be carried out under appropriate supervision and inspection by competent personnel;

so that the control measures would not be relegated into another document check exercise.

488. We believe that if these recommendations are implemented, not only PRH estates, but also other developments in Hong Kong and our community as a whole will be benefited.

VII. ACKNOWLEDGEMENTS

489. We wish to thank Leading Counsel for the Commission Mr Paul Shieh, S.C. who performed his role as Counsel with great skill and energy. We would also like to express our appreciation to junior counsel Mr Richard Khaw and Ms Bonnie Cheng. Mr Richard Khaw in the course of the inquiry has been appointed Senior Counsel to whom we extend our congratulations. They approached all their work with competent enthusiasm.

490. Under the leadership of Mr C. P. Yen, Messrs Lo & Lo had done an excellent job in reviewing all the evidence including huge volume of documents and written statements. Hearing bundles, tables and charts were prepared meticulously.

491. We also wish to thank Mrs Sharon Yip, Secretary to the Commission and her staff in the Secretariat. Mrs Yip applied her considerable administrative and communication skills to the fullest, with the result that the inquiry went expeditiously and smoothly.

492. In the course of the inquiry, the Government Laboratory had provided laboratory services to the independent investigation undertaken by Professor Joseph Lee on the instructions of the Commission. We are indebted to all its staff. The Bailiff of the Judiciary had also been required, pursuant to section 13 of the Ordinance, to assist the Commission in serving witness summonses to persons concerned. We

are grateful for that. The Official Languages Division performed outstanding simultaneous interpretation service which had been praised by all legal teams in the hearing.

493. We cannot conclude without thanking our experts, Professor David Bellinger, Professor John Fawell and Professor Joseph Lee and his research team at the HKUST, in providing invaluable assistance and opinion to the Commission within such a short space of time.

Andrew Chan Hing Wai Judge of the Court of First Instance of the High Court	Alan Lai Nin, GBS, JP

Dated 11 May 2016

EXPERT REPORT

PREPARED BY

PROFESSOR DAVID C. BELLINGER

Expert Witness appointed by the Commission of Inquiry into Excess Lead Found in Drinking Water

1 December 2015

Professor David C. Bellinger
Professor of Neurology and Professor of Psychology at Harvard Medical School
Professor in Department of Environmental Health at Harvard School of Public Health
Developmental Psychologist (with additional training in epidemiology)

Specialist Field	:	See **Appendix I**
Appointed on behalf of	:	The Commission of Inquiry into Excess Lead Found in Drinking Water (the "**Commission**")
Prepared for	:	The Commission
On instructions of	:	Messrs. Lo & Lo, Solicitors for the Commission ("**Lo & Lo**")
Subject matter / Scope of engagement:	:	To assist the Commission in discharging its duties under the Terms of Reference and by acting as an expert witness in the inquiry hearings
Documents reviewed	:	See **Appendix II**

The Terms of Reference of the Commission are as follows:

(a) to ascertain the causes of excess lead found in drinking water in public rental housing developments;

(b) to review and evaluate the adequacy of the present regulatory and monitoring system in respect of drinking water in Hong Kong;

(c) make recommendations with regard to the safety of drinking water in Hong Kong

Instructions

I have been instructed to give my opinion on the matters under the Terms of Reference.

In providing my opinion, I have also been instructed to consider the following areas and undertake the following tasks:

(1) to explain the short, medium and/or long term health effect(s) (if any) of elevated blood lead level on human beings in general, and in particular on (a) infants; (b) children under six years of age; (c) children/teenagers between six and eighteen years of age; (d) pregnant women; (e) lactating mothers; (f) elderly persons; (g) immunocompromised patients and (h) long term patients with chronic illnesses;

(2) to explain the internationally accepted or recognised guidelines and/or parameters (and their rationales), particularly those adopted by the World Health Organization ("**WHO**"), on the content of lead in (a) tap water and (b) blood in human beings;

(3) if the guidelines and parameters considered in (2) above have changed/ evolved over time, to explain the reasons for such changes;

(4) to opine on the adequacy and suitability of the reference values for blood lead level and the care plan published or followed by the Hong Kong Special Administrative Region Government;

(5) to opine on the adequacy and suitability of the acceptance criteria laid down by the Water Supplies Department ("**WSD**") for heavy metals and make recommendations, if necessary.

Introduction

I, Professor David C. Bellinger of Boston, U.S.A., have been appointed as the Commission's expert to assist the Commission in determining the matters under the Terms of Reference. The opinion and conclusions which are set out in this Report were formed on the basis of the evidence and the selected documents collected by the Commission from the Involved Parties since 20 August 2015 that I have seen. I appear as an independent expert for the Commission unrelated to any other work.

My Opinion

(1) The short, medium, and/or long term health effect(s) (if any) of elevated blood lead level on human beings in general, and in particular on (a) infants; (b) children under six years of age; (c) children/teenagers between six and eighteen years of age; (d) pregnant women; (e) lactating mothers; (f) elderly persons; (g) immuno-compromised patients and (h) long term patients with chronic illnesses

Introductory Comments

More is known about the adverse effects of lead on human health than about any other environmental chemical. When the National Toxicology Program (NTP) of the U.S. National Institute of Environmental Health Sciences evaluated the scientific literature on lead's health effects, its search identified more than 28,900 peer-reviewed publications (as of April, 2012). Therefore, the evidence base permits robust inferences about the range of effects of exposure to lead, as well as the characteristics of the dose-response and dose-effect relationships that describe the levels of exposure associated with increased risk. In my responses to the queries, I focus on the so-called "subclinical" health effects of chronic exposure to lead, that is, at levels of exposure that do not cause clinical signs and symptoms, as the likelihood that clinical lead poisoning would occur from consuming water with the lead concentrations measured in the Hong Kong estates is very low. To establish the context within which to consider such exposures, however, I briefly discuss the blood lead levels at which such clinical signs and symptoms occur. A very high level of lead exposure can be fatal, although it rarely occurs unless a child's blood lead level exceeds 150 µg/dL, and some children have survived a blood lead level of several hundred µg/dL. Overt signs of acute intoxication occur at blood lead levels of 100-120 µg/dL in adults and at 80-100 µg/dL in children. These signs include restlessness, irritability, poor attention span, headaches, muscle tremor, abdominal cramps, kidney damage, hallucinations, loss of memory, cerebral oedema or haemorrhage, confusion, coma, and seizures. Chronic lead exposure (e.g., blood lead levels of 50–80 µg/dL in adults and 25-50 µg/dL in children) can also produce sleep problems, fatigue, irritability, constipation, poor appetite, anaemia, headaches, and joint pain. As such non-specific signs and symptoms can occur as the result of other medical conditions, it can be difficult to diagnose lead exposure as the cause.

Lead is often characterized as a "multi-media" pollutant because of the diverse ways in which human exposure can occur. The major classes of sources/pathways of exposure to inorganic lead (the form of lead in solder) include food, air, soil, paint, and water, although exposure can also occur as a result of many other activities (e.g., use of contaminated folk or herbal medicines). Once lead enters the body, its toxicity is the same regardless of the source/pathway through which exposure occurred. An individual's blood lead level reflects exposures from all sources/pathways, so to evaluate the magnitude of the contribution of a specific source/pathway, it is necessary to consider information about other important sources/pathways. The lead in a person's body resides in three major "pools," and can move among them. Among adults approximately 90% of the total body burden is in mineralized tissues, such as bone. The lead accumulated in hard (cortical) bone might remain there for several decades, whereas the lead accumulated in more porous (trabecular) bone, which is in greater contact with the circulatory system, might remain there for much less time. In children, lead in bone accounts for approximately 70% of the total body burden, and appears to move in and out of bone much more rapidly than it does in adults due to the rapid changes in bone turnover that occur during childhood. Most of the rest of an individual's body burden of lead is in soft tissues such as the brain, liver, and kidneys. Only a small percentage, about 5%, is in blood. Lead can be mobilized from mineralized tissues and re-introduced into blood by a variety of physiologic and pathophysiologic states that increase bone turnover, such as pregnancy, lactation, menopause, infection, and osteoporosis. Therefore, the blood lead level measured for an individual at any given time reflects the equilibrium between an individual's current exposure to "new" lead and the "legacy" lead from past exposures. The half-life of lead in blood is approximately 30 days, meaning that if two atoms of lead enter the blood, in a month's time only one will remain there, and the other one either excreted from the body or moved to storage in hard or soft tissue. Because of the re-equilibration processes, the half-life of 30 days does not mean that an individual's blood lead level will fall by half in a month's time if major exposure sources/pathways are removed. The greater an individual's past exposures to lead, the harder it will be to reduce blood lead by an intervention (e.g., chelation, removal of exposure source/pathway). Indeed, in one study of children who had a blood lead level of 25-29 μg/dL and were placed in a case management system, it took an average of two years for the blood lead to drop below 10 μg/dL. On the other hand, if an individual's exposure is acute and prior exposure to lead has been low, the total body lead burden would be modest, and the individual's blood lead level would be expected to decline relatively rapidly following cessation of the current exposure.

1a and 1b. Infants and children under six years of age

Humans of any age can be harmed by exposure to lead, but young children are considered to the most vulnerable subgroup of the population, and the developing central nervous system is considered to be the most vulnerable organ. Children with blood lead levels below 25 μg/dL generally do not show any signs or symptoms that bring them to medical attention. What a plethora of studies show, however, is that children with such levels are at increased risk of a variety of cognitive and behavioural adversities that are persistent and affect many aspects of an individual's health and well-being. In its recent evaluation, the U.S. NTP characterized the weight of evidence on an association between blood lead level and a health outcome as sufficient, limited, or inadequate. Evidence for an association was characterized as "sufficient" if methodological factors such as chance, bias, and confounding could be ruled out with reasonable confidence, as "limited" if the association had been observed but that the methodological factors could not be ruled out with reasonable confidence, and as "inadequate" if, "The available studies are insufficient in quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an association…or no data in humans are available." The NTP concluded that, in children, the evidence is *sufficient* to conclude that blood lead levels <5 μg/dL are associated with adverse neurological effects, including reduced intelligence, neuropsychological function, and academic achievement and increased incidence of attention-related and other problem behaviours. The most complete and compelling evidence available pertains to children's intelligence. A set of analyses in which the data from 7 prospective studies were pooled (a sample size of 1,333 children) found that the inverse association between children's IQ scores and their blood lead concentrations had a supra-linear form, such that the slope of the association (the rate of decline in IQ per μg/dL increase in blood lead concentration), was steeper over the range below 10 μg/dL than it was over the range between 10 and 30 μg/dL. Although the biological mechanism of this is not known, the finding has now been replicated in several independent studies. The details of this dose-effect relationship suggests a child with a blood lead level of 0 will, all other things being equal, have an IQ score about 5 points

(1/3 standard deviation) higher than a child with a blood lead level of 10 µg/dL. A large number of studies support the hypothesis that this effect of lead on children's IQ scores is only the "tip of the iceberg." Even among children with blood lead levels less than 10 µg/dL, those with higher levels perform significantly worse on tests of academic achievement and more often require special educational supports in school.

A series of neuroimaging studies of young adults (mean age 20 years) in whom detailed histories of lead exposure prior to the age of 6 years were available provides evidence that early-life exposure produces persistent changes in brain structure and function. Higher blood lead levels in childhood, which in these children were generally than 10 µg/dL, were associated with inverse linear decreases in grey matter volume, most strikingly in the frontal regions of the brain (anterior cingulate cortex, ventro-lateral prefrontal cortex). Diffusion-tensor imaging studies revealed lead-related changes in myelination and axonal integrity throughout the white matter of the brain (i.e., reduced fractional anisotropy). Proton magnetic resonance spectroscopy revealed that blood lead levels in childhood predicted reduced level of metabolites in several regions of grey matter and white matter, suggesting altered patterns of brain function. Functional magnetic resonance studies showed that activation patterns in the left frontal cortex and left middle temporal gyrus while performing a language task differed among individuals with different levels of childhood lead exposure. It is noteworthy that these differences in brain structure and function were related to blood lead levels measured nearly two decades earlier.

Much less information is available about the associations in children between lead exposure and other organ systems. The NTP considered the evidence to be *limited* for the association between blood lead levels <10 µg/dL and aspects of immune function (increased hypersensitivity/allergy by skin prick test of allergens and increased IgE). The evidence was considered to be *inadequate* for associations between blood lead levels <10 µg/dL and other aspects of immune function (asthma, eczema, non-allergy immune function) as well as with cardiovascular function and decreased kidney function in children <12 years of age.

1c. Children and Teenagers between 6 and 18 years

Several of the major prospective studies of lead and neurodevelopment have included follow-up intervals that extend as far as the fourth decade of life (Boston, Port Pirie, Cincinnati, Kosovo). These studies provide evidence that the inverse associations between early-life lead exposure and neurodevelopment persist, though perhaps in somewhat weakened form, over this interval. In one prospective study, the lead concentration in umbilical cord blood, reflecting prenatal exposure, was still inversely related to IQ scores at more than 30 years of age.

The US NTP evaluation concluded that the evidence is *sufficient* for the association between blood lead level <10 µg/dL and both decreased hearing, delayed puberty, and reduced postnatal growth. In cross-sectional data on pubertal development in girls aged 8-18 years from the U.S. NHANES III (National Health and Nutrition Examination Survey), blood lead levels above 3 µg/dL were associated with delays of 2 to 6 months in breast and pubic hair development (i.e., progression to the next Tanner stage), and the onset of menarche, though these associations were stronger in African-American and Mexican-American girls than in Non-Hispanic White girls. In another study of Native American girls 10-17 years of age, those with a blood lead concentration greater than the median of 1.2 µg/dL reached menarche 10.5 months later than girls with a concentration below the median. In a study in 8 to 9 year old boys, a blood lead concentration ≥5 µg/dL was associated with slower progression through stages of genital development and, at a follow-up examination several years later, boys with higher blood lead levels were less likely to have begun puberty, with the differences in testicular volume and staging of genitalia and pubic hair corresponding to delays of 6 to 8 months.

A considerable body of evidence now exists in support of the hypothesis that greater lead exposure places a child at increased risk of meeting diagnostic criteria for Attention Deficit Hyperactivity Disorder. In one study of 6 to 16 year olds (NHANES 1999-2002), children in the fifth quintile of current blood lead (>2 µg/dL) were 4.1 times more likely than children in the first quintile (<0.8 µg/dL) to have parent-reported ADHD. In a subsequent study, when outcome classification was based on a diagnostic interview rather than parent-report (NHANES 2001-2004), 8-15 year olds with a blood lead concentration in the upper tertile of the distribution (>1.3 µg/dL) were 2.3 times more likely than children in the lowest tertile to meet diagnostic criteria. In a study conducted in South Korea, children with a blood lead level >3.5 µg/dL were 1.96 times more likely than children with a blood lead level <1 µg/dL to have ADHD. In a case-control study conducted in China, children with a blood lead level of 5 to 10 µg/dL were 5.2 times more likely to have ADHD than children with a blood lead level <5 µg/dL, and children with a blood lead level ≥10 µg/dL were 7.2 times as likely.

Several studies, varying in design from case series, ecologic, case-control, cross-sectional, and prospective cohort, have suggested that greater childhood lead exposure is associated with an increased propensity for violence and aggression, as reflected by homicide rates, the diagnosis of Conduct Disorder, being an adjudicated delinquent, ratings by parents or teachers of rule-breaking or antisocial behaviour, self-reported offenses and convictions, and arrests. Such studies are difficult to conduct and subject to a variety of biases, but, in aggregate, the evidence for this association is strongest for blood lead levels >10 µg/dL.

The NTP considered the evidence to be *limited* for the associations between blood lead levels <5 µg/dL and decreased kidney function in children ≥12 years of age (reduced glomerular filtration rate). Among 12-20 year olds who participated in the NHANES III survey, adolescents with a blood lead level in the highest quartile (≥3 µg/dL) had a significantly lower estimated glomerular filtration rate (based on serum cystatin-C or, to a lesser extent, serum creatinine) than adolescents with blood lead levels in the first quartile (≤1 µg/dL).

1d. Pregnant Women

Lead crosses the placenta by the process of passive diffusion. As a result, the concentration of lead in the umbilical cord blood of a neonate will be similar to the concentration of lead in maternal blood at delivery. In other words, the lead exposure of a foetus is essentially the same as that of the pregnant woman. Certain physiologic changes associated with pregnancy, and with the progression of pregnancy, alter lead kinetics in complex ways. These include increasing blood volume, decreasing haematocrit, saturation of the lead-binding capacity of red blood cells, increased bone re-sorption (and thus mobilization of long-term lead stores), and possibly increased intestinal absorption of lead. Studies using lead isotopic ratios have shown that a substantial fraction of the lead in the blood of a pregnant woman cannot be attributed to her current external exposure but reflects lead from past exposure that has been mobilized by the rapid turnover of bone that occurs during the second and third trimesters of pregnancy. Animal studies suggest that up to 40% of the lead in the foetal skeleton came from maternal bone.

Considerable research has been conducted on the potential effects of lead exposure on the health of the pregnant woman herself, in particular her reproductive health, the course of pregnancy, and the health of her foetus at birth and in the postnatal period. In 2010, the U.S. Centers for Disease Control issued guidelines for the identification and management of lead exposure in pregnant and lactating women. The literature review conducted evaluated the evidence regarding the associations between lead exposure and a variety of health endpoints.

Fertility. Greater lead exposure in a woman is associated with a longer time to conceive a pregnancy, but only at blood lead levels exceeding 10 µg/dL.

Gestational hypertension. Cohort and case-control studies have shown that a greater concentration of lead in maternal blood during pregnancy or in cord blood is significantly associated with pregnancy hypertension and elevated blood pressure during pregnancy or at delivery. Although these associations are statistically significant, they are very modest in magnitude (e.g., correlations <0.10, suggesting little shared variance). In many such studies, the mean blood lead levels of the participants were less than 10 µg/dL and, in some, less than 5 µg/dL. The dose-effect relationship has not been well-characterized, however, and it is uncertain whether the elevated risk is associated with a woman's acute exposure to lead during pregnancy, to chronic exposure, or both. Pre-existing hypertension could affect a woman's renal function during pregnancy, altering lead kinetics, causing increased lead retention (i.e., reverse causation). Evidence linking lead exposure to the risk of pre-eclampsia (elevated blood pressure accompanied by proteinuria) is weak and based on only a few studies.

Spontaneous abortion. Most studies evaluating the risk of spontaneous abortion in relation to maternal lead exposure have not identified a significant relationship at blood lead levels below 30 µg/dL. One high-quality prospective study conducted in Mexico City did, however, report that the risk began to increase, and increased consistently thereafter, when maternal blood lead level exceeded 5 µg/dL (Borja-Aburto et al., 1999).

Fetal growth. Many studies have evaluated lead exposure as a risk factor for outcomes such as length of gestation, birth weight, low birth weight (<2500 grams), infant birth length, infant head circumference, and congenital anomalies. Although significant associations have been reported, the evidence is somewhat inconsistent, and the maternal blood lead level at which risk begins to increase is uncertain.

In considering the overall evidence, the U.S. CDC recommended that a pregnant woman with a blood lead level ≥5 µg/dL receive follow-up testing, education, and environmental, nutritional, and behavioural interventions to reduce, if possible, her exposure and that of her foetus and newborn child. It does not recommend universal screening of pregnant women.

The NTP concluded that the evidence was is *limited* for the association between blood lead levels <5 µg/dL and "decrease in measures of cognitive function," as well as for the association between blood lead levels <10 µg/dL and "decreased IQ, increased incidence of attention-related and problem behaviours, and decreased hearing."

1e. Lactating Mothers

Bone turnover is greater during lactation than pregnancy and continues as long as an infant is nursing. As much as 5% of a woman's bone mass is mobilized during this period. Isotopic studies of the lead in breast milk indicates that at least some of the lead comes from maternal bone, and the concentration of lead in maternal bone, measured using X-ray fluorescence, is positively related to the concentration of lead in breast milk. However, the concentration of lead in breast milk is low, comparable to that in the plasma fraction of blood (which accounts for only about 1% of the lead in whole blood). Thus, this pathway of exposure likely contributes relatively little to an infant's lead exposure.

Water can be a very important pathway of lead exposure for infants who consume formula made up with water that contains lead. Balancing the known benefits of breastfeeding and the slight risks of substantial lead exposure from breastfeeding , the U.S. CDC encourages mothers with a blood lead level ≤40 μg/dL to breastfeed.

1f. Elderly Persons

Relatively few studies have investigated the association between lead exposure and health outcomes in the elderly, and most of these have relied on measurements of bone lead as the exposure index rather than blood lead. This is because, as noted, lead accumulates in bone over time so that its concentration in this tissue is thought to provide a more accurate measure of cumulative exposure than does an individual's current blood lead level, which tends to reflect largely recent exposure. Another factor that might render an elderly person's current blood lead level less informative about his or her current exposure is the fact that physiologic and pathophysiologic processes that involve increased bone turnover, such as osteoporosis, result in some of the lead stored in bone being mobilized into soft tissues and to blood. As a result, some of an elderly person's blood lead likely reflects not only lead to which he or she was recently exposed but also so-called "legacy" lead, that is lead to which exposure occurred in the past. In a study conducted in Boston, the concentration of lead in patella (knee-cap, a trabecular bone) was significantly higher in older men who, 14-19 years previously, had lived in homes with a first-flush water lead concentration greater than 50 μg/L.

In aggregate, the available studies, which have been conducted mostly in elderly men, provide reasonably consistent evidence that numerous aspects of health, including cognitive function, mental health, renal function, hearing, and cardiovascular function, are inversely related to bone lead concentration. Because lead is an accumulative toxicant, however, it is difficult to determine the contribution, if any, of current (or recent) lead exposure to these associations.

One recent development in lead toxicology that is generating considerable interest is the evidence, in animal models, that early-life lead exposure is a risk factor for accelerated neurodegeneration in later life. In rodents and non-human primates, early-life lead exposure, but not current lead exposure, is associated with later overexpression, in adulthood, of genes involved in the production of a protein, beta-amyloid, that is a constituent of the amyloid plaques that are found in the brains of patients with Alzheimer's Disease. The extent to which this might be true in humans is unknown.

1g. Immuno-compromised Patients

There is some limited evidence that greater exposure to lead can produce changes in immune function. To my knowledge, however, immuno-compromise has not been investigated as an effect modifier of lead toxicity.

1h. Long-Term Patients with Chronic Illnesses

Relatively limited information is available about the effects of lead exposure on individuals with comorbid conditions that might make them more vulnerable to lead. In general, such information has come from subgroup analyses of study cohorts. These analyses have sometimes, but not always, suggested that lead exposure of a given intensity is more harmful to individuals with some pre-existing medical conditions.

Kidney Function. In analyses of adults (≥20 years) in the NHANES III survey, significant associations between concurrent blood lead level and kidney function (e.g., elevated serum creatinine, reduced glomerular filtration rate) were found only in individuals with hypertension. Compared to individuals in the lowest quartile of blood lead level (0.7 to 2.4 µg/dL), individuals in the second (2.5 to 3.8) and third quartiles (3.9 to 5.9 µg/dL) were more likely to have chronic kidney disease. In a prospective study, a lead-related decline in renal function (specifically the rise in serum creatinine concentration) over a 6-year follow-up period was greater in individuals who, at baseline, had diabetes. Lead burden was measured in bone (tibia), however, reflecting chronic exposure, so it is difficult to determine the blood lead level at which this increased vulnerability is expressed. A study using data from NHANES 1999-2006 reported that the risk of lead-associated reduction in kidney function (albuminuria and reduced glomerular filtration rate) was increased two-fold among individuals who had greater exposure to cadmium, another metal that is well-known to impair kidney function.

Cardiovascular Function. Hypertension has long been known to be one result of greater lead exposure in adults. In one study of adult men, greater bone lead concentrations (patella but not tibia) were associated with changes in heart rate variability (higher low frequency power, ratio of low to high frequency power) but only among men with metabolic syndrome.

Cognitive function. Little evidence is available regarding co-morbidities that affect the likelihood or severity of lead-associated impact on cognitive function. Several genetic polymorphisms are hypothesized to modify lead neurotoxicity, but the findings are inconsistent across studies. One study of individuals exposed to lead occupationally suggested that the inverse associations between an index of lifetime lead exposure and scores on neuropsychological tests were greater in individuals who had "low cognitive reserve" operationalized as poorer reading achievement, an outcome that presumably predated the onset of occupational exposure to lead. The idea is that such individuals are less able to weather an insult to the brain. A similar hypothesis has been advanced with regard to children. Several studies have suggested that the inverse association between lead and neurodevelopmental test scores is greater among children who, for reasons other than lead, have scores that place them in the lower reaches of the distribution. In other words, children whose neurodevelopment is imperiled by factors such as low socioeconomic status, stress, nutritional deficiencies, and other co-morbidities, suffer more from a given exposure to lead than do children without these characteristics. In one study, the impact of blood lead level on children's neurodevelopment was greater among children with nutritional deficiencies (e.g., folate, iron).

(2) The internationally accepted or recognised guidelines and/or parameters (and their rationales), particularly those adopted by the World Health Organization, on the content of lead in (a) tap water and (b) blood in human beings;

(3) If the guidelines and parameters considered in (2) have changed/evolved over time, to explain the reasons for such changes

(a) Lead in tap water

World Health Organization. In 1958, the WHO recommended a maximum allowable concentration of 0.1 mg/L (100 µg/L) in water. This recommendation was health-based. In 1963, it was reduced to 0.05 mg/" (50 µg/L), however, a value of 0.1 mg/kg was re-established, "...because this level was accepted in many countries and the water consumed for many years without apparent ill effects, and it was difficult to reach a lower level in countries where lead pipes were used." In the 1st edition of the WHO Guidelines for Drinking water Quality (1984), a health-based guideline of 0.05 was again recommended. Based on the JECFA Provisional Tolerable Weekly Intake (PTWI) of 3.5 µg/kg of body weight per day (1986) for infants and children, the 1993 edition of the drinking water guidelines recommended a value of 0.01 mg/l, based on the assumption of a 50% allocation of the PTWI to drinking-water for a 5 kg bottle-fed infant consuming 0.75 litre of drinking-water per day. As infants were considered to be the most sensitive subgroup of the population, this guideline value was thought to also be protective for other age groups. In light of JECFA's recent withdrawal of the PTWI (25 µgPb/kg body weight/week), the WHO guideline for drinking water lead was re-evaluated in 2011. The value of 10 µg/L was retained. The reasons were that lead exposure arises from a range of sources, of which water is frequently a minor one, and it is extremely difficult to achieve a concentration lower than 10 µg/l by central conditioning, such as phosphate dosing. However, this is designated as "provisional" on the basis of treatment performance and analytical achievability. The WHO further stated that, "... lead is exceptional, in that most lead in drinking-water arises from plumbing in buildings, and the remedy consists principally of removing plumbing and fittings containing lead, which requires much time and money. It is therefore emphasized that all other practical measures to reduce total exposure to lead, including corrosion control, should be implemented." (Lead in Drinking Water: http://www.who.int/water_sanitation_health/dwq/chemicals/lead.pdf?ua=1).

U.S. Environmental Protection Agency. In the U.S., the allowable concentration of lead in water was established under the Safe Drinking Water Act of 1974. Until 1991, the limit for lead in drinking water was 0.05 mg/L (50 µg/L). With passage of the Lead and Copper Rule in 1991, this concentration was reduced to 0.015 mg/L (15 µg/L). For most contaminants, the EPA establishes a Maximum Contaminant Level (MCL). Lead is handled differently because it does not enter water at the source but as a result of corrosion of plumbing materials in the distribution system, and typically those materials close to the point of consumption. Therefore, rather than establishing an MCL for lead, the EPA established a treatment technique that water authorities must use to reduce the corrosivity of water. If more than 10% of the tap water samples collected exceed the action level of 0.015 mg/L (15 µg/L), a water system is required to take steps such as corrosion control treatments, lead service line replacement, source water monitoring and treatment, and public education about reducing exposure.

(b) Lead in the blood of human beings

At the present time, the World Health Organization identifies a blood lead level of

10 µg/dL as the upper limit of the acceptable range. A WHO committee is currently reviewing the guidelines for the diagnosis and treatment of lead poisoning, however. As noted, in its most recent evaluation of lead, the FAO/WHO JECFA withdrew the PTWI, of 25 µgPb/kg body weight/week, which had been established in 1993. The rationale was that the absence of a threshold for lead toxicity means that no level of exposure is safe (thus "tolerable"). Moreover, it was not possible to establish a new PTWI that would be considered to be health protective."

In the U.S., the reference value (explained below) is currently 5 µg/dL for children. Among adults, 5 µg/dL is the upper value for pregnant and lactating women, 10 µg/dL for others. These values are of relatively recent origin. The toxicity of lead exposure at high dose has been recognized for two millennia, but it is only in the past 40 years that we have learned that exposures that do not produce clinical toxicity can, nevertheless, reduce an individual's health and quality of life. Over this recent period, the steady accumulation of evidence has motivated a series of reductions in the blood lead level identified as "acceptable" in young children. In paediatric textbooks of the 1960's, a blood lead level of 60 µg/dL was considered to be the upper limit of a "normal" value. In 1971, the U.S. Surgeon General reduced this cut-off to a blood lead level of 40 µg/dL. The U.S. CDC subsequently identified an "action level" of 30 µg/dL in 1975, 25 µg/dL in 1985, and 10 µg/dL in 1991. Each reduction in the concentration considered to be acceptable stimulated a new round of research to determine whether the new action level did, indeed, provide children with an adequate margin of safety. Each time, these studies clearly indicated that the answer was "no" because adverse health effects were consistently found at blood lead levels below the action level. The current consensus is that there is no "safe" blood lead concentration below which adverse effects do not occur. As a result, in 2012, the U.S. CDC abandoned the concept of an action level, substituting for it a "reference level". This level is defined solely on a statistical basis, as the 97.5th percentile of the blood lead distribution of young children in the U.S. Therefore, this is not a health-based value, and its purpose is simply to identify children who are the most highly exposed. This concentration is currently 5 µg/dL, but it will be updated, as necessary, every four years using the blood lead distribution measured in the two most recent NHANES surveys. If these surveys indicate that the blood lead level corresponding to the 97.5th percentile has changed, the reference value will be changed accordingly. As stated by the U.S. CDC, because of the absence of an identified threshold for adverse effects, it cannot specify "an allowable exposure level, level of concern, or any other bright line intended to connote a safe or unsafe level of exposure" (2010, p.12).

(4) **The adequacy and suitability of the reference values for blood lead level and the care plan published or followed by the Hong Kong Special Administrative Region Government**

The reference values selected by the Hong Kong Special Administrative Region Government for prioritizing individuals for follow-up based on blood lead level are appropriate and consistent with those identified by authoritative international bodies. The following tables present the recommendations of the U.S. CDC for responding to the identification of a child or adult with a blood lead level greater than the reference value (5 μg/dL for children, 10 μg/dL for adults).

Recommendations for Follow-up Actions, Children (U.S. CDC, 2012)

Blood Lead Concentration < 5 μg/dL	Blood Lead Concentration 5-45 μg/dL
Lead education (dietary, environmental)	Lead education (dietary, environmental)
Environmental assessment for pre-1978 housing	Follow-up blood lead monitoring (see following table for schedule)
Follow-up blood lead monitoring (see following table for schedule)	Complete history and physical examination
	Lab studies (iron status—consider haemoglobin or haematocrit)
	Environmental investigation
	Lead hazard reduction
	Neurodevelopmental monitoring
	Abdominal X-ray (if particulate lead ingestion suspected; bowel decontamination if indicated)

Schedule for Follow-up Blood Lead Testing in Children (U.S. CDC)

Venous Blood Lead	Early Follow-up Testing (2-4 Months after Identification	Later Follow-up Testing After Blood Lead is Declining
≥reference value but <10 μg/dL	3 months	6-9 months
10-19 μg/dL	1-3 months	3-6 months
20-24 μg/dL	1-3 months	1-3 months

Source: http://www.cdc.gov/nceh/lead/acclpp/final_document_030712.pdf.

Recommendations for Follow-up Actions, Adults (Association of Occupational and Environmental Clinics, U.S., 2007)

Blood lead concentration 5-9 μg/dL	Blood lead concentration 10-29 μg/dL
Lead education (occupational, environmental, reproduction)	Consider clinical assessment
Follow-up blood lead monitoring	History (occupational, environmental, medical)
	Examination, lab work
	Identify risk factors
	Blood lead levels of family members
	Exposure assessment (air testing, Workplace)
	Consider consultations (occupational medicine, industrial hygiene, public health department

	Lead hazard reduction
	Follow-up blood lead monitoring

Source: http://www.aoec.org/documents/positions/MMG_FINAL.pdf.

In developing my opinion about the adequacy of the care plan to address the issue of lead exposure in the 11 affected public rental housing estates, I considered the information provided on the second blood tests conducted on individuals who first blood lead results exceeded 5 µg/dL (line-listing of 163 persons, with results as of 22 October 2015) [Bundle E1/537-546]. The results of repeat blood lead tests are reported for 28 individuals. For 24 individuals, the interval between the initial and repeat test was approximately 3 months. For 4 of the remaining individuals (all pregnant women), the interval ranged from 1 week to 1 month. These groups are considered separately. For the 24 non-pregnant individuals, the average decline in blood lead level was 30.8% (2.7-55.5). There is some evidence of regression to the mean (i.e., if a variable is extreme on its first measurement, it will tend to be closer to the average on its second measurement). The 10 individuals who showed the largest decreases between measurements had an initial blood lead level that averaged 8.46 µg/dL (range 5.58-14.18), while the other 14 individuals had an initial level that averaged 6.30 µg/dL (range 5.28-8.62). It would have been helpful to conduct repeat blood lead tests on a sample of individuals whose initial result was below the reference value. This would have permitted a more certain interpretation of how much of the decline in blood lead observed in all of the non-pregnant individuals can be attributed to reduction in lead exposure and how much to regression to the mean.

The 4 pregnant women showed changes in blood lead level that were smaller than those observed in the non-pregnant individuals (-0.81, -1.55, +0.09, and -0.91). The average change was a decrease of 13.7%. Several factors could explain this. First, the interval between tests was much shorter, providing less time for change. Second, as noted previously, the kinetics of lead change during pregnancy. Several studies show that blood lead level tends to decrease over the early stages of pregnancy. This is likely due to haemodilution, i.e., the approximately 50% increase in plasma blood volume that occurs during this period. On average, however, a woman's blood lead level begins to increase from the middle of pregnancy on. This is likely due to the mobilization of maternal bone to meet the increasing calcium required to meet the needs of the fetal skeleton as it develops. As noted earlier, this process mobilizes lead, as well as calcium, into the blood. These considerations complicate the interpretation of short-term blood lead changes in pregnant women. No information is provided in the line-listing about the stage of pregnancy of the 4 individuals so it is difficult to draw conclusions.

In my opinion, the general components of the care plan proposed for residents are appropriate, although some are not described in detail, making the adequacy of the plan somewhat difficult to evaluate. Continued follow-up blood lead testing for individuals whose blood lead concentration remains above the age-appropriate reference value is very important. Because of the multiplicity of sources and pathways of lead exposure, it might be that sources/pathways other than water contribute to an individual's continued blood lead elevation. Therefore, while the plan to conduct an "exposure assessment" is sound, no information is provided about what this assessment will include and what methods will be used. In general, such an assessment involves consideration of lead hazards in an individual's home environment (paint, food, hobbies, use of folk medicines, children's toys, etc.), outside activities (soil, proximity to lead-emitting point sources), and any other environments in which an individual spends substantial time (e.g., school, day care centre, workplace). The care plan also stipulates a "health evaluation" (children <18 years, pregnant women) for individuals with a blood lead level of 5-44 µg/dL and a "medical assessment" for individuals with a blood lead level >44. What will be included in these activities, and whether the clinicians performing them will be experienced in assessing lead-exposed individuals are not described. Whether the "developmental assessment" will involve use of screening tools, parent-questionnaires, or in-person clinical evaluations is not described.

(5) The adequacy and suitability of the acceptance criteria laid down by the Water Supplies Department for heavy metals and, if necessary, to make recommendations

In my opinion, the acceptance criteria specified by the Water Supplies Department for four metals, lead (≤10 µg/L), cadmium (≤ 3 µg/L), chromium (≤ 50 µg/L), and nickel (≤ 70 µg/L), are all based on sound reasoning. They are either more protective or equally as protective of human health than are guidelines for these metals in drinking water established by authoritative bodies such as the World Health Organization and the U.S. Environmental Protection Agency. In establishing the guidelines, these bodies have relied on thorough consideration of the routes of human exposure, kinetics of the metals in the human body, and the critical health effects. The guidelines have undergone extensive peer review and reflect the medical and scientific consensuses at the times that the guidelines were established.

Lead. As discussed earlier, the WHO guideline for lead in drinking water is 10 µg/L, the same as the acceptance criteria established by the Hong Jong WSD. This guideline is somewhat stricter than that used by the U.S. Environmental Protection Agency. If more than 10% of the tap water samples collected exceed 0.015 mg/L (15 µg/L), a water system is required to take steps such as corrosion control treatments, lead service line replacement, source water monitoring and treatment, and public education about reducing exposure.

Cadmium. It is known that cadmium in the zinc of galvanized pipes or cadmium-containing solders in fittings, water heaters, water coolers and taps can contaminate drinking water. The concentration is increased in the presence of low pH, as this would tend to make water more corrosive. WHO has established a guideline of 0.003 mg/L for cadmium in drinking water. In re-evaluating the PTWI for cadmium in 2011, the FAO/WHO JECFA substituted a Provisional Tolerable Monthly Intake of 25 µg/kg of body weight for the PTWI of 7 µg/kg of body weight due to the very long half-life of cadmium in the kidney. This change did not affect the water cadmium guideline, however. The change from a PTWI to a PTMI had no effect on the guideline value however, which remained 0.003 mg/L (3 µg/L).

The US EPA maximum contaminant level for cadmium in water is 0.005 mg/L (5 µg/L), a level that is considered to be protective of public health.

Chromium. Chromium differs from lead and cadmium in that it is an essential nutrient, with the daily requirement for adults estimated to be 0.5–2 µg of absorbable trivalent chromium (chromium-III). Hexavalent chromium (chromium-VI), however, is extremely toxic. If a fractional absorption value of 25% for "biologically incorporated" chromium-III is assumed, the requirement would be met by a daily dietary intake of 2–8 µg of chromium-III, equivalent to 0.03–0.13 µg of chromium-III per kg of body weight per day for a 60-kg adult. Ideally, different guideline values should be set for chromium-III and chromium-VI, but for a variety of reasons the chromium guideline value refers to total chromium in water. This is because these forms of chromium can convert back and forth in water and in the human body depending on environmental conditions. The WHO has established a guideline of 0.05 mg/litre (50 µg/L) for total chromium. This is considered to be unlikely to give rise to significant risks to health.

In the U.S. the drinking water standard for total chromium is 0.1 mg/L (100 μg/L). In order to ensure that the greatest potential risk is addressed, this regulation assumes that the more toxic form, chromium-VI accounts for all of the total chromium value. This is considered to be protective because the actual fraction of chromium-VI varies depending on the water type (ground water versus surface water, raw water versus treated drinking water, etc.), geographical location, and the oxidation-reduction potential of the water.

Nickel. Like chromium, nickel is an essential trace mineral. Drinking water is thought to contribute only a minor proportion of daily intake, although this depends on the concentration of nickel in groundwater. Based on a "lowest observed adverse effect level" of 12 μg/kg body weight per day, the WHO estimated that a guideline value of 0.07 mg/L (70 μg/L) would adequately protect human health (assuming a 60 kg adult drinking 2 litres of water per day, and assuming that this intake accounts for 20% of the daily intake of nickel).

In the U.S., the EPA recommends that drinking water levels for nickel should not be more than 0.1 mg/L (100 μg/L).

Summary of Conclusions

Lead serves no biological purpose in the body. There is no "safe" level of lead, as adverse effects in different organ systems, particularly the central nervous system, have been observed at blood lead levels less than 5 µg/dL. Therefore, the ideal blood lead concentration for a human is 0 µg/dL. Because of the ubiquity of lead in the contemporary environment, this will not be achievable in the near term. All lead exposure is preventable, however. The goal, therefore, must be to reduce exposure as much as is feasible. The many sources and pathways of lead exposure complicate the path to achieving this goal. Removing one pathway/source might produce only a modest reduction in blood lead level. That lead is an accumulative toxicant stored in multiple pools in the body besides blood introduces an additional complication. The partial data available demonstrating an average reduction of approximately 30% in the blood lead levels of residents of the affected public housing estates following interruption of the water pathway suggests to me that lead in the drinking water was, indeed, contributing to the exposure of the residents. I would anticipate that, over time, the residents' blood lead levels will re-equilibrate and reach a new steady state that reflects their lead exposure from other (non-water) sources and their endogenous lead sources reflecting past exposures. The blood lead concentrations achieved will therefore depend on what other sources/pathways contribute to an individual's lead exposure, as well as the magnitude of the individual's historical lead exposure.

Expert's Declaration

I, PROFESSOR DAVID C. BELLINGER DECLARE THAT:

1. I declare and confirm that I have read the Code of Conduct for Expert Witnesses as set out in Appendix D to the Rules of High Court, Cap. 4A and agree to be bound by it. I understand that my duty in providing this written report and giving evidence is to assist the Commission. I confirm that I have complied and will continue to comply with my duty.
2. I know of no conflict of interests of any kind, other than any which I have disclosed in my report.
3. I do not consider that any interest which I have disclosed affects my suitability as an expert witness on any issues on which I have given evidence.
4. I will advise the Commission if, between the date of my report and the hearing of the Commission, there is any change in circumstances which affect my opinion above.
5. I have been shown the sources of all information I have used in Appendix II.
6. I have exercised reasonable care and skill in order to be accurate and complete in preparing this report.
7. I have endeavoured to include in my report those matters, of which I have knowledge or of which I have been made aware, that might adversely affect the validity of my opinion. I have clearly stated any qualifications to my opinion.
8. I have not, without forming an independent view, included or excluded anything which has been suggested to me by others, including my instructing solicitors.
9. I will notify those instructing me immediately and confirm in writing if, for any reason, my existing report requires any correction or qualification.
10. I understand that:
    (a) my report will form the evidence to be given under oath or affirmation;
    (b) questions may be put to me in writing for the purposes of clarifying my report and that my answers shall be treated as part of my report and covered by my statement of truth;
    (c) the Commission may at any stage direct a discussion to take place between the experts for the purpose of identifying and discussing the issues to be investigated under the Terms of Reference, where possible reaching an agreed opinion on those issues and identifying what action, if any, may be taken to resolve any of the outstanding issues between the parties;

(d) the Commission may direct that following a discussion between the experts that a statement should be prepared showing those issues which are agreed, and those issues which are not agreed, together with a summary of the reasons for disagreeing;

(e) I may be required to attend the hearing of the Commission to be cross-examined on my report by Counsel of other party/parties;

(f) I am likely to be the subject of public adverse criticism by the Chairman and Commissioners of the Commission if the Commission concludes that I have not taken reasonable care in trying to meet the standards set out above.

Commission of Inquiry into Excess Lead
Found in Drinking Water

Statement of Truth

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. I believe that the opinions expressed in this report are honestly held.

David C Bellinger

Professor David C. Bellinger
1 December 2015

APPENDIX I

CURRICULUM VITAE OF PROFESSOR DAVID C. BELLINGER

DAVID C. BELLINGER

Professor of Neurology and Professor of Psychology at Harvard Medical School
Professor in Department of Environmental Health at Harvard School of Public Health Developmental Psychologist (with additional training in epidemiology)

PERSONAL DETAILS

Year of birth:	1950	
Nationality:	United States of America	
Qualifications:	1971 B.A.	Williams College
	1977 Ph.D.	Psychology, Cornell University
	1987 M.Sc.	Epidemiology, Harvard School of Public Health
Awards:	1971	B.A. magna cum laude with Highest Honors, Williams College
	1970	Phi Beta Kappa, Williams College
	1977	Phi Kappa Phi, Cornell University
	1985-1990	National Institute of Environmental Health Sciences Research Career Development Award
	1996	MillerComm Lecturer, University of Illinois at Urbana-Champaign
	2008	Elsevier Distinguished Lecturer, Neurobehavioral Teratology Society
	2011	M.I.N.D. Institute Distinguished Lecturer, University of California-Davis
	2011	Jakob Hooisma Plenary Lecture, International Neurotoxicology Association
	2011	Environmental Health Perspectives, Reviewer of the Year
	2013	Newburger-Bellinger Cardiac Neurodevelopmental Award (inaugural recipient, with Jane W. Newburger)
	2013	Bernstein Lecturer, Department of Psychiatry, Boston Children's Hospital
Professional interests:	Environmental Epidemiology, Toxicology, Child Development, Public Health, Neuropsychology	

Other (voluntary) positions:	International Society for Children's Health and the Environment, President 2010-present Editor-in-Chief, *Toxics* (2012-present) Associate Editor (children's environmental health), *Environmental Health*, 2013-present	
	1993	World Health Organization/International Programme on Chemical Safety Task Group on Environmental Criteria for Lead, Brisbane, Australia
	1997	World Health Organization/International Programme on Chemical Safety, Consultation on Methods Used to Study Neurobehavioral Development of Children Exposed In Utero to Methylmercury, Montreal, Canada
	1998-1999	WHO Temporary Advisor, Joint FAO/WHO Expert Committee on Food Additives and Contaminants, Work Group on Methyl Mercury, Rome, Italy
	1999-2000	WHO Temporary Advisor, Joint FAO/WHO Expert Committee on Food Additives and Contaminants, Work Group on Cadmium, Geneva, Switzerland
	2002	World Health Organization/International Programme on Chemical Safety, Project to Update the Principles and Methods for the Risk Assessment of Chemicals in Food, London, England
	2002-2003	WHO Temporary Advisor, Joint FAO/WHO Expert Committee on Food Additives and Contaminants, Work Group on Methylmercury, Work Group on Cadmium, Rome, Italy
	2004-2005	Member, Joint FAO/WHO Expert Committee on Food Additives and Contaminants, Rome, Italy
	2007-	Member, World Health Organization, Foodborne Disease Burden Epidemiology Reference Group (core group, Chemical Task Force, Source Attribution Task Force, Country Burden Task Force)
	2009	Consultant, European Food Safety Authority, Use of the Benchmark Dose

	Approach in Risk Assessment
2009-2010	WHO Temporary Advisor, 72nd Joint FAO/WHO Expert Committee on Food Additives and Contaminants, Rome, Italy
2009-2010	WHO Temporary Advisor, 73rd Joint FAO/WHO Expert Committee on Food Additives and Contaminants, Geneva, Switzerland
2011-	WHO Guidelines on the Prevention and Management of Lead Poisoning, World Health Organization (Chairperson)
2011-	Member, WHO Expert Advisory Panel on Food Safety, World Health Organization
2014-	Member, Biology and Medicine Panel, Research Grants Council, University Grants Committee, Hong Kong

Publications on Lead

Original Articles

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Edited

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Co-Edited

Needleman H, Bellinger D, editors. Prenatal Exposure to Environmental Toxicants: Developmental Consequences. Baltimore: The Johns Hopkins Press; 1994.

EMPLOYMENT EXPERIENCE

1977-1978	Public Health Service Postdoctoral Fellow, Department of Psychiatry, University of Rochester School of Medicine
1978-1979	Public Health Service Postdoctoral Fellow, Department of Psychology, Boston University
1983-1987	Instructor in Neurology (Psychology), Harvard Medical School
1987-1994	Assistant Professor of Neurology (Psychology), Harvard Medical School
1994-2003	Associate Professor of Neurology (Psychology), Harvard Medical School
2003-	Professor of Neurology, Harvard Medical School
2004-	Professor in the Department of Environmental Health, Harvard School of Public Health

2013- Professor of Psychology in the Department of Psychiatry, Harvard Medical School

1 December 2015

APPENDIX II

DOCUMENTS PROVIDED TO PROFESSOR DAVID C. BELLINGER (for the purpose of this report)

1. Selected documents collected by the Commission from the Involved Parties since 20 August 2015.

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JOINT EXPERT REPORT
(Preliminary)

PREPARED BY

PROFESSOR JOHN FAWELL &
PROFESSOR JOSEPH HUN-WEI LEE

Expert Witnesses appointed by the Commission of Inquiry into Excess Lead Found in Drinking Water

12 November 2015

The Terms of Reference of the Commission are as follows:

(a) to ascertain the causes of excess lead found in drinking water in public rental housing developments;

(b) to review and evaluate the adequacy of the present regulatory and monitoring system in respect of drinking water in Hong Kong;

(c) make recommendations with regard to the safety of drinking water in Hong Kong

Professor John Fawell

Biologist/Toxicologist

(Consultant on drinking water and environment)

Specialist Field	:	Assessment and management of risks from drinking water contaminants
Appointed on behalf of	:	The Commission of Inquiry into Excess Lead Found in Drinking Water (the "**Commission**")
Prepared for	:	The Commission
On instructions of	:	Messrs. Lo & Lo, Solicitors for the Commission ("**Lo & Lo**")
Subject matter / Scope of engagement:	:	To assist the Commission in discharging its duties under the Terms of Reference and by acting as an expert witness in the inquiry hearings
Curriculum Vitae		**Appendix I**

Instructions to Professor Fawell

I have been instructed to give my opinion on the matters under the Terms of Reference.

In providing my opinion, I have also been instructed to consider the following areas and undertake the following tasks:

(a) review and verify the findings of the Interim and Final Reports of the Task Force led by the Water Supplies Department (WSD) in respect of the Waterworks system and the Inside Service system in public rental housing developments, including the overall methodology adopted in the investigation;

(b) identify and explain the international standards (particularly those laid down by the World Health Organisation (WHO)) in respect of the following matters for the purpose of ensuring safety and quality of drinking water in Hong Kong :

- (i) hazards and hazardous events;
- (ii) risk assessment, prioritization and management;
- (iii) control measures;
- (iv) construction and maintenance;

(v) inspection and monitoring;

(vi) management procedures;

(vii) rectification;

(viii) the supply and use of plumbing materials; and

(ix) the procedures and protocols regarding the use and installation of plumbing materials;

(c) in the context of the international standards in (a) –

(i) review and evaluate the adequacy of the existing Water Safety Plans of the WSD;

(ii) review and evaluate the existing regulatory and monitoring regimes (both prior and subsequent to the excess lead in drinking water incidents as a result of which new measures have been put in place by public authorities) on quality of drinking water :

(1) at the pre-construct stage;

(2) at the construction stage;

(3) at the completion of construction (before the WSD issues the certificate for water supply connection); and

(4) at the maintenance stage;

(iii) opine on whether any further metal(s), chemical(s) and/or microorganism(s) should be included as parameter(s) in addition to those set out in the WSD Circular Letter No. 1/2015 for testing of water samples, and if so, the thresholds, benchmarks and/or the acceptance criteria to be set for them; and

(iv) the effectiveness of the recommendations made by the Review Committee;

(d) opine on how the inadequacies (if any) identified for the matters above may be rectified or improved and to make recommendations with regard to the safety of drinking water in Hong Kong; and

(e) state, provide advice and recommendations on other areas of concern (if any).

Professor Joseph Lee

Chair Professor, Department of Civil and Environmental Engineering
Vice-President for Research & Graduate Studies
Hong Kong University of Science and Technology

Specialist Field	:	Environmental engineering: environmental hydraulics & water resources Environmental hydraulics/fluid mechanics; water quality modelling
Appointed on behalf of	:	The Commission
Prepared for	:	The Commission
On instructions of	:	Lo & Lo
Subject matter / Scope of engagement:	:	To assist the Commission in discharging its duties under the Terms of Reference and by acting as an expert witness in the inquiry hearings
Curriculum Vitae		**Appendix I**

Instructions to Professor Lee

I have been instructed to give my opinion on the matters under paragraph (a) of the Terms of Reference. In providing my opinion, I have also been instructed to consider the following areas and undertake the following tasks:

(a) to ascertain the factual source(s) of excess lead found in drinking water in public rental housing and to advise on what work and tests are to be performed;

(b) to evaluate the methodologies and to review and verify the findings of the WSD Task Force's Interim and Final Reports in respect of the Waterworks system and the Inside Service system in public rental housing developments, from the perspective of a civil engineer; and

(c) to conduct, if necessary, independent investigation on behalf of the Commission into the above systems in order to ascertain the factual source(s) of excess lead found in drinking water.

Preliminary Joint Opinion

The sampling protocol to identify whether lead is present in the pipework or fittings of drinking water systems in buildings is important in assessing the risks of lead contamination in drinking water. The contact time with lead-containing components such as soldered joints or fittings is a key factor in determining lead concentrations in drinking water. Indeed, a number of authorities suggest fixed stagnation periods before withdrawing samples while others propose first draw samples.

The International Standards Organization Standard (ISO-5667-5) on sampling techniques of drinking water from treatment works and pipe distribution systems states that "If the effects of materials on water quality are being investigated, then the initial draw off should be sampled. Samples may also be taken after a specified period of stagnation to provide information on the rate at which materials affect quality or the maximum likely effect." For example, in the UK (England and Wales) standards for drinking water quality, the sampling requirement is to take the first litre of water drawn from the tap without flushing. The USEPA also requires that one-litre first draw samples are taken to indicate the level of exposure to lead and copper. In Japan the requirement is to first flush for five minutes and then take a sample for analysis after 15 minutes stagnation.

Fully flushed samples on their own may serve the purpose of assessing the general quality of a drinking water as supplied, but will not give a representative assessment of the concentration of lead or other metals from the internal distribution system to which the consumer is exposed.

Based on the above, data from fully flushed samples are not likely to be representative of the extent of lead exposure.

Expert's Declaration

I, PROFESSOR JOHN FAWELL DECLARE THAT:

1. I declare and confirm that I have read the Code of Conduct for Expert Witnesses as set out in Appendix D to the Rules of High Court, Cap. 4A and agree to be bound by it. I understand that my duty in providing this written report and giving evidence is to assist the Commission. I confirm that I have complied and will continue to comply with my duty.

2. I know of no conflict of interests of any kind, other than any which I have disclosed in my report.

3. I do not consider that any interest which I have disclosed affects my suitability as an expert witness on any issues on which I have given evidence.

4. I will advise the Commission if, between the date of my report and the hearing of the Commission, there is any change in circumstances which affect my opinion above.

5. I have exercised reasonable care and skill in order to be accurate and complete in preparing this report.

6. I have endeavoured to include in my report those matters, of which I have knowledge or of which I have been made aware, that might adversely affect the validity of my opinion. I have clearly stated any qualifications to my opinion.

7. I have not, without forming an independent view, included or excluded anything which has been suggested to me by others, including my instructing solicitors.

8. I will notify those instructing me immediately and confirm in writing if, for any reason, my existing report requires any correction or qualification.

9. I understand that:

(a) my report will form the evidence to be given under oath or affirmation;

(b) questions may be put to me in writing for the purposes of clarifying my report and that my answers shall be treated as part of my report and covered by my statement of truth;

(c) the Commission may at any stage direct a discussion to take place between the experts for the purpose of identifying and discussing the issues to be investigated under the Terms of Reference, where possible reaching an agreed opinion on those issues and identifying what action, if any, may be taken to resolve any of the outstanding issues between the parties;

(d) the Commission may direct that following a discussion between the experts that a statement should be prepared showing those issues which are agreed, and those issues which are not agreed, together with a summary of the reasons for disagreeing;

(e) I may be required to attend the hearing of the Commission to be cross-examined on my report by Counsel of other party/parties;

(f) I am likely to be the subject of public adverse criticism by the Chairman and Commissioners of the Commission if the Commission concludes that I have not taken reasonable care in trying to meet the standards set out above.

Statement of Truth

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. I believe that the opinions expressed in this report are honestly held.

Professor John Fawell
12 November 2015

Expert's Declaration

I, PROFESSOR JOSEPH LEE DECLARE THAT:

1. I declare and confirm that I have read the Code of Conduct for Expert Witnesses as set out in Appendix D to the Rules of High Court, Cap. 4A and agree to be bound by it. I understand that my duty in providing this written report and giving evidence is to assist the Commission. I confirm that I have complied and will continue to comply with my duty.

2. I know of no conflict of interests of any kind, other than any which I have disclosed in my report.

3. I do not consider that any interest which I have disclosed affects my suitability as an expert witness on any issues on which I have given evidence.

4. I will advise the Commission if, between the date of my report and the hearing of the Commission, there is any change in circumstances which affect my opinion above.

5. I have exercised reasonable care and skill in order to be accurate and complete in preparing this report.

6. I have endeavoured to include in my report those matters, of which I have knowledge or of which I have been made aware, that might adversely affect the validity of my opinion. I have clearly stated any qualifications to my opinion.

7. I have not, without forming an independent view, included or excluded anything which has been suggested to me by others, including my instructing solicitors.

8. I will notify those instructing me immediately and confirm in writing if, for any reason, my existing report requires any correction or qualification.

9. I understand that:

(a) my report will form the evidence to be given under oath or affirmation;

(b) questions may be put to me in writing for the purposes of clarifying my report and that my answers shall be treated as part of my report and covered by my statement of truth;

(c) the Commission may at any stage direct a discussion to take place between the experts for the purpose of identifying and discussing the issues to be investigated under the Terms of Reference, where possible reaching an agreed opinion on those issues and identifying what action, if any, may be taken to resolve any of the outstanding issues between the parties;

(d) the Commission may direct that following a discussion between the experts that a statement should be prepared showing those issues which are agreed, and those issues which are not agreed, together with a summary of the reasons for disagreeing;

(e) I may be required to attend the hearing of the Commission to be cross-examined on my report by Counsel of other party/parties;

(f) I am likely to be the subject of public adverse criticism by the Chairman and Commissioners of the Commission if the Commission concludes that I have not taken reasonable care in trying to meet the standards set out above.

Statement of Truth

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. I believe that the opinions expressed in this report are honestly held.

Professor Joseph Lee
12 November 2015

APPENDIX I

CURRICULUM VITAE OF PROFESSOR JOHN FAWELL

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CURRICULUM VITAE OF PROFESSOR JOSEPH LEE

CURRICULUM VITAE

NAME:	**Professor JOHN FAWELL**
PROFESSION:	**Consultant on drinking water and environment.**
PROFESSIONAL BACKGROUND:	Biologist/Toxicologist
PRIMARY SPECIALISATION:	Assessment and management of risks from drinking water contaminants and from re-use of wastewater
YEAR OF BIRTH;	1945
NATIONALITY:	British
HONOURS:	MBE He received the International Society of Regulatory Toxicology and Pharmacology 2013 International Achievement Award
QUALIFICATIONS:	BSc Applied Biology University of Bath 1969 MI Biol C Biol 1972 (now C Biol MSB) M CIWEM 1983 (resigned 2010) Diploma in Toxicology, Royal College of Pathologists 1986
PROFESSIONAL AFFILIATIONS:	Society of Biology British Toxicology Society American Water Works Association Scientific Fellow, of the Zoological Society of London International Water Association Appointed visiting professor at Cranfield University May 2011.
WORKING LANGUAGE:	English

EXPERIENCE

Prof Fawell has worked on the implications of contaminants in the environment for human health and aquatic life since 1979 and is actively involved at both a national and international level.

Key areas included:

- Closely involved in the WHO Guidelines for Drinking Water Quality as a member of the co-ordinating team since 1988. For the 1993 revision he was co-ordinator for inorganics and substances which affect acceptability to consumers, rapporteur for organics, pesticides and disinfection by-products and organiser of working group meetings on radioactivity and treatment and analysis. Prepared background documents on the toxicology and health risks of a wide range of substances, with proposed guideline values, for 1993 revision and the 1998 addendum. He was coordinator for naturally occurring substances and substances from agriculture, industry and human settlements for the preparation of the third edition of the Guidelines in 2003 for which he also prepared several revised background documents. Actively involved in the rolling revision of the Guidelines he was Chairman of the 1998 Medmenham meeting on Aspects of Protection and Control and of Microbiological Quality. Subsequently he has continued as Co-ordinator for naturally occurring substances and substances from agriculture, industry and human settlements but has added pesticides for use in controlling Denghe fever vectors in drinking water containers. He has continued in that role for the fourth edition of the Guidelines published in July 2011. He was part of the WHO expert group establishing guidelines for the supply of safe drinking water by desalination and a member of the expert group considering the significance of beneficial minerals in drinking water. He was one of the three co-ordinators and one of the authors of the WHO publication "Chemical safety of drinking-water: assessing priorities for risk management". He is coordinator for most of the chemical parameters for the preparation of the fourth edition of the Guidelines and has been closely involved with the preparation of most of the other sections. He is a member of the WHO expert group on pharmaceuticals in drinking water.

- Works closely with WHO regional offices, including liaison between the European Commission and the European Regional Office on water and between WHO HQ and the Commission on re-use of wastewater.
- Member of several IPCS expert groups and author of working documents on chemical contamination for the WHO working group on bathing water quality. He has served on JECFA for substances in which drinking water is a key source of exposure and is a member of the panel of experts.
- Has led programmes of research on the toxicology and health implications of by-products of disinfection for government and water suppliers since 1982. Has acted as external supervisor for two PhD students on the epidemiology of disinfection by-products and adverse reproductive outcomes. He has also carried out research on the risks to health and risk assessments of blue-green algal toxins, polycyclic aromatic hydrocarbons and a wide range of other environmental contaminants.
- Previously chief scientist in the team which provides advice to UK water undertakers and regulators on the risk assessment of contaminants in the environment, particularly for human health, through drinking water, including a 24 hour service for incidents involving drinking water and the aquatic environment. He is currently contracted to provide toxicological and risk assessment advice to the Drinking Water Inspectorate.
- Provided independent advice and reviews on chemicals, which are used in drinking water or which may reach the environment, for chemical companies and groups of chemical companies and provided advice on water contaminants and disinfection processes to the food industry. He has been involved in preparing an ILSI Europe document on the use of water and its treatments in the food industry and this includes food processing. Provides advice on monitoring and assuring water quality for water used in beverage and food manufacturing.
- Prof Fawell provides advice on water contaminants and their management for a number of public drinking water suppliers, including acting as an independent reviewer of water quality of both raw and treated water.

- Has provided advice on the significance and nature of contaminants to large producers of bottled and natural mineral waters. These include both naturally occurring inorganic contaminants/constituents and anthropogenic contaminants from a number of sources, including microbiological contaminants. He has also been involved in the assessment of remineralisation needs for demineralised water processes for desalinated waters.
- Has been a member of committees advising government and regulatory bodies such as the Sub-Committee on Pesticides, The Environment Agency National Advisory Group for Determining Substances for the EC Groundwater Directive and subsequently technical advisor to the Joint Agency Groundwater Directive Advisory Group, The Toxic Algae Task Group and the Steering Group for the Revision of the UK National Environmental Health Action Plan. He was invited to give evidence to the Royal Commission on Environmental Pollution at the beginning of their study on environmental regulations. He has worked closely with the International Life Sciences Institute (ILSI) in the USA and Europe and was previously chairman of the ILSI Europe Task Force on Environment and Health.
- Provides independent advice on regulatory and environmental issues to the drinking water inspectorate in the UK and a variety of industries and government departments, including governments outside the UK. He has provided an independent opinion on the work of the Irish drinking water regulator and the value for money that it provides.
- Closely involved in the development and implementation of water safety plans and their incorporation into regulation both in the UK and in a number of regions of the world, including involvement in advising the Romanian government on establishing drinking water regulations to meet the provisions of the drinking water directive. He has also been closely involved in a WHO initiative to develop advice for member states on developing regulations based on the Guidelines.
- One of the lead members of a team commissioned to prepare proposals for revising the chemicals section of the European Drinking Water Directive taking into account the introduction of water safety plans.

Prof Fawell has been recently involved in research on a number of priority contaminants in the environment and drinking water including endocrine disrupters, disinfection by-products and pharmaceuticals. In this respect he has close ties with The Department of Epidemiology at Imperial College and the Small Area Health Statistics Unit in particular. He has a particular interest in and is actively working in the field of risk assessment of chemicals and microorganisms in the environment. This includes the development of strategies to manage risks and perceived risks in the managed water cycle by early intervention through developments in wastewater and drinking water treatment. He was part of the team, with WCA Environment and Cranfield University, which carried out an assessment of the significance of pharmaceutical residues for drinking water for DWI and is part of a WHO/USEPA joint initiative on pharmaceutical residues.

He worked with CREH Analytical to develop a framework for managing microbial and chemical risks in drinking water (Water safety Plans) and with CREH Analytical and Owen Hydes to develop a framework for developing criteria for the safe reuse of wastewater. He also acts as consultant on projects for reuse of wastewater and the safe implementation of desalination as a drinking water source. In some cases these two are combined. He has also worked with the Spanish consultancy Eptisa in Romania to assist the Ministry of Health in meeting the requirements of the EU drinking water and bathing water directives, including introducing water safety plans in Romania. He and Owen Hydes have assisted water companies in developing and implementing their strategy for the introduction of drinking water safety plans and he was a consultant to IWA for their outreach programme to water suppliers on drinking water safety plans, including activities in Brazil, India and the Far East.

Prof Fawell has an international reputation and is involved in a number of international forums in addition to WHO, and has close contacts with regulators, industry and researchers in many parts of the world including North America and Japan. In 1998 he carried out a WHO mission to Kuwait to advise on environmental and environmental health issues. He was chairman of the Expert Committee on Health Aspects of Water Supply for KIWA in the Netherlands. He has acted as a consultant on drinking water standards and drinking water related materials to the Canadian Government and has close links with the USEPA Office of Water. He has assisted the USEPA and Health Canada on research requirements for the assessment of disinfection by-products in drinking water.

Prof Fawell is interested in the public perception of risk and the communication of risks to the public. He has acted as a PhD examiner on this subject and has made numerous radio and television appearances to discuss risks of a wide range of environmental contaminants and issues surrounding environmental contamination.

Prof Fawell is an author of over 90 publications in the open literature and is author of many project and other reports found in the grey literature.

Following a period of 20 years with WRc, he joined Warren Associates (Pipelines) Ltd as a Director of the Environmental Division in January 2000 and transferred to an equivalent position in the Infrastructure and Environment Management Division of FaberMaunsell when Warren Associates (Pipelines) Ltd was acquired by AECOM. He now works independently.

He was non-executive chairman of the board of WCA Environment, stepping down to non-executive board member in 2011 and retiring from the board in January 2013. He was appointed visiting professor in the Water Science Institute at Cranfield University in the UK in May 2011.

EMPLOYMENT EXPERIENCE

December 2002-	**Independent consultant**
April 2001 – December 2002	**Technical Director, Environmental Management Division, Metcalf and Eddy Ltd. Group Leader for Drinking Water and Environmental Toxicology.**
Jan 2000 – April 2001	**Director, Environmental Division, Warren Associates**
May - Dec 1999	**WRc-NSF Ltd - Chief Scientist**
1979 - April 1999	**WRc plc**
1988 - 1999	**Principal Toxicologist and Chief Scientist of the National Centre for Environmental Toxicology (1995)** Principal Scientist for toxicology, advising on the implications and significance of contaminants in drinking water and the aquatic environment. Responsible for the scientific quality of the work of the National Centre for Environmental Toxicology.
1981 - 1988	**Head, Toxicology Section** Leading a team investigating the significance of organic and inorganic pollutants in drinking water. Investigation of mutagens in drinking water and mutagens formed in drinking water treatment and their significance.
1979 - 1981	**Toxicologist, Water Quality and Health Group** Primarily assessing the implications for health of organic pollutants in drinking water.
1977 - 1979	**RHM Research Ltd Scientist i/c Pathology, Nutrition and Toxicology Department** Experimental pathology of novel foods. The effects of nutritional imbalance on kidney pathology .
1972 - 1977	**Inveresk Research International, Section Manager, Quantitative Histology and Histochemistry, Pathology Division** Experimental pathology of tobacco smoke on respiratory structure and function and of drugs on GI tract, heart and liver. Short term bioassays for predicting carcinogenic potential.
1970 - 1972	**Huntingdon Research Centre, Research Officer, Pathology Department** Experimental Pathology. Quantification of Experimental Emphysema and Bronchitis in rodents and primates.
1969 - 1970	**Lake Mweru Research Unit, Zambia** **Scientific Officer** - Limnology and fish stock assessment.

Selected Publicly Available Contract Reports

C. Jorgensen, H. Buchardt Boyd, DHI. J. Fawell, O.D. Hydes. Independent Consultants. September 2008. Final report on establishment of a list of chemical parameters for the revision of the Drinking Water Directive. European Commission. ENV.D.2/ETU/2007/0077r

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J Fawell, J Littlejohn, J Watkins 2005 Development of Drinking Water Safety Plans in Scotland. Scottish Executive Project No: ENV3/04/03

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71. FAWELL, J.K. and WATTS, C.D. (1988) Pesticides in Drinking Water. Proceedings of 4th Sherkin Island Conference on the Environment. Domestic and Industrial Wastes, Sherkin Island Marine Station 1988.

72. FAWELL, J.K. (1988) Toxicology of Pesticides. Paper to the European Institute of Water Seminar on the EEC Directive 80/778 in the Quality of Water Intended for Human Consumption: Pesticides. Como, May 1988.

73. FAWELL, J.K. and HUNT, S. (1988) Environmental Toxicology - Organic Pollutants. Ellis-Horwood/Wiley.

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75. FAWELL, J.K., FIELDING, M. and RIDGWAY, J.W. (1987) Health risks of chlorination, is there a problem? *Journal of the Institute of Water and Environmental Management* 1, 61-66.

76. FAWELL, J.K. and VOLANS, G.N. (1987) Toxicology information service responses to chemical incidents involving drinking water. *Proceedings of World Conference on Chemical Accidents* CEP Consultants Edinburgh, 200-203.

77. HUNT, S.M., CHRZANOWSKA, C., BARNETT, C.R., BRAND, H.N. and FAWELL, J.K. (1987) A comparison of *in vitro* cytotoxicity assays and their application to water samples. *ATLA* 15, 20-29.

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79. JONES, F. and FAWELL, J.K. (1987) Lessons learnt from the River Dee pollution incident January 1984 - Public Health. *Proceedings of World Conference on Chemical Accidents*. CEP Consultants Edinburgh, 223-226.

80. POON, G.C., PRIESTLEY, I.M., HUNT, S.M., FAWELL, J.K. and CODD, G.A. (1987) Purification procedure for peptide toxins form the cyanobacterium *Microcystis aeruginosa* involving high-performance thin-layer chromatography. *J. Chromatography* 387, 551-555.

81. HUNT, S.M., CHRZANOWSKA, C., BARNETT, C.R. and FAWELL, J.K. (1986) The application of *in vitro* cytotoxicity assays to the water industry. *ATLA* 14, 64-71.

82. FAWELL, J.K. and FIELDING, M. (1985) Identification and assessment of hazardous compounds in drinking water. *The Science of the Total Environment* 47, 317-341.

83. FAWELL, J.K. and WATTS, C.D. (1984) The nature and significance of organic by-products of ozonation - a review. Proceedings of IWEM symposium on "Ozone in water treatment practice - the future". IWEM London.

84. HARDING, D. and FAWELL, J.K. (1984) Eds. *Proceedings of Institute of Biology Symposium 'Woodlands, Water and Weather'* Inst. Biology. London.

85. FAWELL, J.K. (1983) The role of toxicology. In: *Environmental Protection Standards Compliance and Costs* Ed. T Lack Ellis Horwood.

86. PACKHAM, R.F. and FAWELL, J.K. (1982) The effects of plastics materials on drinking water quality. *Proceedings of the Conference on the Use of Plastics and Rubber in Water and Effluents*. The Plastics and Rubber Institute.

87. FAWELL, J.K. and JAMES, H.A. (1981) Problems of assessing the toxicological significance of organic micropollutants in drinking water. *Proceedings of Institute of Biology Conference on Organic Micropollutants in Water.*

88. DELVES-BROUGHTON, J., FAWELL, J.K. and WOODS, D. (1980) The first occurrence of `Cauliflower Disease' of eels *Anguilla anguilla* L. In: *The British Isles. Journal of Fish Diseases* 3, 255-256.

89. FAWELL, J.K. and CLARKE, D.G. (1977) An investigation of the biological activity of tobacco and cytrel condensate by the mouse epidermal hyperplasia test. *Proceedings of the European Society of Toxicology* 18, 222-224.

90. FAWELL, J.K. (1976) Electronic measuring devices in the sorting of marine zooplankton. In: *Zooplankton Fixation and Preservation*. ED. H.F. Steedman. The Unesco Press.

91. FAWELL, J.K. (1976) A histochemical investigation of isoprenaline-induced cardiotoxicity in mice. *Proceedings of the European Society of Toxicology* 17, 241-249.

92. FAWELL, J.K. (1975) The use of image analysis in applied biology and medical research. In: *Quantitative Analysis of Microstructures in Medicine, Biology and Materials Development.* Ed H.E. Exner Dr Reiderer-Verlag GmbH Stuttgart.

93. FAWELL, J.K. (1974) Applications of quantitative morphology in toxicology. *Proceedings of ESSDT* 16, 285-289.

94. FAWELL, J.K. (1974) The use of image analysis in the ageing of fish. In: *The Ageing of Fish.* Ed. T.B. Bagenal. Unwin Brothers Ltd.

95. FAWELL,J.K. and NEWMAN, A.J. (1972) Automated method of quantitating experimental pulmonary emphysema. *American Review of Respiratory Disease*, 105 849-851.

96. FAWELL, J.K., THOMSON, C. and COOKE, L. (1972) Respiratory artefact produced by carbon dioxide and pentobarbitone sodium euthenasia in rats. *Laboratory Animals* 6, 321-326.

97. FAWELL, J.K. and LEWIS, D.J. (1971) A simple apparatus for the inflation fixation of lungs at constant pressure. *Laboratory Animals* 5. 267-270.

98. BROWN, V.M., SHURBEN, D.G. and FAWELL, J.K. (1967) The acute toxicity of phenol to Rainbow Trout in saline waters. Water Research 1. 683-685.

JOSEPH HUN-WEI LEE

CURRICULUM VITAE

BORN: 20th October, 1952.

EDUCATION:				
	Massachusetts Institute	Ph.D.	Civil Engg.	June 1977
	of Technology	M.Sc.	Civil Engg.	Sept. 1974
	Cambridge, Mass., USA	B.Sc.	Civil Engg.	Feb. 1973

1969-73 MIT Scholarship
1971-72 Winslow Scholar
Chi Epsilon National Civil Engineering Honorary Fraternity
Tau Beta Pi National Engineering Honorary Fraternity

RESEARCH INTERESTS: Environmental hydraulics/fluid mechanics; water quality modelling

EXPERIENCE:

Nov.2010 - Vice-President for Research & Graduate Studies, Hong Kong University of Science and Technology.

2004-Oct.2010 Pro-Vice-Chancellor, The University of Hong Kong.

2000-2003 Dean of Engineering, The University of Hong Kong (Associate Dean 1999-2000).

Dec 1996- Redmond Chair of Civil Engineering, Department of Civil Engineering, The University of Hong Kong.

1987-96 Senior Lecturer then Reader (1991), and Chair Professor (1995).

1980-87 Lecturer, Department of Civil Engineering, University of Hong Kong.

1977-80 Assistant Professor, Department of Civil Engineering, University of Delaware, USA.

Courses taught: Postgraduate: environmental hydraulics; coastal hydraulics and water quality; water quality modelling; urban hydrology and hydraulics. Undergraduate: fluid mechanics; engineering hydraulics, environmental engineering; water quality control; water supply engineering; wastewater engineering.

Honors/Awards/External Appointments (Selected):

2015 Honorary Member, International Association for Hydro-environmental Engineering and Research (IAHR).

2013 Karl Emil Hilgard Hydraulic Prize, American Society of Civil Engineers

2010 China State Scientific and Technological Progress Award (Second class) for the project "Buoyant jets in complex environments: theory, innovative technology and applications" (Principal Investigator)

Guest Professor, Sichuan University, China (2013)

President, Hong Kong Academy of Engineering Sciences (2010-2013)

Honorary Professor, Nankai University, China (2010)

IAHR-APD Distinguished Member Award, IAHR (2010)

Hunter Rouse Hydraulic Engineering Award, American Society of Civil Engineers (2009)

Fellow, Royal Academy of Engineering, UK (2008)

Best paper award, 14th Biennial Congress of the Asia and Pacific Division (APD) of the International Association of Hydraulic Engineering and Research (IAHR), December 15-18, 2004, Hong Kong.

K.C.Wong Educational Foundation Lectureship, Hohai University (Oct. 2004)

Croucher Laboratory of Environmental Hydraulics Award, Croucher Foundation (April 2004)

Outstanding Researcher Award, University of Hong Kong (2004)

Fellow, Hong Kong Academy of Engineering Sciences (2002)

Innovation Award for Construction Industry, The Hong Kong Institution of Engineers (2002)

Universitas 21 Fellowship, McGill University (1999)

The Croucher Award (Senior Research Fellowship of the Croucher Foundation) (1999)

Visiting Erskine Fellowship, University of Canterbury, New Zealand (July-Aug 1998).

Alexander von Humboldt Research Fellow, University of Karlsruhe, Germany (Feb. 1992-Jan. 93)

K.C.Wong Educational Foundation Lectureship, Tongji and Hohai University (1988)

Commonwealth Academic Staff Fellowship Award, Imperial College of Science and Technology, U.K. (Oct. 1985 - Jul. 86).

Editor in Chief, *Journal of Hydro-environment Research*, Elsevier (2007-).

Associate Editor, *Journal of Hydraulic Engineering*, American Society of Civil Engineers (1997-).

Member, International Editorial Board, *Estuarine Coastal and Shelf Science*, Elsevier (2006-).

Member, International Editorial Board, *Environmental Fluid Mechanics*, Springer (2011-2014).

Member, International Editorial Board, *Ecological Informatics*, Elsevier (2006-).

Member, International Editorial Board, *KSCE Journal of Civil Engineering*, Korea Society of Civil Engineers (2006-).

Associate Editor, *Journal of Engineering Mechanics*, American Society of Civil Engineers (2002-2004).

Associate Editor, *China Ocean Engineering*, Chinese Ocean Engineering Society (1999-2004; 2007-).

Associate Editor, *Communications in Nonlinear Science and Numerical Simulation* (June 2000 -)

Member, Chinese People's Political Consultative Conference (CPPCC), Shanghai Committee (2008-)

Overseas Academic Master, 111 Project on Coastal Tidal Flat Resources Development and Safety, Hohai University, Nanjing (2012-)

Member, Advisory Board, Nanyang Environment & Water Research Institute, Nanyang Technological University, Singapore (2011-)

Member, Selection Committee of the International Climate Protection Fellowship, Alexander von Humboldt Foundation, Germany (2009-)

Member, International Advisory Board (IAB), Glasgow Research Partnership in Engineering, Scottish Funding Council (2007-)

Vice-President, International Association of Hydraulic Engineering and Research (IAHR) (2007-2011)

Member, Aviation Development and Three-runway System Advisory Committee, Hong Kong SAR Government (Aug 2015-)

Member, Land and Development Advisory Committee, Hong Kong SAR Government (2009-2015)

Member, Steering Committee for Research Themes under the Research Endowment Fund, University Grants Committee (2009-2015)

Member (Vice-Chair), Assessment Panel, Public Policy Research Funding Scheme, Central Policy Unit, Hong Kong SAR Government (2014-2015)

Member, Construction Industry Council, Hong Kong SAR Government (2010-2012)

Member, Town Planning Board, Hong Kong SAR Government (2010-2012)

Member, Advisory Council on the Environment, Hong Kong SAR Government (2009-2012)

Council Member, Internet Professionals Association (iProA) (2004-2010)

Chairman, Asia and Pacific Division (APD), IAHR (2003-2007)

Chairman, International Audit Committee for the Review of Delft Hydraulics Software Systems, WL Delft Hydraulics, Delft, Netherlands, August 2005.

Chairman, Fluid Mechanics Section, IAHR (1996-2001)

Council member, International Association of Hydraulic Engineering and Research (IAHR) (2001-03; 2005-11)

Chairman, Built Environment Panel, University Grants Committee Research Assessment Exercise (RAE) 1999, Hong Kong.

Member, Engineering Panel, Hong Kong Research Grants Council, (1993-98)

Visiting Professor, East China College of Hydraulic Engineering, Nanjing, China. (Aug. 1981; gave a one-month course in Environmental Hydraulics)

Advisory Professor, Hohai University, China. (1986-)

Visiting Associate Professor, School of Civil & Environmental Engineering, Cornell University, USA. (Aug.-Sept. 1986)

Technical Consultant, Environmental Sciences Research Center, Zhongshan University, Guangzhou (1986)

Consulting Professor, Tongji University, Shanghai (Apr. 1997 -)

Member, Advisory Council, International Research and Training Centre on Erosion and Sedimentation (IRTCES), Beijing (Oct. 1997 - 2000)

Member, Environmental Impact Assessment Ordinance Appeal Board, Hong Kong Government (1998-2007).

Member, Red Tide Experts Advisory Group, Agriculture, Fisheries and Conservation Department, Hong Kong Government (1998-2014).

Member, International Expert Advisory Panel, European Union Harmful Algal Blooms Expert System (HABES) group research project (2001-2004).

Member, Drainage Appeal Board Panel, HKSAR Government (2001-2007).

Member, Advisory Group on Waste Management Facilities, Environment, Transport and Works Bureau (ETWB), HKSAR Government (Chairman of Technology Sub-group, 2002-2005).

Member of 3-person Tribunal for the Environmental Impact Assessment (EIA) Appeal Case for the KCRC Sheung Shui - Lok Ma Chau Spur Line ('Long Valley' case), 2000-2001.

Member, Working Group on the Review of the Academic Structure for Senior Secondary Education and Interface with Higher Education, Education Commission, Hong Kong Government (2000-2003).

External assessor for Chair Professorship/senior promotion, and External Examiner for MPhil/PhD theses for many universities in Hong Kong and overseas (e.g. Imperial College London, University of Liverpool, University of British Columbia, Delft University of Technology, University of Manchester, University of Alberta, University of Canterbury, US Environmental Protection Agency, HKUST, City University of Hong Kong, Nanyang Technological University). (1996-2015)

External Examiner, M.Sc. Course in Civil Engineering, Hong Kong Polytechnic, 1990-1994.

Consultancy Appointments

Served as consultant/advisor on over 30 environmental hydraulic projects to international consulting engineers (including UK Water Research Centre, Binnie, Black and Veatch, Montgomery Watson, Ove Arup and Partners, Maunsell Consultants Asia, Walter Vivendi Joint Venture Australia, AeCOM) and Water Supplies Department, Drainage Services Department and Environmental Protection Department of Hong Kong Government. Representative projects include the Initial Dilution study for the UK Water Research Centre, River Indus Hydraulic Model Study, Sydney Deepwater Outfall post-operation monitoring, EIA study of the Hong Kong Strategic Sewage Disposal Scheme, Review of Deep Bay Water Quality Regional Control Strategy, Yuen Long Bypass Floodway, Tai Hang Tung Storage Scheme, Lai Chi Kok Transfer Scheme, and Hong Kong Harbour Area Treatment Scheme.

Professional Societies/Activities (Selected):

- Fellow, American Society of Civil Engineers.
- Fellow, The Hong Kong Institution of Engineers.
- Member, The Chartered Institution of Water and Environmental Management (IWEM), U.K.
- Chairman, Sub-Committee on Turbulence, Engineering Mechanics Division, American Society of Civil Engineers (2002-04).
- Vice-Chairman, Executive Committee, International Association for Hydraulic Research (Asia and Pacific Division), (2000-2002)
- Member, Fluid Mechanics Section, International Association for Hydraulic Research (1990-1995).
- Reviewer for Journal of Hydraulic Engineering, Journal of Environmental Engineering, Journal of Engineering Mechanics (ASCE), Journal of Hydraulic Research, Journal of Fluid Mechanics, International Journal for Numerical Methods in Fluids, Journal of Hydrology, Water Research, Limnology and Oceanography, Journal of Marine Systems, Environmental Fluid Mechanics, Proceedings of Institution of Civil Engineers (ICE), Applied Mathematical Modelling, Science in China, Marine and Freshwater Research, Ecological Modelling, Coastal Engineering, Estuarine Coastal

and Shelf Science, Marine Pollution Bulletin, US National Science Foundation, Swiss National Science Foundation, Hong Kong Research Grants Council, Hong Kong Innovation and Technology Fund.

- Member, Technical Standards Committee: Water Pollution Control (Amendment) Bill 1990, Hong Kong Government Secretariat, 1990.
- Member, Construction and Other Technologies Panel, Hong Kong University Grants Committee (UGC) Research Assessment Exercise, 1994 and 1996.
- Founding Chairman, The Hong Kong Chapter of the International Association for Hydraulic Research, April 1997.
- Member, Working Group on Upgrading of Water Quality and Hydraulic Mathematical Models, Civil Engineering Department, Hong Kong Government, 1997-98.
- Chairman, Organizing Committee, The 7th International Symposium on River Sedimentation and 2nd Int. Symposium on Environmental Hydraulics, December 16-18, 1998, Hong Kong.
- Chairman, Organising Committee, Second HKIE Symposium on the Sustainable Development of Guangdong, Hong Kong, and Macau, 8-10 April 2003, Hong Kong.
- Chairman, Organising Committee, The 14th IAHR Asia-Pacific Congress and 4th International Symposium on Environmental Hydraulics, December 15-18, 2004, Hong Kong.
- Chairman, Organising Committee, Symposium for the 10th Anniversary of IAHR-HK: "Hydrology and Water Resources with a focus upon Hong Kong and the Yangtze River, China", The University of Hong Kong, March 25-26th, 2008.
- Co-Chairman, International Scientific Committee and Chairman of Best Paper Selection Panel, 16th IAHR Asia-Pacific Congress, October 20-23, 2008, Nanjing.
- Chairman, Local Organising Committee, 6th International Conference on Asian and Pacific Coasts (APAC2011), December 14-16, 2011, Hong Kong.
- Executive Chairman, Local Organising Committee, 35th IAHR Congress, September 8-13, 2013, Chengdu, China.
- Member, Grand Judging Panel of the Hong Kong ICT Awards 2013; Chairman, Final Judging Panel of Best Collaboration Award.

Hobbies/Passion: Study Ballet; tennis; music; competitive Table Tennis.

EXTERNAL RESEARCH GRANT AWARDS

(as sole or principal investigator (PI) unless otherwise indicated)

1. *Multiport Thermal Diffusers as Line Momentum Sources in Shallow Water*, U.S. Engineering Foundation US$12,000, 1980-82.
2. *Mathematical Modelling of Marine Water Quality and Eutrophication Dynamics*, Croucher Foundation, HK$530,000, 1986-89 (Co-PI).
3. *Hydraulic and water quality modelling of Victoria Harbour, Hong Kong*, UPGC Research Grant, HK$450,000, 1989-92 (Co-PI)
4. *Mixing of Submerged Buoyant Jets in a Current*, Croucher Foundation, HK$743,240, 1991-94.
5. *Sea Water Intrusion into Tunnelled Outfalls*, Hong Kong Research Grants Council (RGC), HK$459,000, 1994-97.
6. *Hydraulics of Sediment Oxygen Demand (SOD) Chambers*, Hong Kong Research Grants Council (RGC), HK$836,000, 1995-98.
7. *Hydraulics of Duckbill Valve Jets*, Hong Kong Research Grants Council (RGC), HK$990,000, 1998-2001
8. *Environmental Management of Mariculture in Hong Kong*, Environment and Conservation Fund, HK$1,388,000, 1998-2001.
9. *Dynamics of Algal Blooms and Red Tides in Sub-Tropical Coastal Waters: Monitoring, Modelling and Prediction*, Hong Kong Research Grants Council (RGC)/Central Allocation (1998-99) (Group Research Project), HK$4,300,000, 1999-2002 (PI)
10. *Sediment-Water-Pollutant Interactions in Estuarine and Coastal Waters - with Particular Reference to Bohai Bay and Deep Bay*, Natural Science Foundation of China (NSFC)/Hong Kong Research Grants Council (RGC) Joint Research Scheme, HK$700,000, 1999-2002 (Hong Kong PI)
11. *Innovative Modelling and Visualization Technology for Environmental Assessment and Education*, Hong Kong Innovation and Technology Fund (ITF), HK$5,500,000, 2001-2003.
12. Croucher Advanced Study Institute on *Recent Developments in Coastal Eutrophication Research*, Croucher Foundation, HK$632,000, 2001.
13. *3D Modelling of Coastal Outfall Discharge in Random Wave Environment*, Hong Kong Research Grants Council, HK$610,000, 2001-2003 (Co-I).
14. *Mixing of Submerged Multiple Jet Group in Crossflow*, Hong Kong Research Grants Council (RGC), HK$480,000, 2002-2004
15. *Dynamics of Algal Blooms and Red Tides in Sub-Tropical Coastal Water*, Hong Kong Research Grants Council (RGC)/Central Allocation (Group Research Project Renewal), HK$1,500,000, 2003-04 (PI)
16. *Mixing of Rosette Jet Group from Ocean Outfalls*, Hong Kong Research Grants Council (RGC), HK$569,200, 2003-04
17. *Experimental Investigation on the Zone of Flow Establishment in a Submerged Round Jet in a Current*, Hong Kong Research Grants Council (RGC), HK$569,220, 2003-04 (Co-I)

18. *UGC Area of Excellence on Marine Environmental Research and Innovative Technology (MERIT)*, HK$45 M, 2004-2009 (Co-I)

19. *Croucher Laboratory of Environmental Hydraulics*, Croucher Foundation, HK$2 M (2004)

20. *Integrated Physical and Ecological Management of Rivers - with Particular Reference to the East River*, National Natural Science Foundation of China/Hong Kong Research Grants Council (NSFC/RGC), HK$572,800, 2004-06 (PI, Hong Kong)

21. *Data Assimilation for Forecasting of Coastal Water Quality*, Hong Kong Research Grants Council (RGC), HK$496,691, 2004-2006

22. *Investigation of Island Wake Hydraulics*, Hong Kong Research Grants Council (RGC), HK$686,715, 2004-2006 (Co-I)

23. *Hydraulics of Bottom Rack Intakes for Supercritical Storm Flow Diversion*, Hong Kong Research Grants Council (RGC), HK$436,000, 2006-2008

24. *Real Time Hydro-environmental Modelling and Visualization System for Public Engagement*, Innovation and Technology Support Programme (ITSP, Tier 3), Hong Kong Innovation and Technology Fund (ITF), HK$1,000,000, 2006-2007

25. *U21 Water Futures for Sustainable Cities* Collaborative Research Initiative, Funding for Management Costs, Universitaes 21 Secretariat, University of Birmingham, USD67,180 (Co-I; HKU share USD 7711)

26. *WATERMAN - Water Quality Forecast and Management System for Hong Kong*, Jockey Club Charities Fund, 2008-2011, HK$29.8 million.

27. *Mixing of Dense Jet in a Current*, Hong Kong Research Grants Council (RGC), HK$392,576, 2008-2010.

28. *Hydraulics of Horizontal Sediment-laden Jet*, Hong Kong Research Grants Council (RGC), HK$375,316, 2008-2010 (Co-I)

29. *Recent developments in nearshore coastal water quality research: prediction, hydro-biological interactions and management*, Croucher Advanced Study Institute (ASI) HK$602,000, Croucher Foundation, 2009.

30. *Renewal of UGC Area of Excellence on Marine Environmental Research and Innovative Technology (MERIT)*, HK$20.5 million (+20.5M matching), 2009-2012 (Co-I)

31. *Fluid mechanics of tangential vortex intakes*, Hong Kong Research Grants Council (RGC), HK$642,500, 2009-2012.

32. *Air-water interaction in vortex intakes and drainage tunnels*, Hong Kong Research Grants Council (RGC), HK$500,000, 2014-2016.

33. *Smart Urban Water Supply Systems*, Theme-based Research Scheme, Hong Kong Research Grants Council (RGC), HK$33.26 million, 2016-2020 (Co-PI).

PUBLICATIONS:

Books/Edited Volumes:

1. Wei H.P., Lee, J.H.W. and Qian, D.R., *Hydraulic Modeling Practice in Environmental Engineering*, China Ocean Press, 2001, 344 pp. (in Chinese, ISBN 7-5027-5273-0)

2. Lee, J.H.W. and Chu, V.H., *Turbulent jets and plumes - a Lagrangian approach*, Kluwer Academic Publishers, 2003, 390 pp. (ISBN 1-4020-7520-0).

3. Wang, Z.Y., Lee, J.H.W. and Melching, C.S., *River Dynamics and Integrated River Management*, Springer, 2013, 600 pp.

4. Lee, J.H.W. and Cheung, Y.K. (ed.), *Proceedings of the International Symposium on Environmental Hydraulics*, Hong Kong, December 16-18, 1991: A.A. Balkema, Netherlands 1991, Vol. 1 and 2, 1659 pp. (ISBN 90-5410-038-9)

5. Cheung, Y.K., Lee, J.H.W. and Leung, A.Y.T. (ed.), *Proceedings of the Asian Pacific Conference on Computational Mechanics*, Hong Kong, December 11-13, 1991: A.A.Balkema, Netherlands 1991, Vol. 1 and 2, 1813 pp. (ISBN 90-5410-029)

6. Chwang, A.T., Lee, J.H.W. and Leung, D.Y.C. (ed.), *Hydrodynamics - theory and applications*, Proc. of the Second International Conference on Hydrodynamics, Hong Kong, December 16-18, 1996: A.A. Balkema, Netherlands 1996, Vol. 1 and 2, 1366 pp. (ISBN 90-5410-860-6)

7. Lee, J.H.W., Jayawardena, A.W. and Wang, Z.Y. (ed.), *Proceedings of the Second International Symposium on Environmental Hydraulics*, Hong Kong, December 16-18, 1998: A.A. Balkema, Netherlands 1999, 976 pp. (ISBN 90-5809-035-3)

8. Jayawardena, A.W., Lee, J.H.W., and Wang, Z.Y. (ed.), *Proceedings of the Seventh International Symposium on River Sedimentation*, Hong Kong, December 16-18, 1998: A.A. Balkema, Netherlands 1999, 1012 pp. (ISBN 90-5809-034-5)

9. Lee, J.H.W. (Ed.), *Special Issue on Environmental Hydraulics, Journal of Hydraulic Research*, Vol.39, No.6, 2001, pp.563-666.

10. Lee, J.H.W. and Lam, K.M. (ed.), *Environmental Hydraulics and Sustainable Water Management*, Taylor and Francis, London, 2005, 2315 pp. (ISBN 04-1536-546-5)

11. Lam, K.M. and Lee, J.H.W. (Guest Editors), *International Journal of River Basin Management*, Vol.4, No.1, 2006, pp.1-73.

12. Fang, H.H.P. and Lee, J.H.W. (Editors), *Sustainable and safe water supplies*, Water Science and Technology: Water Supply, Vol.7, No.2, 2007, 220 pp.

13. Lee, J.H.W. and Ng, C.O. (Editors), *Asian and Pacific Coasts 2011*, Proc. of the 6th International Conference on Asian and Pacific Coasts (APAC 2011), December 14-16, Hong Kong, 2011, World Scientific Publishing Co., 2153 pp.

Journal Papers/Book Chapters

1. Lee, J.H.W. and Jirka, G.H., Discussion of "Horizontal buoyant jets in quiescent shallow water", by V. Balasubramanian and S. Jain, Journal of the Environmental Engineering Division, Proc. ASCE, Vol.105, EE4, August 1979, pp.790-792.

2. Lee, J.H.W., Jirka, G.H., Harleman, D.R.F., "Heat recirculation induced by thermal diffusers", Journal of the Hydraulics Division, Proc. ASCE., Vol. 105, HY10, 1979, pp.1219-31.

3. Lee, J.H.W., "Near field flow generated by a thermal diffuser in shallow water", *Developments in Theoretical and Applied Mechanics*, Vol. 10, April 1980, pp.373-396.

4. Lee, J.H.W. and Jirka, G.H., "Multiport diffuser as line source of momentum in shallow water", Water Resources Research, Vol. 16, No. 4, August 1980, pp.695-708.

5. Lee, J.H.W., "Near field mixing of staged diffuser", Journal of the Hydraulics Division, Proc. ASCE, Vol. 106, No. HY8, August 1980, pp.1309-1324.

6. Lee, J.H.W., "An Hourglass Experiment", International Journal of Mechanical Engineering Education, Vol. 9, No. 1, 1981, pp.39-46.

7. Lee, J.H.W. and Jirka, G.H., "Vertical round buoyant jet in shallow water", Journal of the Hydraulics Division, Proc. ASCE, Vol. 107, No. HY12, 1981, pp.1651-1675.

8. Liu, P.L.F., Ligget, J.A. and Lee, J.H.W., "Boundary integral equation solutions to moving interface between two fluids in porous media", Water Resources Research, Vol. 17, No. 5, October 1981, pp.1445-1452.

9. Lee, J.H.W., "Internal hydraulic jump in stratified counterflow", Journal of the Engineering Mechanics Division, Proc. ASCE, Vol. 108, No. EM5, October 1982, pp.986-990.

10. Lee, J.H.W. and Jirka, G.H., Reply to discussions of "Vertical round buoyant jet in shallow water", Journal of Hydraulic Engineering, ASCE, Vol. 109, No. HY3, 1983, pp.494-496.

11. Yu, T.C. and Lee, J.H.W., "An upwind shallow water circulation model", Chinese Journal of Oceanology and Limnology, Vol. 2, No. 1, 1984, pp.20-33.

12. Lee, J.H.W. and M.D. Greenberg, "Line momentum source in shallow inviscid fluid", Journal of Fluid Mechanics, Vol.145, August 1984, pp.287-304.

13. Lee, J.H.W., "Boundary effects on a submerged jet group", Journal of Hydraulic Research, Vol. 22, No. 4, Sept. 1984, pp.199-216.

14. Lee, J.H.W., "Comparison of two river diffuser models", Journal of Hydraulic Engineering, ASCE, Vol. 111, No. 7, July 1985, pp.1069-1078.7

15. Li, C.W. and Lee, J.H.W., "Continuous source in tidal flow - a numerical study of the transport equation", Applied Mathematical Modelling, Vol. 9, August 1985, pp.281-288.

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EXPERT REPORT

PREPARED BY

PROFESSOR JOHN FAWELL

Expert Witness appointed by the Commission of Inquiry into Excess Lead Found in Drinking Water

4 February 2016

Professor John Fawell

Biologist/Toxicologist

(Consultant on drinking water and environment)

Specialist Field	:	Assessment and management of risks from drinking water contaminants.
Appointed on behalf of	:	The Commission of Inquiry into Excess Lead Found in Drinking Water (the "**Commission**")
Prepared for	:	The Commission
On instructions of	:	Messrs. Lo & Lo, Solicitors for the Commission ("**Lo & Lo**")
Subject matter / Scope of engagement:	:	To assist the Commission in discharging its duties under the Terms of Reference and by acting as an expert witness in the inquiry hearings
Documents reviewed	:	Selected documents from the Hearing Bundles
Date of Inspection of some of the Affected Estates (*name of the estates*)	:	**10 November 2015** Kwai Luen Estate Phase 1 (Luen Yat House) Kai Ching Estate Phase 2 (Hong Ching House) Tak Long Estate (Tak Long House)
Other Site Visits	:	**9 November 2015** Shatin Water Treatment Works Government Laboratory **12 November 2015** Ngau Tam Water Treatment Works Hong Kong University of Science and Technology (Materials Characterization and Preparation Facility and Health, Safety & Environment Laboratory)

Instructions

I have been instructed to give my opinion on the matters under the Terms of Reference of the Commission.

In providing my opinion, I have also been instructed to consider the following areas and undertake the following tasks:

(a) review and verify the findings of the Interim and Final Reports of the Task Force led by the Water Supplies Department (WSD) in respect of the Waterworks system and the Inside Service system in public rental housing developments, including the overall methodology adopted in the investigation;

(b) identify and explain the international standards (particularly those laid down by the World Health Organisation (WHO)) in respect of the following matters for the purpose of ensuring safety and quality of drinking water in Hong Kong :

- (i) hazards and hazardous events;
- (ii) risk assessment, prioritization and management;
- (iii) control measures;
- (iv) construction and maintenance;
- (v) inspection and monitoring;
- (vi) management procedures;
- (vii) rectification;
- (viii) the supply and use of plumbing materials; and
- (ix) the procedures and protocols regarding the use and installation of plumbing materials;

(c) in the context of the international standards in (b) –

- (i) review and evaluate the adequacy of the existing Water Safety Plans of the WSD;
- (ii) review and evaluate the existing regulatory and monitoring regimes (both prior and subsequent to the excess lead in drinking water incidents as a result of which new measures have been put in place by public authorities) on quality of drinking water :
  - (1) at the pre-construction stage;
  - (2) at the construction stage;

(3) at the completion of construction (before the WSD issues the certificate for water supply connection); and

(4) at the maintenance stage;

(iii) opine on whether any further metal(s), chemical(s) and/or microorganism(s) should be included as parameter(s) in addition to those set out in the WSD Circular Letter No. 1/2015 for testing of water samples, and if so, the thresholds, benchmarks and/or the acceptance criteria to be set for them; and

(iv) the effectiveness of the recommendations made by the Review Committee;

(d) opine on how the inadequacies (if any) identified for the matters above may be rectified or improved and to make recommendations with regard to the safety of drinking water in Hong Kong; and

(e) state, provide advice and recommendations on other areas of concern (if any).

Introduction

1. I Professor John K Fawell, independent consultant on drinking water and environment of Bourne End in the county of Buckinghamshire in the United Kingdom, have been appointed as one of the Commission's experts to assist the Commission in determining the matters under the Terms of Reference.

2. Lead in drinking water arises from lead leached from lead pipes, lead solder and other lead containing fittings, including brass and gun metal and also unplasticised PVC (uPVC) pipe not manufactured to current standards, i.e. containing high concentrations of lead stabilizer. It is not normally found due to contamination of source water or in water up to the boundary of buildings unless there are lead service connections or lead stabilized PVC pipe (service connections are the pipes that deliver water from the water main to the building). Leaching can be exacerbated by galvanic corrosion as a result of other metals being joined to lead and will be dependent on factors such as hardness and pH. The level of leaching can be very variable from property to property, depending on the configuration of plumbing and also on whether there are lead service connections. The concentration of lead in water is also a function of the surface area of the lead source in relation to the volume of water, so a small surface area in relation to a large volume will result in lower concentrations than a large surface area of a similar source in a similar volume. The concentration at any tap will also vary according to the temperature and the period during which the water has been in contact with the lead source. Typically first draw water will have a much higher concentration of lead but this may not reflect the concentrations of lead in water ingested in normal use. Equally, flushed samples would be expected to underestimate the concentration of lead in water ingested in normal use.

3. There are no internationally agreed sampling protocols that can truly reflect average consumption of lead from drinking water and which are reasonably practical to apply. The most effective approach is to identify whether lead is present in the pipework leading to the tap used for drinking water and cooking. This is achieved by taking samples of sufficient magnitude to provide a sample of the water in the internal plumbing that is likely to have been in contact with any lead in the system for a sufficient period of time to allow measurable

concentrations of lead to be reached. A positive result, i.e. a lead concentration close to or in excess of the WHO provisional guideline value of 10 µg/litre, or another chosen trigger value, e.g. 5 µg/litre, would then trigger an investigation as to the source of the lead, e.g. leaded solder, and the necessary remedial steps to reduce exposure. (See preliminary joint expert report 12 November 2015 **[V1/1/1-44]**). Samples taken from the freshwater roof tanks of three public housing blocks show no lead, which suggests that there are no lead service connections or lead stabilized uPVC pipes **[A1/19/658, Section 2.2.2]**.

4. The World Health Organization develops Guidelines for Drinking Water Quality, which are revised on a regular basis. The current edition is the fourth and was published in 2011 **[C2/18/1244+]**. The Guidelines outline a Framework for Safe Drinking Water, which considers the overall management of water supplies and includes the concept of Water Safety Plans which provide a proactive means of preventing and managing hazards and risks from the catchment to the point at which consumers receive their drinking water, frequently referred to as the source to tap approach **[C2/18/1277]**. The Guidelines are regarded as the scientific point of departure for the development of National Standards which should take into account the specific circumstances of the country concerned. The guideline values for chemical contaminants provide a basis for assessing the risks to health from drinking water but WHO indicates that local circumstances should always be taken into account in setting national standards and recommend that individual guideline values should be considered in the appropriate context. In this respect the statement that "A guideline value (*for a chemical constituent*) **normally** (my emphasis) represents the concentration of constituent that does not result in any significant risk to health over a lifetime of consumption"**[C2/18/1258]** should be treated with caution because it does not mean that contamination can be allowed to increase to the guideline value. In addition, some guideline values for chemicals are designated provisional and may be set at a higher value than would be the case for a strictly health-based value because of practical considerations, e.g. lead. It is appropriate to try and achieve as low a concentration of a contaminant as possible within the constraints of cost and practicality.

5. Lead has been included in all editions of the Guidelines. In the second edition, published in 1993 **[C21/175-2/18941]**, a guideline value of 10 µg/litre was

proposed for lead based on a provisional tolerable weekly intake (PTWI) developed by the WHO/FAO Joint Expert Committee on Food Additives and contaminants (JECFA), this guideline value was retained in the third edition in 2004 and 2008 **[A3/38/2101-2103]**. JECFA re-evaluated lead in 2011 and withdrew the PTWI, stating that it was not possible to establish a new PTWI that would be health protective because the dose-response analyses did not provide any indication of a threshold. The fourth edition was published in 2011 **[C2/18/1244+]** and although the guideline value of 10 µg/litre was retained **[C2/18/1246-1447]**, this was because of practicality in dealing with older systems with existing lead pipes, fittings and solder and cannot be considered in the same light as in the previous editions of the Guidelines. Lead solder was identified as a source of lead in drinking water in the second, third and fourth editions of the Guidelines **[C21/175-2/18940, A3/38/2101, C2/18/1246]**.

6. In spite of the fact that leaded solder is known to be a significant source of lead in drinking water installations in buildings and that lead solder is banned from use for drinking water systems in many countries, incidents in which lead solder has been used in new buildings continue to occur. In 1997 a new housing estate in Scotland was found to have been plumbed with copper piping installed with lead solder **[A1/14/198+ and A1/15/244+]** and in 2001 new properties in Wales were also identified has having lead solder **[A1/13/190+]**. New guidance to health professionals, with regard to lead in drinking water was issued by Health Protection Scotland in 2012, which included guidance on investigations and water sampling at the tap to identify if lead is present **[A1/12/148+]**.

(a) Review and verify the findings of the Interim and Final Reports of the Task Force led by the Water Supplies Department (WSD) in respect of the Waterworks system and the Inside Service system in public rental housing developments, including the overall methodology adopted in the investigation.

Background of the Incident

7. It is my understanding that between April and June 2015, samples of water taken from taps in some public rental housing in Hong Kong (Kai Ching Estate, Kowloon) were shown to have lead levels above the World Health Organization provisional guideline value of 10 µg/litre (0.01 mg/litre)**[A1/3/24 LegCo Paper, 21.07.2015 §2]**. This finding was in spite of the fact that, in drinking water systems in buildings in Hong Kong, there are no recently installed lead pipes, lead in the form of lead solder is not permitted and the level of lead in metal alloy fittings is restricted

[B15.1/337/37521-37522, §§30-32]. Subsequently further samples showed that some met the WHO provisional guideline value and others did not. As a consequence the Water Supplies Department (WSD) established a Task Force with the following terms of reference:

(a) To carry out investigation to ascertain the causes of the recent incidents leading to the presence of lead in water drawn by households;

(b) To recommend measures to prevent recurrence of similar incidents in future; and

(c) To follow up on a recent case of Legionnaires' Disease found at Kai Ching Estate. [**C5/69/4116**].

This last issue is dealt with separately later in my report.

Final Report of the Task Force led by the Water Supplies Department (WSD)

8. I have studied the final report prepared by the Task Force set up to investigate the source of elevated lead concentrations in drinking water in some housing units in Hong Kong **[A1/19/650+]**.

9. As a consequence I made further enquiries to ascertain the sampling protocol that had been used to take water samples at the tap to identify the proportion of affected properties. It was confirmed that where samples had been taken at the kitchen tap inside apartments the water had been flushed for 2 to 5 minutes before a sample was taken for analysis. The consequences of this approach for identifying properties in which lead solder has been used are considered in more detail below.

10. In order to answer this and other questions regarding the quality of drinking water in Hong Kong and the procedures in place to assure drinking water quality, I made a visit to Hong Kong from the 9th to the 13th November 2015. During this visit I met with staff from the WSD, the WSD led Task Force on Lead in Drinking Water, the Housing Department and the Government Laboratory. I also made two visits to Water Treatment Works in Hong Kong, WSD Laboratories and

Public Housing Developments at which investigations had been carried out. I was able to see the samples of pipework and fittings, including soldered joints and to ascertain the quality assurance procedures in place to ensure that the analysis for lead and other metals was of an appropriate standard. At all points I was afforded access to all the information that I requested and all questions were answered openly.

11. I have read statements and depositions regarding the detection of elevated concentrations of lead in drinking water in some public housing estates in Hong Kong and also on mechanisms in place in Hong Kong to ensure the safety and quality of fresh water (drinking water). These have formed the basis for my conclusions regarding the current situation in Hong Kong.

My Opinion Regarding the Investigations and Conclusions of the Task Force

12. The WSD led Task Force has carried out a thorough investigation of the affected systems using appropriate methodology. They have taken a sound systematic approach using techniques that have proved of value in similar investigations in other parts of the world such as in Scotland [**A1/14/198+ and 15/244+**]. The source of lead is confirmed as being primarily within the final stages of the distribution system inside the housing blocks, i.e. after the water meter.

13. The conclusions of the Task Force that lead solder used for soldering copper pipe joints is the major cause of the lead concentrations that were shown to exceed the WHO guideline value is supported by the evidence presented and the results from the investigations carried out by and on behalf of the Task Force.

14. Detailed examination has revealed that in some places solder containing very high levels of lead (basically lead solder) has been used in installing copper pipe and fittings [**A1/19/667, section 2.5.10**]. This lead solder has resulted in the deposition of lead carbonates and hydroxides downstream of soldered joints on the inside of the pipes [**A1/19/665-666, section 2.5.5**].

15. Static tests have shown significant leaching of lead from these joints. In view of lead concentrations greater than 10 μg/litre observed in some flushed tap samples, I would conclude that there is the additional possibility of particles of lead carbonates/hydroxides appearing in water samples taken to assess lead

concentrations at the tap. A number of copper alloy fittings were also shown by elemental analysis to contain more lead than would be allowed if they were to meet the requirements of the relevant British Standard **[A1/19/691, section 3.3.2 and A1/19/779-781, Annex 3.2]**. However, all copper alloy fittings do contain some lead and leach some lead into water, although at very much lower rates than lead solder **[A1/19/ 664, 666, 668-671, section 2]**.

16. Isotope analysis of the lead in the water does, however, confirm that lead solder is the main source of the lead in the water where elevated concentrations of lead have been found **[A/19/674-677, section 2.9]**.

17. The potential for cumulative leaching of lead from copper alloy fittings, valves, water meters and taps, appears to be small in relation to the leaded solder joints, although there are copper alloy fittings containing a greater proportion of lead in the alloy than permitted by the relevant British Standard. A number of the copper alloy fittings are associated with the down pipe and here the surface area available for leaching in relation to the volume of water is small. In addition the down pipe is unlikely to have extended periods of zero flow. This means the concentration of lead in the water will be small. The contribution of copper alloy fittings will primarily come from the meter to the tap and the volume of water is small enough to allow it to be flushed quite quickly and the contribution to lead concentrations will be much lower than lead solder joints. In the absence of lead solder the concentrations will be much lower, although lead may be detected at low concentrations. The modelling carried out by the Task Force supports the conclusion that, although these components do contribute to the lead in water, they on their own are very unlikely to result in concentrations in excess of the WHO provisional guideline value [**A/19/687-689, Section 3.1, § 3.1.7**].

18. In paragraph 3.2 of the Task Force Report **[A1/19/689-690]**, the Task Force considered that the design of the inside service and the specifications of the pipes and fittings in the other 9 affected developments were similar to Kai Ching and Kwai Luen Estates and suggest that all findings in the report should be applicable to all the 11 affected developments. The design, construction of and the contractors used in building all of the 11 estates were similar and there is no clear evidence to suggest that the level of supervision of the plumbing installations was greater or less than with Kai Ching and Kwai Luen,

Consequently, it is reasonable to make a worst case assumption that the findings of the report would apply to all of the developments and to assume that lead solder was also used in those developments. While sampling and examination of the additional estates would have taken more time and delayed the publication of the report and the process of identifying suitable remedial actions, the assumption would need to be confirmed by further testing for lead solder in joints or by suitable water sampling.

19. Samples taken from water supplies in a number of housing blocks might be considered to show that the extent of contamination giving rise to lead concentrations above the WHO provisional guideline value is limited **[A2/915+]** but these findings must be treated with caution because the approach used for taking samples may underestimate the presence of lead.

Sampling Protocol of the WSD and the WSD Task Force

(a) WSD

20. According to information provided by the WSD [WSD Sampling Manual 2014 **(C2/22/1635+)**, and in particular **Section 7** thereof **(C2/22/1666-1669)**, Water Sampling Procedure with reference to ISO5667 Part 5 **(C5/45/3735+)** and Fourth Witness Statement of Chan Kin Man **(C19.6/145/14517+)**], the practice of taking samples for water quality testing in Hong Kong has been based on using samples in which the system is flushed i.e. the pipes were flushed for 2-5 minutes or longer if necessary at a uniform rate before samples were collected **[C19.6/145/14518** and **C5/45/3735]**. Where the sample is to be taken from a consumer's tap, the water actually sampled is likely to represent the water as supplied from the public water supply distribution system, or at least the water in the roof storage tank and down pipe, and does not fully reflect the water in the internal distribution system that has been in contact with the associated plumbing after the meter for an extended period of time. While this is appropriate for examining the water quality parameters that will not be affected by the internal distribution system, it is not suitable to ascertain the concentration of parameters that will change as a result of contact with or which arise wholly from the internal distribution system. These last parameters include, lead, copper, nickel and sometimes cadmium and zinc where galvanised pipes have been used, as was the case in Hong Kong in the past and possibly antimony. While it is quite possible that there is only limited contamination with lead in the public housing

stock, the data cannot be used to conclude that under normal conditions of use there is no possibility of the WHO guideline value being exceeded in any sample unless it is known and verified that plumbing standards were met during construction or alteration, i.e. no leaded solder was used and fittings all meet the requirements for low lead. In this case there is no need to take water samples for lead because no source of excessive lead will be present in the system. Equally, because lead concentrations can vary widely over a 24 hour period, compliance with the guideline value cannot be assured with single samples, unless these reflect the worst case.

21. It is not possible to identify a threshold for the adverse effects of lead so there should ideally be no measurable lead in drinking water. WHO recognises that this is not practical because there will be many existing systems with lead service connections or lead pipe from a time when the adverse effects of lead were not fully recognised. It is not possible to get to average concentrations well below the provisional guideline value in such systems just by treating the water to reduce plumbosolvency (the tendency of the water to dissolve lead) by such means as dosing orthophosphate. It is not intended that meeting the guideline value should be an excuse to install new lead, which best practice dictates should not happen, hence the strictures on lead solder and copper alloy fittings in Hong Kong. Meeting the guideline value is not a means of protecting health, it is a means of reducing exposure while further actions can be taken to remove lead from the systems and to achieve as low a level of lead exposure from drinking water as possible. The situation in the new Hong Kong public housing developments is different to other older systems since the use of lead solder and "high lead" copper alloy fittings is not allowed and there should be no lead in the system except traces that arise from copper alloy fittings that meet the requirements for low lead. The object of sampling water at consumers' taps in this case should be to identify where lead solder may have been used.

22. If the lead concentration in the water after an extended period of contact is less than 10 μg/litre then it is reasonable to assume that the concentration will always be less than 10 μg/litre and there is unlikely to be significant lead in the system. The study carried out by Professor Lee on behalf of the Commission of Inquiry was designed to determine how the time the water flows will impact on the concentrations of lead in a range of domestic systems in the public housing

developments and to inform the development of a suitable sampling protocol. It also provides supporting data regarding the presence of lead in significant concentrations in the public housing developments.

23. In the interim report issued by myself and Professor Lee we used the term fully flushed in the context of lead in domestic plumbing between the meter and the tap indicating that the system is likely to be flushed after 5 minutes and the water sampled would be from the down-pipe from the fresh water storage tank with a minimal contact time with the plumbing.

24. Mr Chan in his fourth statement **[C/19.6/14517-14529]** states that samples taken after a period of stagnation cannot be considered representative of the average concentration of lead at the tap to which the consumer is exposed on a routine basis. This is correct but neither can flushed samples. This is dealt with above in more detail in paragraphs 2 and 3. Mr Chan also makes a statement in paragraph 11 of his fourth statement regarding compliance with the WHO guidelines, or rather the guideline values. This is a misunderstanding of the guideline value for lead and I have dealt with this in more detail in paragraph **21** of this Report.

25. Under the circumstances described above, the most probable cause of the lead exceeding 10 μg/litre in flushed samples is particles of lead compounds mobilised by the flushing process from the deposits downstream of the joints containing lead solder.

(b) WSD Task Force

26. The investigations of the Task Force into the effects of stagnation and flushing of water in pipework on lead concentrations are helpful in making a preliminary assessment of the impact of the intermittent use of water by consumers on the average exposure to lead in water over time, i.e. the effect of the normal use of water from the drinking water tap on lead concentrations. The Task Force commissioned studies showed that the concentration of lead in affected systems increased significantly with the period of stagnation in the pipes but that the concentration fell very quickly with a relatively short flushing time due to the short lengths of pipe involved **[A1/19/685-686, section 2.12 and A1/19/685-773, Annex 2.8]**. While much of the water consumed would be expected to have contained low lead concentrations, concentrations in the initial quantities of

water drawn after standing for extended periods would be expected to contain much higher concentrations of lead as would water drawn from the hot water supply **[C19.6/140/14205+]**. The quantity of lead ingested would depend on individual habits. This is demonstrated by the evidence given by four residents who described their patterns of use of water for drinking and cooking and who fall into two categories, those who flush the water for a period in the morning and those who use first draw water **[AC1/7-10/46-76]**. However, this evidence does not provide sufficient information to estimate the potential for exposure to lead contaminated water through the day following varying periods of standing time.

27. The study by Professor Lee has provided significant data that assists both in assessing the extent of lead contamination and the short to medium term means of ameliorating the problem. This is the most comprehensive study carried out to date and allows a number of important conclusions to be drawn. Firstly, the extent of contamination is significantly greater and more widespread than was indicated by the WSD/HD data, primarily because the sampling method was designed to detect the presence of lead in the system. Secondly, a relatively short flushing period will generally reduce the lead in the drinking water drawn from the tap to a low level, although the necessary flushing period required does vary. It would be helpful to make a more detailed study of the patterns of stagnation and use throughout the day in order to formulate the best advice to consumers as to how to manage lead concentrations in their domestic systems. Thirdly, the study provides some evidence that there may be passivation (reaction of lead at the surface forming coatings of lead carbonates, hydroxides and phosphates) of the exposed lead surfaces over time in the older systems resulting in a lower level of leaching. However, changes in the water system can destabilize these layers and this has caused problems elsewhere, e.g. USA. Fourthly, the study shows that the problem is complex and that care will be required in designing a sampling protocol that is suitable for verifying that lead has not been used in new developments. This is important for the quality assurance procedures to be adopted in the future.

Task Force Recommendations

28. I am generally in agreement with the recommendations of the Task Force **[A1/19/702-704, Chapter 5]**.

29. In the case of recommendation a (ii) **[A1/19/703]**, I would stipulate that samples for heavy metals should not be based on flushed samples but that a suitable sampling regime should be adopted that will reflect a reasonable worst case for the leaching of heavy metals. In addition I would recommend adding copper, antimony and zinc to the list of metals for a limited period until sufficient data are collected to show exactly which metals are leached from the system. Copper can leach from copper piping used in internal plumbing systems and is known to cause acute gastric irritation when concentrations exceed about 2 mg/litre, which is the WHO guideline value. Copper is usually only a problem in new copper plumbing systems after extended periods of standing although other circumstances can give rise to high copper concentrations. Antimony is seen in samples at the tap in Europe and although concentrations are relatively low (5 µg/litre or less) it would be prudent to collect some information on concentrations at the tap in Hong Kong. Zinc may be released from galvanised pipes and although it is not a concern for health it can cause problems with acceptability at concentrations above about 3 mg/litre. If antimony, zinc, cadmium and possibly chromium are subsequently shown not to be an issue in Hong Kong, then they could be dropped from the monitoring suite of parameters influenced by leaching from distribution systems. However, it would be prudent to maintain the full suite for initial samples taken from new buildings to ensure there are no unexpected sources.

(b) identify and explain the international standards (particularly those laid down by the World Health Organisation (WHO)) in respect of the following matters for the purpose of ensuring safety and quality of drinking water in Hong Kong :

(i) hazards and hazardous events;
(ii) risk assessment, prioritization and management;
(iii) control measures;
(iv) construction and maintenance;
(v) inspection and monitoring;
(vi) management procedures;
(vii) rectification;
(viii) the supply and use of plumbing materials; and
(ix) the procedures and protocols regarding the use and installation of plumbing materials

The WHO Provisional Guideline Value for Lead

30. The WHO guideline value of 10 µg/litre was originally based on a provisional tolerable weekly intake (PTWI) of 25µg of lead per kilogram of body weight in

infants and children on the basis that lead is a cumulative poison and there should be no accumulation of body burden of lead. The guideline value was derived by assuming a 5 kg formula-fed infant, considered to be the most sensitive sub-group of the population, drinking 0.75 litres per day and assuming 50% of the PTWI came from water. The PTWI was developed by the WHO/FAO Joint Committee on Food additives and Contaminants (JECFA) in 1986. This guideline value was adopted in the second edition of the Guidelines in 1993 **[C21/175-2/18941]** but was designated as provisional in the fourth edition in 2011 **[C2/18/1244+, see 1258 and 1446]** on the basis of the JECFA re-evaluation of the PTWI in 2011. In that re-evaluation JECFA concluded that there is currently no measurable threshold for effects on childhood IQ and learning or on systolic blood pressure. The previously established PTWI was withdrawn and it was not considered possible to establish a new PTWI that would be considered protective of health. The reason for WHO retaining the existing guideline value was that it is extremely difficult to achieve a lower concentration in systems by central conditioning, such as phosphate dosing **[A1/17/422-424]**. This consideration is based on systems with a significant existing amount of lead but it presumes that no lead will be introduced into new systems that should be effectively lead-free.

Legionella

31. *Legionella* are heterotrophic bacteria that are found in a wide range of aquatic environments. They are all considered to be potential pathogens for man. *Legionella pneumophila* is the cause of Legionellosis, a severe form of pneumonia, and Pontiac fever, which is milder and usually self limiting with flu-like symptoms. The route of transmission is almost invariably by inhalation of infected droplets of water that carry organisms. *Legionella* are unusual for water borne pathogens in the route of infection and the fact that they grow readily in biofilms and sediments at temperatures between about 25° C and 50° C. They can and do infect water systems in buildings, mostly associated with biofilms and frequently in association with free living amoebae, where these are present.

32. The best approach to prevention is considered to be management of water in buildings and in this case water in the hot and possibly cold water distribution systems in buildings. Disinfection and temperature control are normally the way this is managed but it should be noted that monochloramine is a more effective

disinfectant in this regard than free chlorine, probably because it is more effective at penetrating biofilms.

33. There is a clear potential for the growth of *Legionella sp* in apartment blocks in Hong Kong and this requires a suitable building management plan to be formulated and properly executed. Such a plan should also include advice to tenants regarding regularly cleaning items, such as shower heads, that can generate aerosols and in which biofilms can thrive. The recommendations from the WA that tanks in housing blocks should be cleaned every 3 months [**C20.1/167-1/15545**] is to be welcomed but it would be best to develop a comprehensive strategy for managing the internal fresh water supply in large buildings to prevent *Legionella*.

Description of the WHO Guidelines for Drinking Water Quality as the International Norm

34. The World Health Organization develops Guidelines for Drinking Water Quality which are revised on a regular basis. The current edition is the fourth and was published in 2011 [**C2/18/1244+**]. The Guidelines for Drinking Water Quality were first published in 1984 and superseded the International Standards for Drinking Water. The change from Standards to Guidelines was in recognition that the WHO Guidelines had no legal force and there was a need for member states to develop their own legally enforceable drinking water standards taking into account local requirements and local circumstances. WHO do not encourage member states to simply adopt the guideline values as standards without due consideration of the local situation.

35. The Guidelines have evolved over time and in 2004 introduced the concept of the Guidelines as a framework for safe drinking water. It was recognised that assuring safe drinking water requires more than simply measuring microbial indicators and standards for individual chemicals in the water as supplied (often termed end of pipe monitoring). The concept of water safety plans was introduced in order to encourage a proactive preventive approach to managing risks to drinking water from the catchment to the point at which consumers receive their drinking water, frequently referred to as the source to tap approach. [**A3/38/1687+, Chapter 4**].

36. Water Safety Plans (WSP) require a system assessment from catchment to tap, identifying hazards, assessing risks from those hazards, establishing mitigation measures and ensuring that the measures are working. It also includes monitoring and surveillance, usually by an independent authority or regulator. There are recommended supporting activities such as ensuring that materials in contact with drinking water do not cause degradation of the quality of the supply or introduce new risks to health. The Guidelines are supported by a range of documents including a Water Safety Plan Manual and documents such as Water Safety in Distribution Systems and Water Safety in Buildings **[A2/35/1066+ and 36/1230+]** and Health Aspects of Plumbing **[A4/50/2590-2728]**. The Guidelines emphasise the need for close stakeholder liaison with different groups who have responsibility for different parts of the water supply or who have influence on the water supply.

37. The Guidelines are regarded as the scientific point of departure for the development of National Standards providing guidance on microbiological, chemical and radiological quality and on acceptability to consumers. The guideline values for chemical contaminants provide a basis for assessing the risks to health from drinking water but WHO indicates that local circumstances should always be taken into account in setting national standards and recommend that individual guideline values should be considered in the appropriate context. In this respect, and as mentioned above, the statement that "A guideline value (*for a chemical constituent*) **normally** (my emphasis) represents the concentration of a constituent that does not result in any significant risk to health over a lifetime of consumption"**[C2/18/1258, §1.1.4]** should be treated with caution because it does not mean that contamination can be allowed to increase to the guideline value. In addition some guideline values for chemicals are designated provisional and may be set at a higher value than would be the case for a strictly health-based value because of practical considerations. It is appropriate to try and achieve as low a concentration of a contaminant as possible within the constraints of cost and practicality. WHO has introduced the concept of health-based values for a number of potential contaminants rather than formal guideline values. This approach will, for example, include pesticides to discourage simply copying the list of guideline values into national standards.

38. Chemicals present in water can vary significantly between water sources, and because water supplies vary significantly in size and resources, the Guidelines emphasise the need to be selective and to prioritise chemicals so that the most important for the country or local region are considered for inclusion in national standards and monitoring programmes. The most important parameters should be identified during the hazard and risk assessment phases of the Water Safety Plans. Monitoring programmes for chemical contaminants should be designed to provide the greatest focus on those parameters that are likely to be present in significant concentrations. Sampling points should reflect whether the parameter is likely to change between the treatment works and the tap. Those substances that either change in distribution such as trihalomethanes or are introduced from materials in the distribution system, such as lead, should be monitored close to or at the tap to reflect the worst case. Sampling frequency should reflect the variability of the concentration of a parameter over time. However, WHO emphasises that the Guidelines do not cover all possible chemical contaminants and other contaminants identified as a risk under the Water Safety Plan may need to be considered.

39. The International Organization for Standardization (ISO) also develops standards that may contribute to the process of assuring drinking water quality. These standards provide guidance in the field of water quality, including definition of terms, sampling of waters, measurement and reporting of water characteristics, including numerous standards relating to analytical methods, but it specifically excludes standards on the limits of acceptability for water quality.

40. As part of the process of developing Water Safety Plans it is important to identify hazards, which are pathogenic microorganisms or chemicals, including radionuclides, which are of possible concern for health or which could render drinking water unacceptable to consumers. In the process of understanding the water supply it is also considered important to identify hazardous events. These are circumstances in which the probability of a hazard reaching consumers at concentrations of concern is increased. Examples would be heavy rainfall resulting in a significant increase in raw water turbidity or the number of pathogens in raw water, a failure in a treatment process, a sudden drop in mains pressure allowing ingress of contamination, the installation of inappropriate

materials such as lead solder or cross connections between drinking water systems and salt water or wastewater systems.

41. In each case when deciding the preventive or mitigation measures necessary it is usually appropriate to consider the possible risks associated with a particular hazard, taking into account existing barriers and mitigation procedures such as water treatment. In this case it is important to consider the likelihood of a hazard reaching the consumer and the severity of the outcome. While this may be related to health, such as disease caused by pathogens, it may also be related to the effects on consumer acceptance of the water or the probability of exceeding a standard or guideline value. This process allows prioritization of those hazards that are of greatest concern and for which management steps are the most important. It also allows prioritization of monitoring for chemicals so that the focus is on the most important. Normally managing the risks begins in the catchment but much of Hong Kong's water comes from catchments outside the control of the Hong Kong authorities. Even when this is the case some understanding of the probable hazards in the catchment and their risks is still necessary for establishing the appropriate barriers by blending sources or in treatment and the ability of those barriers to meet the challenges when they are at their greatest. These hazards may or may not be covered by guideline values.

42. There is a clear difference between the ways in which the risks from pathogens are considered compared to the ways in which chemical contaminants are considered. Pathogens pose an acute risk, i.e. a single exposure through ingestion of water containing pathogens can lead to disease in susceptible individuals. Even after exposure has stopped, if infection has taken place the disease will develop. This is not the case with most chemicals for which extended exposure at a sufficiently high concentration would be required to cause adverse effects on health and those effects might not be obvious. The exposure period may be for weeks to months in the case of a chemical like lead, to years in the case of a chemical such as arsenic. For many chemicals there is no direct evidence that they do cause adverse health effects through consumption of drinking water but there is indirect evidence that they can cause harm if exposure is great enough. The guideline values for chemicals are developed to provide a benchmark against which to judge concentrations of concern and there is usually a significant margin of safety built into these guideline values. There are exceptions and lead is one of

those since the provisional lead guideline is not based directly on health but on what can be achieved by treatment without removal of all lead in the system.

43. Pathogens can take the form of bacteria, viruses or protozoa, such as *Cryptosporidium* but these cannot be easily measured and so the absence of indicators of faecal contamination in 100mls of water is used, i.e. *Escherichia coli* (*E. coli*) or *Enterococci.* Meeting the guideline values for microbiological quality does not, on its own, assure microbiological safety. They are indicators of the potential for faecal pathogens to be present but rely on very small samples in relation to the total amount of water supplied. By the time results are available the water will most probably have reached the consumer. The numbers of pathogens can be highly variable in space and time and a single exposure can lead to disease, particularly since the infective dose can be very small. As a consequence the approach to assuring safe drinking water is also to monitor operational parameters such as turbidity and free chlorine to ensure that barriers such as treatment processes are operating at their optimum at all times with a rapid response to correct the system when the operational parameters start to indicate that the processes are becoming less than optimum.

44. Other microbial indicators are used, such as total coliforms or plate counts of heterotrophic bacteria. These are not indicators of the presence of pathogens but can be general indicators of ingress into the distribution system, a change in the system or deterioration in water quality. In certain cases a sharp increase in plate counts can be an indicator of the presence of opportunist pathogenic bacteria such as *Pseudomonas aeruginosa* which can grow in distribution or in water systems in buildings.

45. The control measures outlined above should start in the catchment with the prevention or amelioration of contamination of the source. Where this is not possible or inadequate, water treatment processes may be installed and monitored to ensure that they continue to work efficiently. Prevention of contamination of the drinking water in distribution requires that the system is properly maintained and operated. This would include prevention of ingress of contaminated water into service reservoirs and distribution, and management procedures to operate the distribution system to minimise risks, for example

operating valves to minimise surges. Control measures also include preventing contamination from materials and chemicals in contact with drinking water.

46. The Guidelines recommend that chemicals and materials in contact with drinking water should be of an appropriate quality to prevent contamination of water by chemicals leaching in significant quantities from the materials, i.e. that cause or contribute to a failure of a standard or guideline value. However, it should be borne in mind that concentrations of chemicals should always be kept as low as is feasible within the constraints of cost and resources. While there is no formal international approval scheme for materials in contact with drinking water, there are a number of approval systems in place in different countries and these can form the basis of assuring the suitability of chemicals and materials more widely, for example, NSF International in North America and Regulation 31 of the Water Supply (Water Quality) Regulations 2000 managed by the Drinking Water Inspectorate ("**DWI**") in the UK. The European Union is also discussing the establishment of an EU wide scheme. There are also systems to ensure that materials used in buildings do not result in contamination or deterioration of the quality of the supply, for example the Water Regulations Advisory Scheme (WRAS) in the UK. All of these schemes require that materials and/or fittings are submitted for testing to demonstrate that they will not result in contamination of the water. NSF also carries out inspections of factories and all require some retesting at various intervals to demonstrate that the quality has not changed. NSF has their own testing laboratories but the UK regulation 31 allows the testing to be carried out by accredited laboratories. In all cases, any change in the formulation of materials or in manufacturing practice must be notified and if necessary retesting will be required to retain approval. By specifying the use of approved materials, such as those meeting specified British Standards, Hong Kong has in place the fundamental structure to take advantage of other approval systems without the cost and difficulties associated with establishing a separate scheme. The problem has been the implementation of the existing arrangements for listing acceptable (approved) products and ensuring that the lists are both current and easily accessible. The introduction of a modern website that categorises different materials and fittings in accordance with their purpose and where they are used with a listing of approved products would be helpful, easy to use and encourage submission of locally manufactured materials and fittings to one of the designated approval procedures. The site would also be a useful way of

explaining why using approved products is important. Currently this process is the responsibility of the WSD/WA but it is essential that the process and the requirement are taken seriously. However, no system will be truly effective unless there is enforcement of the rules.

47. The Housing Authority (HA) specify in their contractual arrangements that low lead copper alloy fittings and lead free solder should be used. However, there also needs to be an active process by which checks are made that the requirements are being met. This is the responsibility of the HA but, because there appeared to be a lack of understanding of the importance of the specification, clear allocation of this supervisory task does not seem to have taken place. The HA must understand and act upon the contractual requirements for construction and not just assume that because it is in the contract it will happen. If staff in the HA are unaware or unsure why a contractual requirement is included then this should be rectified before the contract is let. The proposals from HA and discussions with senior HA staff during my visit show that the HA do now understand the problem and are taking steps to correct the situation. The HA Review Committee have made a number of appropriate and constructive suggestions to improve this situation **[B15.4/398/40288+]**. However, significant responsibility also lies with the main contractor to ensure that both it and its sub-contractors fulfil the requirements of the contract. In this respect, Licensed Plumbers also have a key role in ensuring that their plumbing workforce has been properly trained and comply with the specifications for the materials to be used. Part of the tender process should also be a demonstration that quality assurance procedures are in place and are sufficiently robust to deliver the requirements of the contract in all areas. In this case, none of the responsible parties had carried out the basic checks. It would seem that it is particularly unfortunate that the Licensed Plumbers who should have been fully aware of the potential for using the wrong kind of solder, which is both cheaper and easier to use, did not ensure that installation of plumbing met all the specifications of the contract. Once the labels have been removed and solder cut into strips, it is difficult to identify leaded solder from unleaded. The suggestion by HA that it may be appropriate to have central purchasing of items such as unleaded solder has considerable merit. However, if there are circumstances in which leaded solder can be used on non-potable systems then appropriate steps will need to be taken to ensure the unleaded and leaded solders are kept apart and the two cannot get mixed up.

Effectively the responsibility for monitoring what is actually being used, both unleaded solder and low lead copper alloy fittings, lies with the main contractor and the Licensed Plumber(s). The HA has a higher level supervisory role but this role is key in the early stages of a contract ensuring that the main contractor or its sub-contractors are proposing to use appropriate approved materials and are aware of their responsibility to ensure that there is no deviation during construction.

48. The Benchmarking Study of Overseas Regulations and Practices on Management and Control of Inside Plumbing Services identifies a number of schemes along with different practices regarding licensing and certification of plumbers **[C19.6/143/14398+]**. I broadly agree with the conclusions from that study but I have reservations regarding reliance on testing post installation. Hong Kong has procedures in place to ensure that inappropriate materials are not installed, at least in public housing and these procedures should be simplified and strengthened. There should be consequences for Licensed Plumbers, who do not properly fulfil their responsibilities with regard to using craft trained plumbers who will carry out much of the actual work, e.g. removal of license or suspension of license with a requirement for re-examination and demonstration of competence over a suitable period, reflecting the severity of the breach of conditions, before the license could be restored. There should also be a requirement for all Licensed Plumbers to attend periodic short courses to ensure that their knowledge is up to date. Hong Kong has one of the few national public certification and training schemes for plumbers (Scotland also established such a scheme in 2002) but it is essential that the system is not undermined by not being properly and rigorously applied. It is important that all individuals in plumbing, including those trained practically through apprenticeships and similar schemes, understand the reasons why certain materials should not be used and why system design is important.

49. Construction and maintenance of water supply systems not only requires that the correct materials are used. It also requires that under the Water Safety Plans there are appropriate procedures in place to ensure that the safety and quality of the drinking water is not compromised by the design of the system. Similarly it is essential that management procedures are in place for maintenance. Not only is it necessary that procedures are in place for construction and maintenance but

training is required to make sure that the reasons for the procedures, e.g. lead is hazardous to health and dead ends result in deterioration of quality because of microbial growth, are fully understood. This also applies to maintenance procedures because understanding why procedures are necessary is an important step in ensuring that they are taken seriously, e.g growth of *Legionella*.

50. Maintenance of systems is emphasised under water safety plans including preventive maintenance and regular planned maintenance of important equipment and fittings. Maintenance is particularly important in the water treatment works and the distribution system but it is also important in the water infrastructure in buildings, for example the requirement now proposed by WSD for disinfection and cleaning of systems every 3 months.

51. There are currently no formal international standards for inspection and monitoring of water supplies or for the building and construction of water systems although there are a number of areas in which guidance is available, either through WHO documents that support the Guidelines or through other networks such as the International Water Association (IWA) Operation and Maintenance Network. The reason for this is that inspection and monitoring needs to be tailored to specific circumstances and requirements which vary significantly around the world.

52. Management procedures are a key part of Water Safety Plans. They are vital in ensuring that water supplies are capable of delivering safe drinking water and continue to do so. In the fourth edition of the WHO Guidelines it is stated that "a Water Safety Plan comprises, as a minimum, three key components that are the responsibility of the drinking water supplier in order to ensure that drinking water is safe. These are a system assessment, effective operational monitoring and management and communication **[C2/18/1278]**". Management and communication are key parts of any process to assure quality. Management procedures that are clearly laid out and understood underpin the delivery of safe water from source to tap. In addition the Guidelines state "effective management implies definition of actions to be taken during normal operational conditions, of actions to be taken in specific 'incident' situations where a loss of control of the system may occur and of procedures to be followed in unforeseen (emergency) situations. Management procedures should be documented alongside system

assessment, monitoring plans, supporting programmes and communication required to ensure safe operation of the system" **[C2/18/1289, §4.4]**. Supporting programmes would include systems for ensuring that only appropriate materials are used both in terms of approval and ensuring that only approved materials and chemicals that meet the appropriate quality criteria are used.

53. The documented management procedures should ensure that when any part of the system has a problem that problem is rectified in due time to prevent any unnecessary risk to consumers. Systems must be capable of responding quickly at any time because water is supplied for 24 hours per day and 7 days per week. This also means that staff must be properly trained and understand the limits of their authority to take decisions, however decisions should be delegated to the lowest appropriate level to ensure rapid response. It is also important that there is an appropriate on-call support system that is properly staffed and able to function at any time.

Plumbing Materials and their Installation

54. The development of detailed Water Safety Plans that include buildings is difficult because of the variations in building design and ownership. However, one of the key areas that can be included is the approval of plumbing materials to ensure that only those that do not cause an unacceptable deterioration of the water quality are used. Lists of approved products need to be up to date and readily available and stakeholders such as construction companies, plumbers and suppliers of plumbing material need to made aware of the requirements and why those requirements are in place. The WHO document entitled Water Safety in Buildings mentions the use of inappropriate materials and specifically mentions lead in this context **[A2/35/1083]**. Lead is also specifically mentioned as a potential hazard in the drinking water system in buildings **[A2/35/1089]** and as a chemical that can leach from materials used in pipework with particular mention of solder **[A2/35/1126]**. These mentions of lead in the context of building construction reinforce the statements regarding lead in the Guidelines for Drinking Water Quality **[C2/18/1446]**. In terms of installation, requirements such as not leaving dead ends in systems should be made clear to architects, construction companies and plumbers along with their responsibilities with regard to ensuring safe water. The WHO document Water Safety in Buildings

states "This should include minimizing sources of hazards (e.g. stagnant water, long branch pipes and dead legs), as well as enabling access for monitoring and maintenance" **[A2/35/1089]**.

(c) in the context of the international standards in (a) –

- **(i) review and evaluate the adequacy of the existing Water Safety Plans of the WSD;**
- **(ii) review and evaluate the existing regulatory and monitoring regimes (both prior and subsequent to the excess lead in drinking water incidents as a result of which new measures have been put in place by public authorities) on quality of drinking water :**
  - **(1) at the pre-construction stage;**
  - **(2) at the construction stage;**
  - **(3) at the completion of construction (before the WSD issues the certificate for water supply connection); and**
  - **(4) at the maintenance stage;**
- **(iii) opine on whether any further metal(s), chemical(s) and/or microorganism(s) should be included as parameter(s) in addition to those set out in the WSD Circular Letter No. 1/2015 for testing of water samples, and if so, the thresholds, benchmarks and/or the acceptance criteria to be set for them; and**
- **(iv) the effectiveness of the recommendations made by the Review Committee.**

(i) My Opinion on the introduction of Water Safety Plans by WSD

55. WSD has adopted the concept of Water Safety Plans (WSPs) **[C1/5.1-5.20/47-812]** and it is to be expected that these will be developed further in the future. It is difficult to give a comprehensive opinion regarding WSD's development and implementation of WSPs from the documents available and from the short time available to discuss the plans with WSD staff. The following comments reflect the information available from the documents submitted.

56. WSD's understanding of WSPs would be enhanced by consultation with organisations in other countries that are also actively involved in the process of developing and implementing WSPs. There appears to be some complacency about water quality and the approach appears to be top down with no clear indication of how the Water Safety Plan teams work, which is an important part of the process. How well external stakeholders are engaged is also unclear but the involvement of other stakeholders is key in ensuring full understanding of what WSPs are and their role in assuring safe drinking water.

57. It appears that there may not be clear understanding of the purpose of health-based targets for pathogens: for example in the WSP General Plan **[C1/5-1/57+]** it states that the "absence of thermo-tolerant Coliforms and *E. coli* in 100 ml of treated water is taken as the performance target in ensuring the microbiological quality of treated water". While performance targets are an important part of WSPs, one of the reasons for establishing WSPs is that simply monitoring for faecal indicators is inadequate for ensuring the supply of safe water and so this would not be a suitable performance target. The target would be a removal target for pathogens by treatment processes. Hong Kong has well established multi-barrier treatment in place and performance targets would relate to operational parameters that reflect the efficiency of treatment such as filtration and disinfection.

58. While the overall structure and purpose of WSPs appears to be understood and the WSPs as presented form a very good starting point there are areas that would repay closer examination.

59. It is not clear how the WSPs were prepared but the General Plan **[C1/5-1/47+]** implies they were prepared by one department for others. In fact the WSPs were prepared under the auspices of a WSP team with representatives from various sections to ensure that it reflects actual practice and has the commitment of the different sections. The situation in Hong Kong is complex and so an overarching team that links into external stakeholders on a day to day basis and ensures consistency would be appropriate. This would be supported by small teams associated with each supply train. In terms of distribution this would be much more of a common plan but there would be a clear need to have a proper schematic, preferably using GIS with the associated data on materials, condition and flows in the different sections. There would also need to be records for the position and status of valves, procedures for opening and closing valves and planned maintenance, such as periodically operating valves to ensure that they are still fully operational and flushing mains. Consideration of the operation and maintenance of service reservoirs is also important. As indicated above it is difficult to determine to what extent this is the case due to the lack of time to specifically study the WSPs with WSD staff.

60. For the future it would be beneficial to have a more systematic understanding of the possible hazards and risks from the Dongjiang River in particular, because it is such an important source. This would also apply to the catchments, with less reliance on lists of chemicals that may or may not be there and so may or may not be adequately monitored.

61. The approach to water treatment is sound but the extent that continuous monitoring technology is used to support operational monitoring is less clear. This is an important step to assuring safe water.

62. Distribution system management plans do not appear to be so well developed. It is not clear how the distribution system, including service reservoirs, is managed to minimise the risks of contamination, for example management of operations to open or close valves to prevent surges, which are followed by pressure drops and the extent to which pressure falls after a burst will affect the wider distribution system.

63. There is mention of water distribution systems in buildings as a responsibility of the Customer Services Branch (CSB) but this can only be achieved by appropriate collaboration with other agencies such as the HD. Paragraph 3.8 of the minutes of the First Working Group Meeting on the Development and Implementation of Water Safety Plan for WSD held on 28 February 2005 **[C21/179/18998+, see 19000]** indicates that WSD does have indirect control of systems in private premises after the connection points but it is unclear what actions were put in place to extend WSPs to buildings, possibly through another agency. This is important since WSD do not take responsibility for water quality beyond the supply point into a building. In addition, responsibility for continuing water quality and maintenance associated with water quality, e.g. *Legionella* control, lies with the building manager and individual householders or tenants. WSD have previously taken samples from the buildings before the systems are approved for use but this has been to ensure that there is no danger of back flow contaminating the public water supply and the parameters considered were limited to those that could be indicators of the potential for such contamination. Since the identification of the lead problem the proposal is to take samples at representative sampling points for several metals **[C5/60/4066 and C5/63/4072-4075]** but the objective of such sampling needs to be carefully considered and

clearly stated. In particular, sampling needs to reflect a worst case in order to identify hazards and to determine whether further investigation is required to determine the risks and interventions. In the case of lead, the presence of elevated lead above 5 µg/litre, and possibly less, in a suitable sample indicates a failure of the procedures intended to prevent there being any excess lead in the system. It is important that there is someone responsible for water quality and monitoring water quality at the tap within buildings. Following the source to tap principle of WSPs, WSD would be best placed to do this.

64. While the WSPs developed by WSD broadly cover the recommended steps in a water safety plan, with the reservations indicated above, the WSPs would benefit from an external audit because this can help to identify improvements that are not readily obvious to those who are closely involved. It is not clear how extensively staff have been trained in the development of the plans and how closely involved the operators of the various stages of the supply chain have been. The water treatment sections of the WSPs are the most extensively described. My visits to two water treatment plants and conversations with senior supervisory staff indicate that there is a good understanding of the overall requirements. However, WSPs are also about continuous improvement and it is important that the need for improvement is properly and openly discussed and recognised.

65. The monitoring regimes need to be reassessed and modified to meet the contaminants known to be likely to be present and the points and frequency of sampling adapted to reflect behaviour, presence and concentration. This is referred to as risk-based monitoring and is intended to target resources where they will deliver the greatest benefit.

(ii) Regulatory and Monitoring Regimes for Internal Distribution Systems in Buildings

(iii) Opinion on whether any further metal(s), chemical(s) and/or microorganism(s) should be included as parameter(s) in addition to those set out in the WSD Circular Letter No. 1/2015 for testing of water samples, and if so, the thresholds, benchmarks and/or the acceptance criteria to be set for them

66. The regulatory and monitoring regime prior to the excess lead in drinking water incident should have prevented the incident occurring if it had been fully

implemented. The failure of implementation was largely due to a lack of understanding of the importance for health of lead and other potential contaminants from the internal distribution system. However, the clearly stated requirement that only unleaded solder must be used should have raised questions as to why this was sufficiently important to merit a specific mention. It would appear that no-one had specific responsibility regarding water quality at the tap. This was not helped by WSD's responsibility for water quality ending at the point at which water enters the building and the fact that the HD has no clear mandate in this respect. All depended on meeting the requirements for materials set out by the WA. That a similar situation has occurred elsewhere in the world indicates that unless explicit steps are in place to cover water quality in buildings then what are seen as relatively minor items may be overlooked, particularly when the consequences are not visible.

67. Subsequent to the discovery of the lead in water incident a number of steps have been taken to heighten awareness and to improve the final monitoring step. WSD Circular Letter No. 1/2015 **[C5/60/4066]** and No. 5/2015 **[C5/63/4072-4075]** reiterate the requirement not to use lead solder but do not mention the concern for health. The circular letter adds four metals to the analysis of samples already required but does not add anything about the need to take separate samples with an appropriate sampling protocol to maximise the detection of metals. I would suggest the addition of copper, antimony and zinc to the list of parameters, at least in the short-term, to gather data on concentrations. This has been discussed above in paragraph 29 but the lack of data on metals from plumbing needs to be rectified. However, both the WSD and HD have shown that they are aware of the need to tighten up the supervisory measures at all stages to ensure that drinking water quality in buildings, particularly public housing blocks, is maintained.

68. There is a need to produce guidance for building managers on the continuing maintenance of water systems in buildings to minimise the risk of *Legionella.*

69. The approaches to monitoring the quality of water at the tap in buildings, particularly apartment blocks, proposed by the Task Force have significant merit for newly built or refurbished properties. These ought to provide a final check on materials being used, in particular lead solder. The use of hand held x-ray fluorescence spectrometers to check soldered joints for lead would be highly

beneficial in ensuring that lead solder has not been used (non-destructive testing). The sampling of water at the tap for heavy metals would be in addition to sampling for the eight parameters to protect the public supply in the event of back flow because the sampling protocol would need to be different to ensure detecting these contaminants, e.g. first draw of sufficient quantity or fixed stagnation time. In addition it would be useful to add copper, antimony and zinc to the list of metals for the reasons outlined in paragraphs 29 and 67. Cadmium is unlikely to be present unless lower quality galvanised pipe is present or fittings are used that do not meet the relevant British Standard. Similarly zinc is unlikely to be present unless galvanised pipe is present. Chromium does not appear to leach in significant concentrations from chromium plating. The surface area for chromium in taps in contact with the water will be small but nickel does leach from the nickel base plating onto which the chromium is plated. However, the volume in the taps is very small and will be cleared in a very short flush. This is important because there is significant nickel in the water as supplied. Copper from copper piping is not likely to reach concentrations of more than a few hundreds of micrograms per litre unless there is significant corrosion combined with extended standing times when concentrations can increase significantly but this needs to be confirmed. Copper can cause acute gastric irritation when concentrations exceed about 2 mg/litre, which is the basis for the WHO guideline value. One difficulty with such sampling is determining how many apartments to take samples from if the pattern of lead solder use is not consistent and this will not be known until a significant problem is encountered. It would, therefore, seem appropriate to choose a manageable number of apartments at random depending on the resources that HD and WSD are able to commit.

70. What remains uncertain is to what extent lead has been used in plumbing in other buildings in Hong Kong in the past. To determine this would require an investigative study that could be achieved by random sampling using a suitable sampling protocol but this approach would need to be considered carefully in order to make sure that it was cost effective.

71. In relation to additional microbiological parameters that could be useful to include, enterococci are used in a number of countries. How much information these would add as faecal indicators, along with or instead of *E. coli*, is under consideration by a number of authorities, including WHO. Enterococci tend to

survive longer in the environment than *E. coli* and are more resistant to chlorine although the numbers in human faecal matter are fewer than *E. coli.*

(iv) My opinion on the effectiveness of the recommendations made by the Review Committee

72. The Review Committee have made comments and recommendations to the HD **[B15.4/397/40286-40328]** following the excess lead in water incident. The primary recommendation is that existing procedures should be tightened up and I fully agree with this recommendation. I would strongly support their recommendations regarding education and training to raise awareness of the importance of using lead-free soldering and the consequences of using inappropriate plumbing materials. There is value in establishing a Review Committee because it means that the messages with regard to lead and the potential for what appear to be relatively minor plumbing components to have a significant impact on drinking water quality will be more widely disseminated.

73. However, their view that the incidence of excess lead in water is very low cannot be substantiated by the data because of the sampling protocol requirement for flushed samples. They also show that there is a general misunderstanding as to what the WHO provisional guideline value is intended to achieve and that the provisional guideline value is a health-based standard, which it is not.

(d) opine on how the inadequacies (if any) identified for the matters above may be rectified or improved and to make recommendations with regard to the safety of drinking water in Hong Kong; and

(e) state, provide advice and recommendations on other areas of concern (if any).

Opinion, advice and recommendations.

74. It is my opinion that there is a need for formal drinking water standards and a regulatory structure for drinking water for Hong Kong to ensure that there is coordination of all matters relating to drinking water quality. The standards would incorporate WHO guidelines in the manner recommended by WHO and focus on the most important contaminants. This would also allow external examination of the WSPs and provide an external stimulus to encourage more focused risk-based monitoring of raw and treated drinking water. The regulatory

structure could be quite small but would provide independent oversight of drinking water quality.

75. In the UK and many other countries there is an independent regulator for drinking water quality[1]. The formal structure varies but the regulator reviews and assesses the performance of the water supplier(s) with regard to the quality of the water supplied. In the case of the UK there are three regulators, one for England and Wales and one each for Northern Ireland and Scotland. The model for Northern Ireland and Scotland is more relevant for Hong Kong as there is a single water supplier and the supplier is in public ownership. The regulator assesses compliance with drinking water standards and also determines the risks, in consultation with health professionals, associated with parameters that are found in drinking water or drinking water sources but are not included in the standards, e.g. PFOS (perflurooctane sulfonate). The regulator also agrees the sampling programme and audits the analysis and the results for quality and agrees any remedial steps or improvements. In the UK the three regulators also audit water safety plans, providing a beneficial second view. The inspector has complete and open access to the data and operations of the Water Supplier. It is, however, important that any regulatory structure is appropriate for Hong Kong's particular circumstances.

76. I believe that it would be appropriate for WSD to consider creating the position of water quality manager who would report to the Director and who would have the role of overseeing drinking water quality data and activities from all parts of the organisation. This role would also involve evaluation of the particular trends in water quality data and working to assist operational sections to work towards gradual improvement, which is a key part of the WHO framework for safe drinking water. Hong Kong will undoubtedly face significant challenges to its drinking water supplies in the future and a water quality manager would be a positive step to looking towards the future.

[1] http://dwi.defra.gov.uk/about/index.htm (UK)
http://dwqr.scot/ (Scotland)
https://www.doeni.gov.uk/topics/water/drinking-water-quality (Northern Ireland)
http://www.epa.ie/water/dw/ (Ireland)

77. While I understand the need for and importance of bureaucracy, many of the policies and procedures seem to be fragmented between various documents. I also understand that this gradually happens in many organizations as changes are made but it would be beneficial to consolidate and streamline all documents, particularly as changes are incorporated over time to make the documents easier to access and more transparent, and to ensure that the chance of misunderstanding and using out of date procedures is minimised.

78. While HA has now started to allocate a specific quality assurance role with regard to drinking water, I find the statements that the HA were unaware of the issue of lead rather difficult to understand in view of the HA's specific requirement for using unleaded solder and low lead fittings. This implies that little thought was being applied to the contract. Rather, standard terms were being applied without understanding the reason for their inclusion. It will be important that the new quality assurance regime is proactive in preventing the unauthorised use of materials by a process of simple inquiry. The water sampling provides retrospective verification but this will only be reliable if a suitable sampling method is adopted to maximise the chance of finding unwanted heavy metals. It is also clear that because the WSD did not take any responsibility for water at the tap and had not formally delegated that authority, no one took that responsibility. It is not, therefore, entirely surprising that the current situation occurred. I would anticipate that the HA and the WA will now be aware and will ensure that quality assurance checks are properly carried out. Ultimately, quality assurance to prevent things going wrong will depend on individuals carrying out their responsibilities and in this, I would include Licensed Plumbers and Main Contractors. A central purchasing arrangement for unleaded solder and possibly for low lead copper alloy fittings would assist this greatly but thought should be applied to any other components of the plumbing system from which quality problems could arise, e.g. taps and copper piping.

Summary of Conclusions

79. The WSD led Task Force has carried out a thorough investigation of the affected systems using appropriate methodology.

80. The reason for the exceedance of the provisional WHO guideline value for lead in drinking water in Public Housing was primarily due to the use of lead solder for

joints in copper pipes contrary to the clearly stated requirements for plumbing materials in Hong Kong.

81. The sampling protocol used to take samples of drinking water at consumers' taps for lead was not designed to detect the presence of lead in the plumbing systems in apartments and so may underestimate the scale of contamination; this was confirmed by Professor Lee's study. A suitable sampling protocol should be developed to address this problem.

82. The WHO provisional guideline value is based on practicality and is not a health-based value because it is not currently possible to determine a suitable threshold for the adverse effects of lead. It is based on the premise that no new lead materials will be installed.

83. It would be valuable to investigate whether other metals that can arise from distribution are likely to be present in drinking water at the tap in Hong Kong, these include nickel, chromium, cadmium, copper, antimony and zinc. Those that are shown to be present should be included in the suite of metals to be measured in tap samples along with lead.

84. The possibility of *Legionella* bacteria growing in the internal fresh water systems of housing developments in Hong Kong has been demonstrated. There is a need to develop suitable management strategies to be implemented by building managers and consumers to minimise the risk of *Legionella*.

85. WSD has implemented Water Safety Plans, which are a key part of ensuring the ability of water systems to supply safe drinking water as recommended by WHO. While it is difficult to judge how well this has been done from the documents provided and the short time available for discussions with WSD on this topic, the work on Water Safety Plans would benefit from an external view and external audit.

86. There is a gap in the Water Safety Plans because they do not cover the supply to the tap. Even if WSD do not take responsibility beyond the point at which water is delivered to a building, it is important that someone has clear overall responsibility for water quality in buildings.

87. WSD should develop a risk-based strategy for monitoring contaminants and to improve the approach to operational monitoring to ensure that systems are always operating at their optimum.

88. It is not clear how systematically the hazards from the Dongjiang River have been characterised, particularly with regard to chemicals that are not listed in the WHO Guidelines. For the future it would be beneficial to address this issue as far as possible since it is a key water source. This does not mean that the source is unsafe but it is important to be aware of emerging issues.

89. Systems are in place for regulation and monitoring of plumbing installations but these need to be properly implemented by inspection rather than just documentation. Licensed plumbers must take responsibility for trade trained plumbers who they employ or are sub-contractors and ensure that they follow the requirements to ensure plumbing that is safe.

90. Hong Kong has the elements of a system to ensure that only suitable materials are used in contact with drinking water either in the public supply or in the distribution systems within buildings. This is based on other international approval systems. While there is no need for Hong Kong to develop its own approval system, it should specify more clearly the requirements for acceptance using other international approvals and which international approval systems can be accepted.

91. Hong Kong should develop formal drinking water standards based on the WHO Guidelines but adapted to its own needs.

92. Hong Kong would benefit from the establishment of an independent regulator who would provide a means of reassuring the public about the quality of drinking water in Hong Kong and would provide a means of ensuring that quality is integrated from source to tap. The regulator would also be responsible for auditing Water Safety Plans and for ensuring that drinking water standards are sufficiently up to date in conjunction with other departments.

93. WSD should consider creating the post of water quality manager, independent of operations, to report to the director and to act as a first contact point with the regulator.

94. In responding to this incident HD and particularly WSD have issued a series of documents and memoranda over several months. At no point can I find a desire for the two departments to work together to develop a single document with the input of other stakeholders, which would effectively be a manual covering the installation of plumbing in buildings in Hong Kong. The result is that, to date, there is a fragmented response, when a coordinated response would ensure that all of the key information was in one place and would be much more effective in preventing future problems without excessive effort.

95. It is important that now that a problem with the installation of lead solder in new public housing developments has been identified, the scale of the problem should be properly assessed and actions identified and implemented to rectify the situation and to protect consumers from lead in their drinking water.

Expert's Declaration

I, PROFESSOR JOHN FAWELL DECLARE THAT:

1. I declare and confirm that I have read the Code of Conduct for Expert Witnesses as set out in Appendix D to the Rules of High Court, Cap. 4A and agree to be bound by it. I understand that my duty in providing this written report and giving evidence is to assist the Commission. I confirm that I have complied and will continue to comply with my duty.

2. I know of no conflict of interests of any kind, other than any which I have disclosed in my report.

3. I do not consider that any interest which I have disclosed affects my suitability as an expert witness on any issues on which I have given evidence.

4. I will advise the Commission if, between the date of my report and the hearing of the Commission, there is any change in circumstances which affect my opinion above.

5. I have exercised reasonable care and skill in order to be accurate and complete in preparing this report.

6. I have endeavoured to include in my report those matters, of which I have knowledge or of which I have been made aware, that might adversely affect the validity of my opinion. I have clearly stated any qualifications to my opinion.

7. I have not, without forming an independent view, included or excluded anything which has been suggested to me by others, including my instructing solicitors.

8. I will notify those instructing me immediately and confirm in writing if, for any reason, my existing report requires any correction or qualification.

9. I understand that:

(a) my report will form the evidence to be given under oath or affirmation;

(b) questions may be put to me in writing for the purposes of clarifying my report and that my answers shall be treated as part of my report and covered by my statement of truth;

(c) the Commission may at any stage direct a discussion to take place between the experts for the purpose of identifying and discussing the issues to be investigated under the Terms of Reference, where possible reaching an agreed opinion on those issues and identifying what action, if any, may be taken to resolve any of the outstanding issues between the parties;

(d) the Commission may direct that following a discussion between the experts that a statement should be prepared showing those issues which are agreed, and those issues which are not agreed, together with a summary of the reasons for disagreeing;

(e) I may be required to attend the hearing of the Commission to be cross-examined on my report by Counsel of other party/parties;

(f) I am likely to be the subject of public adverse criticism by the Chairman and Commissioners of the Commission if the Commission concludes that I have not taken reasonable care in trying to meet the standards set out above.

Statement of Truth

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. I believe that the opinions expressed in this report are honestly held.

Professor John Fawell
4 February 2016

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EXPERT REPORT

PREPARED BY

PROFESSOR JOSEPH HUN-WEI LEE

Expert Witness appointed by the Commission of Inquiry into Excess Lead Found in Drinking Water

5 February 2016

Professor Joseph Hun-wei Lee
Chair Professor, Department of Civil and Environmental Engineering
Vice-President for Research & Graduate Studies
Hong Kong University of Science and Technology

Specialist Field	:	Water environment engineering: Environmental hydraulics/fluid mechanics; water quality modelling
Appointed on behalf of	:	The Commission of Inquiry into Excess Lead Found in Drinking Water (the "**Commission**")
Prepared for	:	The Commission
On instructions of	:	Messrs. Lo & Lo, Solicitors for the Commission ("**Lo & Lo**")
Subject matter / Scope of engagement:	:	To assist the Commission in discharging its duties under the Terms of Reference and by acting as an expert witness in the inquiry hearings
Documents reviewed	:	Selected documents from the Hearing Bundles
Documents referred to in this Report	:	See **Appendix I**
Sketches, Photographs and Diagrams integral to this Report by the Author	:	See **Appendix II**
Tables and Summaries	:	See **Appendix III**

Sampling Protocol (affected and unaffected estates)	:	See **Appendix IV**
Sampling Protocol (3 vacant flats)	:	See **Appendix V**
Summary on Computational Fluid Dynamics (CFD) modelling	:	See **Appendix VI**
Date of Inspection of some of the involved estates (*name of the estates*)	:	1) **10 November 2015** (Kwai Luen Estate Phase I - Luen Yat House; Kai Ching Estate - Hong Ching House; Tak Long Estate - Tak Long House) 2) **27 November 2015** (Vacant flat in Un Chau Estate) 3) **12 December 2015** (Vacant flats in Un Chau Estate; Kwai Luen Estate) 4) Field sampling visits to all "affected estates" and selected "unaffected estates" (see **Appendix III, Table 2**)
Site visits	:	1) **9 November 2015** Shatin Water Treatment Works Government Laboratory 2) **12 November 2015** Ngau Tam Water Treatment Works 3) **7 December 2015** Training Centre of the Construction Industry Council

The Terms of Reference of the Commission are as follows:

(a) to ascertain the causes of excess lead found in drinking water in public rental housing developments;

(b) to review and evaluate the adequacy of the present regulatory and monitoring system in respect of drinking water in Hong Kong;

(c) make recommendations with regard to the safety of drinking water in Hong Kong

Instructions

I have been instructed to give my opinion on the matters under paragraph (a) of the Terms of Reference. In providing my opinion, I have also been instructed to consider the following areas and undertake the following tasks:

(a) to ascertain the factual source(s) of excess lead found in drinking water in public rental housing and to advise on what work and tests are to be performed;

(b) to evaluate the methodologies and to review and verify the findings of the WSD Task Force's Interim and Final Reports in respect of the Waterworks system and the Inside Service system in public rental housing developments, from the perspective of a civil engineer; and

(c) to conduct, if necessary, independent investigation on behalf of the Commission into the above systems in order to ascertain the factual source(s) of excess lead found in drinking water.

Introduction

1. I, Professor Joseph Hun-wei Lee of the Hong Kong Special Administrative Region of China, have been appointed as the Commission's expert to assist the Commission in determining the matters under the Terms of Reference. The opinions and conclusions in this Report are based on: (i) a review of key documents and information supplied to me by **Lo & Lo**; (ii) analysis of lead concentration data collected by the Water Supplies Department (WSD) and Housing Department (HD) prior to the end of November 2015; (iii) independent sampling of all buildings in the "affected estates" and selected buildings in the "unaffected estates"; and (iv) analysis and interpretation of lead concentration data using a computational fluid dynamics (CFD) model of a representative household water supply system. Site visits were made to selected housing estates and the chemical laboratories in the water treatment works in Shatin and Nga Tam Mei. Discussions with WSD and HD were also held during the site visits.

Background of the Incident

2. During July – September 2015, following queries from the public, the Water Supplies Department and the Housing Department collected a number of drinking water samples in the Public Rental Housing (PRH) Estates of Hong Kong. The lead concentrations of 106 samples in 11 estates were found to exceed the WHO provisional guideline value of 10 micrograms per liter (μg/L). The WSD "Task Force on Investigation of Excessive Lead Content in Drinking Water" also conducted an investigation on the causes of excess lead. The Task Force Report (October 2015) concluded that the main cause of the excess lead was due to the use of lead solder in the construction of the fresh water supply plumbing system **[A1/19/689, §3.1.7(a)]**. While the main cause of the lead contamination was being reviewed independently, WSD also provided interim alternative drinking water supply to selected estates and recommended precautionary measures of water usage at the consumer tap (e.g. flushing for one to two minutes each morning before taking any water for drinking or cooking **[A1/21/815]**) to reduce possible health risks.

3. Hong Kong has traditionally not monitored lead concentrations in residential flats. There were no drinking water quality standards with respect to lead prior to this excess lead incident, although new parameters for testing of water samples with

respect to lead, cadmium, chromium and nickel were introduced as a result of WSD Circular Letter No. 1/2015 since 13 July 2015 **[C5/60/4066-4067]**.

4. According to the test results of water samples provided by the WSD and the Government Laboratory **[A3/43/2382-2390** and **A3/44/2409-2440]**, lead concentration was measured on 1,325 samples in the 11 "affected estates" (36 buildings; a typical building has around 40 floors and 800 flats). Excess lead (≥ 10 μg/L) is found in 8.0 percent of the samples with 14.6 percent in the range of 5-9 μg/L **[Appendix III, Table 1]**. In addition to the "affected estates", lead measurements were also made for 3,806 samples in 45 estates (163 buildings) completed in or after 2005 (the "unaffected estates")**[A3/43/2391-2401]**. Based on the data, it seems the measurements were made at different times during office hours, with no apparent planned schedule.

5. There has been great concern among the residents and the public on the safety of drinking water in PRH estates since the incident broke out in July 2015. Effective corrective measures must be based on an adequate understanding of the causes of the lead contamination in the "affected estates".

6. The lead concentration of drinking water at the consumer tap in a PRH estate building depends on a complex myriad of factors including: the time of consumption and prior use, the sources of lead in the water supply system, the pipe material and chemical properties of the water, detailed plumbing arrangements, and the age of the building. Different methods of sampling the same household supply will also give different results. There is currently no universal accepted method for sampling lead in drinking water; the appropriate method depends on the particular purpose for which sampling is carried out.

7. As this review progressed, it became clear that an independent field sampling of drinking water at the affected PRH estates would be necessary. The lead concentration measured on the 1,325 drinking water samples in the 11 "affected estates" are all based on "fully flushed samples" (i.e. for each flat a 250 mL sample was taken after flushing the tap for 2-5 minutes). While this sampling method provides a measure of water quality of the bulk water supply, it does not reflect the actual and sometimes high lead concentrations to which the residents are exposed. Such data does not provide an estimate of the mean lead concentration used for

drinking and cooking, nor an adequate basis for assessment of health risks. This concern on the inadequacy of the sampling method adopted by the Water Supplies Department was expressed in the Joint Expert Report (Preliminary) by Fawell and Lee **[V1/1/1-44]**.

8. Unlike other countries where lead contamination has been investigated, lead pipes are not used in the water supply system of Hong Kong. On the other hand, the deposition, release and transport of any lead introduced into the highly compact labyrinth of water supply system in a PRH estate building is a unique feature that has previously not been studied. In view of the enormous scale of the problem and the paucity of data, resort has also to be made to the use of a computational fluid dynamics (CFD) model to assist with the data interpretation. Great effort has also been made by **Lo & Lo** to examine, retrieve, collate and analyse all the lead concentration data collected, measured and tracked by different parties (WSD, HD, and the Government Laboratory)**[A3/43-45/2382-2505]**.

Technical Investigation

Sampling of drinking water at PRH estates

9. A field sampling program was designed and implemented during 2 – 22 December 2015. The aim was to provide an independent data set for identification of the causes of lead contamination and to provide a basis for health risk assessment. The sampling covered 36 buildings in the 11 "affected estates" and 7 buildings in 6 selected "unaffected estates". In each building, 3 flats at upper, middle and lower levels were randomly selected by the Housing Department. In total, 129 flats were sampled [see **Appendix III, Table 2**].

10. The field sampling was carried out by trained researchers (six teams, each of two members) from the Hong Kong University of Science and Technology (HKUST). For each flat, a total of 5 samples were taken from the kitchen tap with the water continuously flowing: a "first draw" sample and 4 subsequent samples at 20 second intervals. The sampling was carried out in the early morning (between 6:30-9:00 am); the resident was informed by HD staff to flush the kitchen and wash basin taps the night before the sampling for 5 minutes before going to bed, and not to use the

kitchen tap afterwards before the sampling. The tap flow rate was also measured. The sampling protocol is illustrated in **Figure 1 in Appendix II**.

11. The samples were preserved and logged in by the Health, Safety & Environment Office (HSEO) Laboratory of HKUST and sent to the Government Laboratory (GL) for analysis of lead concentrations. HSEO also carried out lead concentration measurements as a cross-reference and supplement, and for targeted purposes. The HSEO of HKUST is an accredited laboratory under the HOKLAS scheme. In total 645 samples were collected; 290 and 269 samples were analysed by GL and HSEO respectively; cross-checking confirmed the reliability of the measurements. Details of the sampling protocol can be found in **Appendix IV**.

12. More detailed sampling was also carried out in 3 vacant flats of 3 estates (Un Chau Estate, Kwai Luen Estate and Kai Ching Estate)[see **Appendix III, Table 7**]. The aim was to study how lead concentration at the kitchen tap varied with time in relation to water stagnation (out of use) in the water supply chain of the individual flat. This provided a systematic data set for comparison of different sampling methods, for assessment of health risks, and for calibration and validation of the CFD model. For these flats, two additional sampling taps were installed with the assistance of WSD and HD: one at the water meter position for the flat (in the meter room), and one at the entry location to the flat (which may be the kitchen or washroom depending on the design of the flat). The kitchen and wash basin taps were flushed by HD staff the night before; samples were taken at the kitchen tap as well as the two special sampling taps. A longer sampling period of 5 minutes was used. The configuration of the water supply chain pipe of each flat (location and arrangement of meter room; number, type and location of pipe joints, pipe lengths) of each flat was also measured on site. Details of the sampling protocol can be found in **Appendix V**.

    A total of 80 samples were collected for the vacant flats; 40 samples were analysed by GL and HSEO respectively.

Computational fluid dynamics modelling of water supply chain

13. Any sources of lead introduced into the drinking water supply system will affect the lead concentration at the consumer tap. As the WSD measurements indicate absence of lead contamination in the supply line to each building, roof tank, and down pipe

(the central water supply line from the roof tank to the individual households), the focus is on the release, accumulation, and transport of the lead in the branch water supply chain from the down pipe to the individual flats on each floor.

14. Lead can accumulate in the water supply chain and be transported to the consumer tap of a particular flat as follows. An individual parcel of water flows from the down pipe to the meter room and passes a labyrinth of piping to a pipe along the ceiling of the corridor before entry into the flat (either the kitchen or wash room). The water parcel passes through a number of fixtures and joints along the flow path – Tee joints, elbows, water meters and valves. **Figures 2 and 3** in **Appendix II** depict a typical arrangement of a water supply chain for a PRH estate flat.

15. When the water tap is not in use, say overnight, the water in the supply chain of a particular flat is stagnant. Any lead deposits will be released into the water through chemical reaction and molecular diffusion; the lead concentration in the system will increase with time. When the water tap is turned on, say the next morning, the accumulated lead in the system will be transported in the turbulent pipe flow and the lead concentration at the consumer tap depends on the accumulated lead during the stagnation period and the mixing and transport in the system. The distribution of the dissolved lead along the supply chain both during stagnation and after opening the tap can be obtained through computational fluid dynamics (CFD) modelling.

16. CFD modelling is a tool to determine the changes in lead concentration along the supply chain and with time. The supply system is discretized or divided into a large number of cells (finite volumes), and the lead distribution is determined by numerical solution of governing equations based on mass and momentum conservation. The input to the model is the pipe configuration, the pipe flow rate, and the assumed stagnation equilibrium lead concentrations and lead leaching rates at the joints and pipes based on the WSD laboratory data. The output of the model is the lead concentration in each grid cell. Details of the CFD modelling are given in **Appendix VI**. **Figure 4** in **Appendix II** shows the computational grid for a representative vacant flat. **Figure 5** in **Appendix II** shows a typical lead distribution in a pipe joint at different times after stagnation. The model has been calibrated and validated against data obtained from the vacant flat tests by both WSD and the independent experiments of this study. The aim of the computer modelling is to provide an indirect check on the measured lead leaching rates, and to gain more insights into

the causes and possible mitigation measures against risks of drinking lead-contaminated water in PRH estate flats in Hong Kong.

OPINION & FINDINGS

(i) Analysis of Lead Concentration Data

17. The WSD data for the "unaffected estates" provided guidance for the targeted field sampling in December 2015 **[Table 3, Appendix III]**. For these 45 estates (163 buildings) completed in or after 2005 excess lead was found in 11 samples (out of 3806 samples taken). It is notable that 86.3% of the samples had lead concentrations below 1 µg/L (below detection), and 98.1% below 5 µg/L. Lead contamination risks for these estates appear to be very low. The 11 excess lead samples were derived from 5 estates (namely, Shui Chuen O Estate, Yee Ming Estate, Tin Ching Estate, Choi Tak Estate and Kwai Chung Estate) that were labelled "unaffected" probably due to different methods of interpretation. For the purpose of independent lead sampling, a total of 6 "unaffected" estates (Shui Chuen O Estate, Yee Ming Estate, Choi Tak Estate, Kwai Chung Estate, Un Chau Estate (Phase 5) and Sau Mau Ping (South) Estate) were selected **[Table 2, Appendix III]**.

18. Lead concentrations were also measured on a total of 2,639 samples collected from 138 estates (308 buildings) completed before 2005 **[Table 4, Appendix III]**. No excess lead is found in any of the samples. It seems that any lead introduced into the water supply system would have been substantially leached over the 10 year period.

19. The independent and planned sampling of every building with suspected lead contamination (in the "11 + 6" estates) provides independent data for general risk assessment and as a basis for assessment of health risk and sampling protocol, and possible advice to residents.

20. Different sampling methods lead to different lead concentrations. The independent sampling reveals that 47.2% of the "first draw" samples have excess lead – as compared with 8.0% of the fully flushed samples **[Table 5, Appendix III]**. The independent sampling data is also consistent with the information from the Coalition of the Victims of Contaminated Drinking Water **[AC1/1-22]**, although details of the sampling protocol for this set of data are unknown.

21. The complex variation of lead concentration with time is captured by our sampling. Two characteristic patterns of lead concentration variation with time were observed. In about 37% of the cases in which lead was detected, the maximum concentration is observed in the first draw sample, followed by a monotonic decrease in the subsequent samples (at t=20, 40, 60, 80 sec). In other cases (around 63%), the maximum concentration is detected in the second sample at t=20 sec, followed by a sharp decrease **[Figure 6, Appendix II]**. This second pattern is mostly found in flats completed in or after 2010. The delayed peak concentration is usually found in flats with higher lead contamination, and probably reflects the relative location of the lead sources from the kitchen tap (whether the significant lead sources are in the meter room, corridor, or inside the flat).

22. While general patterns can be discerned, the sampling also indicates occasional samples that would not follow any general trend. For example, the lead concentration of four samples (t=0, 20, 40, 80 sec) can be below detection, with the sample (t=60 sec) giving unexpectedly high concentration that may reveal the picking up of a lead particle in the system. Such outliers are rare but reflect the complexity of the problem once lead sources are introduced into the water supply chain.

23. Since multiple samples were taken in each flat, a measure of the lead contamination risk can be given by a mass integrated average lead concentration of the 5 samples taken – the "flat concentration" is the concentration measured by the total mass divided by the total volume collected (450 mL). Based on the flat concentration, 53.2% and 58.2% of the samples have excess lead (depending on 2 or 5 samples respectively) as compared to the 8.0% for the individual flushed sample **[Table 5, Appendix III]**.

24. The average of the flat concentrations of the randomly selected upper, middle, and lower floors gives a "building concentration". The lead contamination of a building can be classified as follows: (i) Class 1 – the building concentration and all sample concentrations are less than 10 μg/L; (ii) Class 2 – the building concentration is less than 10 μg/L but with at least one sample greater than 10 μg/L; (iii) Class 3 – the building concentration is greater than 10 μg/L **[Table 6, Appendix III]**. Out of the 43 buildings sampled, 18 buildings are of Class 2 or above, while 9 buildings are

considered Class 1. The remaining 25 buildings are considered significantly lead contaminated.

(ii) Causes of Excess Lead

25. The detailed data for the three representative vacant flats point to the sources of lead in the water supply chain of the flats. The sampling shows significant lead concentrations measured at the water meter position as well as at the location of first entry to the flat. This means most of the lead contamination comes in the pipe network in the meter room, and along the corridor leading to the flat **[Table 7, Appendix III]**. This is consistent with the significant measured lead deposits and leaching rates found in the meters, valves, elbows (90 degree bend) and pipe joints reported by the WSD task force. **Figure 7** in **Appendix II** shows the measured lead deposits in the water supply chain of Luen Yat House, Kwai Luen Estate. While it is difficult to extrapolate the lead deposits measured on pipe sections of 0.2 m length, it is clear that the elbows and joints contribute significantly to the lead contamination. Flow recirculation patterns around a 90 degree pipe bend will also favour lead accumulation in isolated pockets.

26. Based on the measured leaching rates and maximum stagnation concentrations reported (WSD task force report)**[A1/19/685-686 and C19.6/140/14205-14209]**, the lead concentration at the kitchen tap both during stagnation and after the tap is turned on can be estimated by the CFD model. Considering the limited data and the complexity of the problem, the predictions of the calibrated model are in reasonable agreement with the WSD data **[Figure 8, Appendix II]**. This provides an indirect confirmation of the detailed stagnation lead concentration and leaching rate measurements made by WSD.

27. By adopting lead source strengths within the range of the WSD measurements, the CFD simulation of lead concentrations at the kitchen tap are consistent with our own measurements **[Figure 9, Appendix II]**. For the vacant flats it seems that for both 4-hr and 18-hr stagnation periods the lead concentration drops to below 10 μg/L levels in about 30 seconds. As noted above, in lead contaminated flats, occasional outliers of lead concentration are still possible.

28. Based on a holistic assessment of the collective WSD and HKUST data, and the CFD modelling, it seems that the main cause of the excess lead found in drinking water of PRH estates is due to the leaching of significant lead deposits in the pipe joints and fittings (e.g. elbows, valves, meters). From the soldering demonstration by a plumbing expert of the Construction Industry Council (7 December 2015) and the WSD data, it is clear that lead soldering material can be introduced into the pipe joints due to over use of lead solder and/or poor workmanship. Whether the lead deposits are greater along the pipe length (due to shearing off and sedimentation of lead solder deposits and/or electro-chemical reactions of copper alloys with the water) or at the pipe joints is of secondary importance. In any case, the measured leaching rates are consistent with the lead concentration measured at the tap.

(iii) Review of Findings of the WSD Task Force Reports

29. Overall the Water Supplies Department and the Government Laboratory have carried out a thorough and substantial investigation within the time and other constraints. In particular, the dismantling and chemical analysis of the key components of the water supply chains of three representative flats was a sensible and practical step. Although only three representative flats were selected, the examination of the 134 pipe components and fittings yielded very useful information.

30. The direct measurements on the lead content and leaching rates of pipe sections, joints (elbows, sockets, tees) and fittings (meters, valves, taps) provided valuable data to unravel the causes of excess lead (Annex 2.3 – 2.5 of WSD Report)**[A1/19/744-756]**. There is great variability (one to two orders of magnitude) in the measured leached lead mass from the pipe and joints (elbows and sockets) and fittings (one order of magnitude). The total leached mass from the fittings are similar for the three locations. Given the mass of lead deposited in the components of the water supply chain it can be roughly estimated that it could take as long as 5-10 years for most of the lead mass to be leached into the water, especially for the pipe joints. This is consistent with the present finding that the estates completed in or before 2010 have generally a lower lead concentration.

31. Based on my visit to the Ngau Tam Mei treatment works to see the dismantled "components" and the chemical tests employed, it is clear that the dismantling and

transport of the pipe components and the chemical analysis have been carefully conducted. As the CFD model calculations are based on the measured leaching rates, the credibility of the WSD measurements is also supported by the congruence of the predictions of lead concentrations with data. In view of the variability and randomness of the lead sources within a branch water supply system leading to a flat, it was judged that independent laboratory tests of the lead content of pipe joints and fittings would not have added much value. Rather the effort was directed towards the development of the CFD model.

32. The independent sampling and measurements by two accredited laboratories demonstrated the robustness and accuracy of the lead concentration measurements by the Government Laboratory. Based on the average kitchen tap flow rate of 0.26 L/s, turning on the tap for 2-5 minutes (say 3 min) would cover a supply chain pipe length of over 100 m. Assuming a typical pipe length of around 20 m, this would translate to more than "5 plumbing volumes". Hence the government sampling method was essentially a "fully flushed" sample according to generally accepted definitions (time taken to flush 3-5 plumbing volumes). The WSD sampling would not give the maximum or average lead exposure levels of the consumer. Nevertheless, the collective WSD data was very useful in guiding the independent sampling, and also as a basis for assessing the general lead contamination risk among the PRH estates.

33. The tap-water concentrations measured in this study are consistent with the significant lead contents of the solder measured (between 27% and 42%, p.21 of Task Force Report)**[A1/19/672]**. The use of the isotopic analysis to ascertain the correlation between lead in water and the lead in the solder joints is judged to be reasonable and valid.

34. Measurements on pipe joints in the flat in Hung Hei House of Hung Fuk Estate (HFE) – where stainless steel pipes with mechanical joints and copper pipes with lead-free solder joints are used – show the absence of lead (Annex 2.7 of WSD Report)**[A1/19/772]**. The pipe joints and fittings in these flats are otherwise similar to flats in the affected estates. This control experiment provides solid evidence that the leaded solder joints should be the main cause of excess lead in drinking water and the relative insignificant lead contribution of copper alloy fittings. Tak Long House of Tak Long Estate that we visited is a similar building that uses stainless steel pipes

and mechanical joints. The tap-water lead concentration in one flat of Tak Long House (not included in this report) also indicated below detection levels.

35. The mathematical model adopted in the WSD report is essentially a mass balance assuming fully mixed conditions. Consistent with the present review, the results generally indicate the significance of the contributions of the lead solders (or the lead deposits along the pipes derived from the lead solder). However, it is highly questionable whether the lead sources in the copper pipes (e.g. p.30 of WSD Report) **[A1/19/681]** can be estimated by linear extrapolation of the measurements on short lengths (0.2 m) of copper pipes containing lead deposits. There is also no data to test the scenarios depicted. The estimates of lead mass leached from the pipes for the Kai Ching Estate are hence prone to significant uncertainties. This uncertainty will affect the relative contribution of lead deposits on pipes, joints, and fittings to the water tap lead contamination. Additional tests similar to the vacant flat experiments will help to further resolve this issue.

Summary and Conclusions

36. Independent planned sampling and analysis of lead contamination of 43 buildings in 17 PRH estates have confirmed the main WSD findings. Regardless of the method of sampling, the "affected estates" and the "unaffected estates" are largely confirmed. The more detailed sampling results in a more accurate assessment of the extent of lead contamination in the different estates and buildings. The average lead concentration of about 50% of the samples in the "affected estates" exceeded the WHO provisional guideline value of 10 μg/L.

37. Lead contamination in the densely populated PRH estates seems to be dominated by lead solder deposits in the numerous joints of the water supply chain from the down pipe to the individual flats. The lead concentration at the kitchen tap varies with time in a complex manner possibly due to the random nature of the lead deposits in the system. First draw samples may or may not contain the highest concentration. In general, more sporadic variations and higher concentrations are found in the estates completed in or after 2010.

38. The detailed sampling provides data for health risk assessment. Both the data and CFD results indicate that lead concentration in most cases drop rapidly within 30-60

seconds. A flushing time in the order of 0.5-1 minute appears to be adequate for guarding against risks of lead contamination.

Expert's Declaration

I, PROFESSOR JOSEPH HUN-WEI LEE DECLARE THAT:

1. I declare and confirm that I have read the Code of Conduct for Expert Witnesses as set out in Appendix D to the Rules of High Court, Cap. 4A and agree to be bound by it. I understand that my duty in providing this written report and giving evidence is to assist the Commission. I confirm that I have complied and will continue to comply with my duty.

2. I know of no conflict of interests of any kind, other than any which I have disclosed in my report.

3. I do not consider that any interest which I have disclosed affects my suitability as an expert witness on any issues on which I have given evidence.

4. I will advise the Commission if, between the date of my report and the hearing of the Commission, there is any change in circumstances which affect my opinion above.

5. I have exercised reasonable care and skill in order to be accurate and complete in preparing this report.

6. I have endeavoured to include in my report those matters, of which I have knowledge or of which I have been made aware, that might adversely affect the validity of my opinion. I have clearly stated any qualifications to my opinion.

7. I have not, without forming an independent view, included or excluded anything which has been suggested to me by others, including my instructing solicitors.

8. I will notify those instructing me immediately and confirm in writing if, for any reason, my existing report requires any correction or qualification.

9. I understand that:

(a) my report will form the evidence to be given under oath or affirmation;

(b) questions may be put to me in writing for the purposes of clarifying my report and that my answers shall be treated as part of my report and covered by my statement of truth;

(c) the Commission may at any stage direct a discussion to take place between the experts for the purpose of identifying and discussing the issues to be investigated under the Terms of Reference, where possible reaching an agreed opinion on those issues and identifying what action, if any, may be taken to resolve any of the outstanding issues between the parties;

(d) the Commission may direct that following a discussion between the experts that a statement should be prepared showing those issues which are agreed, and those issues which are not agreed, together with a summary of the reasons for disagreeing;

(e) I may be required to attend the hearing of the Commission to be cross-examined on my report by Counsel of other party/parties;

(f) I am likely to be the subject of public adverse criticism by the Chairman and Commissioners of the Commission if the Commission concludes that I have not taken reasonable care in trying to meet the standards set out above.

Statement of Truth

I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. I believe that the opinions expressed in this report are honestly held.

Professor Joseph Hun-wei Lee
5 February 2016

APPENDIX I

Documents referred to in this Report

Government documents and Witness Statements

1. "Excessive Lead in Fresh Water Supply in Public Housing Estates", LC paper No.: CB(1)1133/14-15(01), Legislative Council Panel on Housing meeting on 22 July 2015. **[A1/2/2-23]**
2. "Lead in Drinking Water Incidents", LC Paper No. CB(2)2195/14-15(01), Legislative Council Special House Committee meeting on 8 October 2015.
3. "Updated background brief on lead in drinking water incidents", LC Paper No. CB(2)2195/14-15(02), Legislative Council Special House Committee meeting on 8 October 2015.
4. Witness Statement of Anthony Cheung Bing Leung, Chairman of the Housing Authority on 29 October 2015. **[B15.1/336/37419-37502]**
5. Witness Statement of Ada Fung Yin Suen JP, Deputy Director of Housing (Development and Construction) of the Housing Department on 29 October 2015. **[B15.1/337/37503-37641]**
6. Water Services Department, "Final Report of the Task Force on Investigation of Excessive Lead Content in Drinking Water", 30 October 2015. **[A1/19/650-801]**
7. Witness Statement of Lam Tin Sing Enoch, Director of Water Supplies on 6 November 2015. **[C19.7/114/10279-10299]**
8. Fourth Witness Statement of Chan Kin Man, Chief Waterworks Chemist, Water Supplies Department, on 4 December 2015. **[C19.6/145/14517-14621]**

Technical References/International standards

1. Bailey, RJ, Holmes, D, Jolly, PK and Lacey, RF, "Lead concentration and stagnation time in water drawn through lead domestic pipes", WRc Environment TR 243, Water Research Centre, UK, October 1986.

2. Drinking Water Inspectorate, UK, "Guidance on the Implementation of the Water Supply (Water Quality) Regulations 2000 (as amended) in England", Version 1.1, March 2012. **[C19.6/145/14569-14573]**

3. Kuch, A and Wagner I, "A mass transfer model to describe lead concentrations in drinking water", Water Research, Vol. 17, No. 10, 1983, pp. 1303-1307.

4. Lacey, RF and Jolly, PK, "Sampling for household water-lead", WRc Environment TR 244, Water Research Centre, UK, October 1986.

5. Ministry of Health, Labour and Welfare, Japan, "the Waterworks Law, Drinking Water Quality Standards", 2004.

6. Moore, MR, "Plumbosolvency of waters", Nature, Vol. 243, 25 May 1972, pp. 222-223.

7. Oliphant, RJ, "Summary report on the contamination of potable water by lead", External Report No. 125E, Water Research Centre, UK, November 1983.

8. Scottish Centre for Infection and Environmental Health," Scottish New Homes Lead Survey Stage 1", October 2000. **[A1/14/198-243]**

9. Scottish Centre for Infection and Environmental Health, "Scottish New Homes Lead Survey Stage 2", 2003. **[A1/15/244-398]**

10. The Hong Kong Institution of Engineers, "Report on the Study of Lead in Drinking Water in Public Housing Estates", 2 November 2015. **[U1/3/3-127]**

11. The International Organization for Standardization, "ISO 5667-5:2006 Water quality - Sampling - Part 5: Guidance on sampling of drinking water from treatment works and piped distribution systems", 2006. **[C2/19/1526-1549]**

12. Van der Leer, D, Weatherill, NP, Sharp, RJ and Hayes, CR, "Modelling the diffusion of lead into drinking water", Applied Mathematical Modelling, Vol. 26, 2002, pp. 681-699.

13. World Health Organization, "Guidelines for drinking-water quality", fourth edition, 2011. **[C2/18/1244-1525]**

APPENDIX II

Photographs, Sketches and Diagrams

Figure	Description
1.	Lead sampling protocol of PRH estates in December 2015. The sampling time and corresponding pipe length and water volume shown is based on the measured average flow of 0.26 L/s and typical pipe diameter of 22 mm.
2.	Typical arrangement of water supply chain for a PRH estate flat (Room 1813, Un Nga House, Un Chau Estate). This example shows a flat with 22 mm diameter supply pipe; total pipe length is 14 m, with 8 right angle bends/elbows), and 5 Tee-joints.
3.	Photos of typical arrangement of water supply chain for a PRH estate flat (Room 1813, Un Nga House, Un Chau Estate).
4.	Typical configuration of computational grid at pipe connections in the water supply chain.
5.	Typical lead distribution in a pipe joint at different times after stagnation.
6.	Typical patterns of tap-water lead concentration variation with time.
7.	Measured lead deposits (mg) and estimated leached mass in 24 hours (μg) inside the different components of the water supply chain (Luen Yat House, Kwai Luen Estate) – from WSD Task Force Report.
8.	Comparison of predicted lead concentration at kitchen tap with WSD data (Kwai Luen estate).
9.	Comparison of predicted lead concentration at kitchen tap with HKUST data (Kwai Luen and Un Chau Estates).

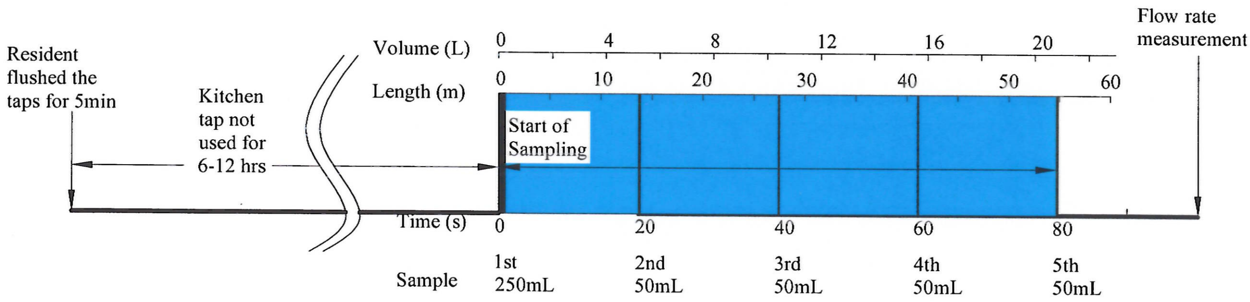


Figure 1 Lead sampling protocol of PRH estates in December 2015. The sampling time and corresponding pipe length and water volume shown is based on the measured average flow of 0.26 L/s and typical pipe diameter of 22 mm

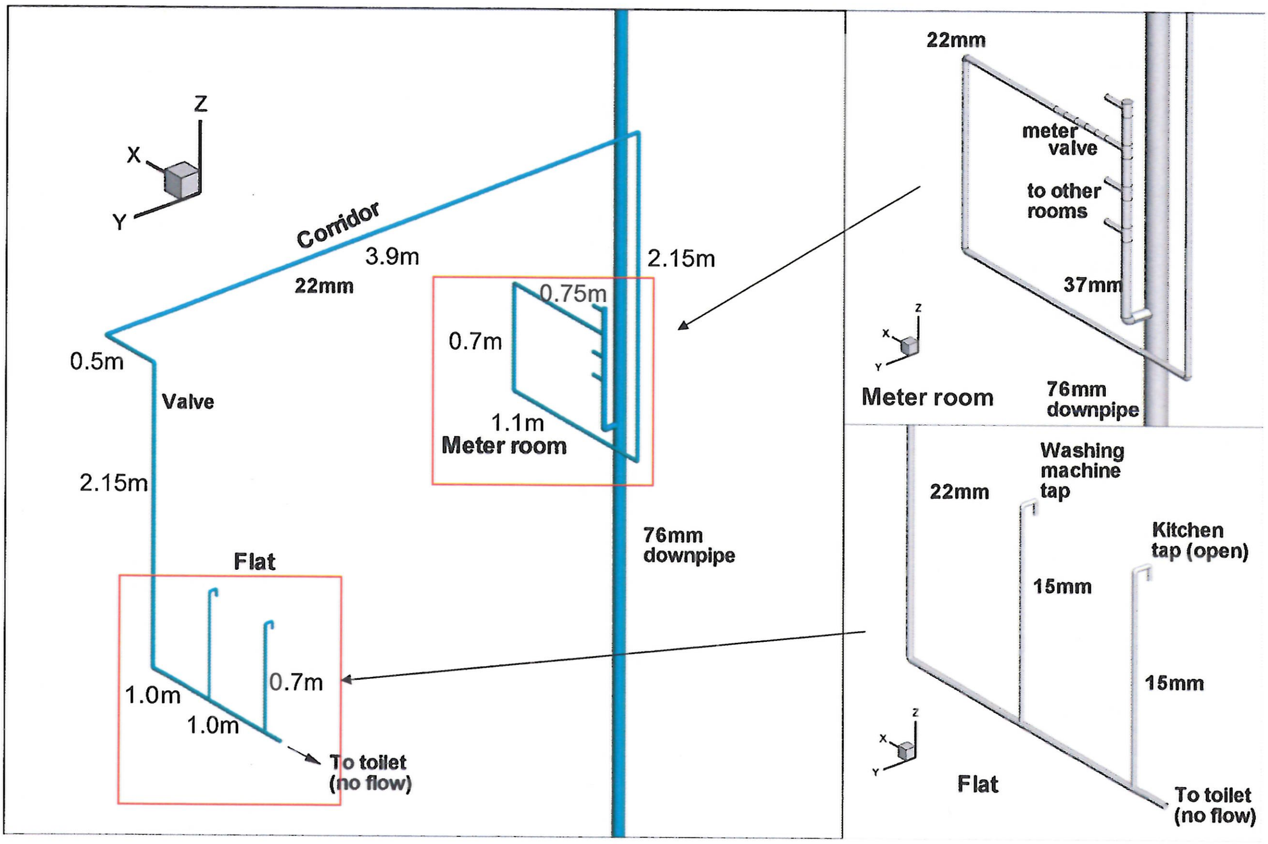


Figure 2 Typical arrangement of water supply chain for a PRH estate flat (Room 1813, Un Nga House, Un Chau Estate). This example shows a flat with 22 mm diameter supply pipe; total pipe length is 14 m, with 8 right angle bends/elbows), and 5 Tee-joints

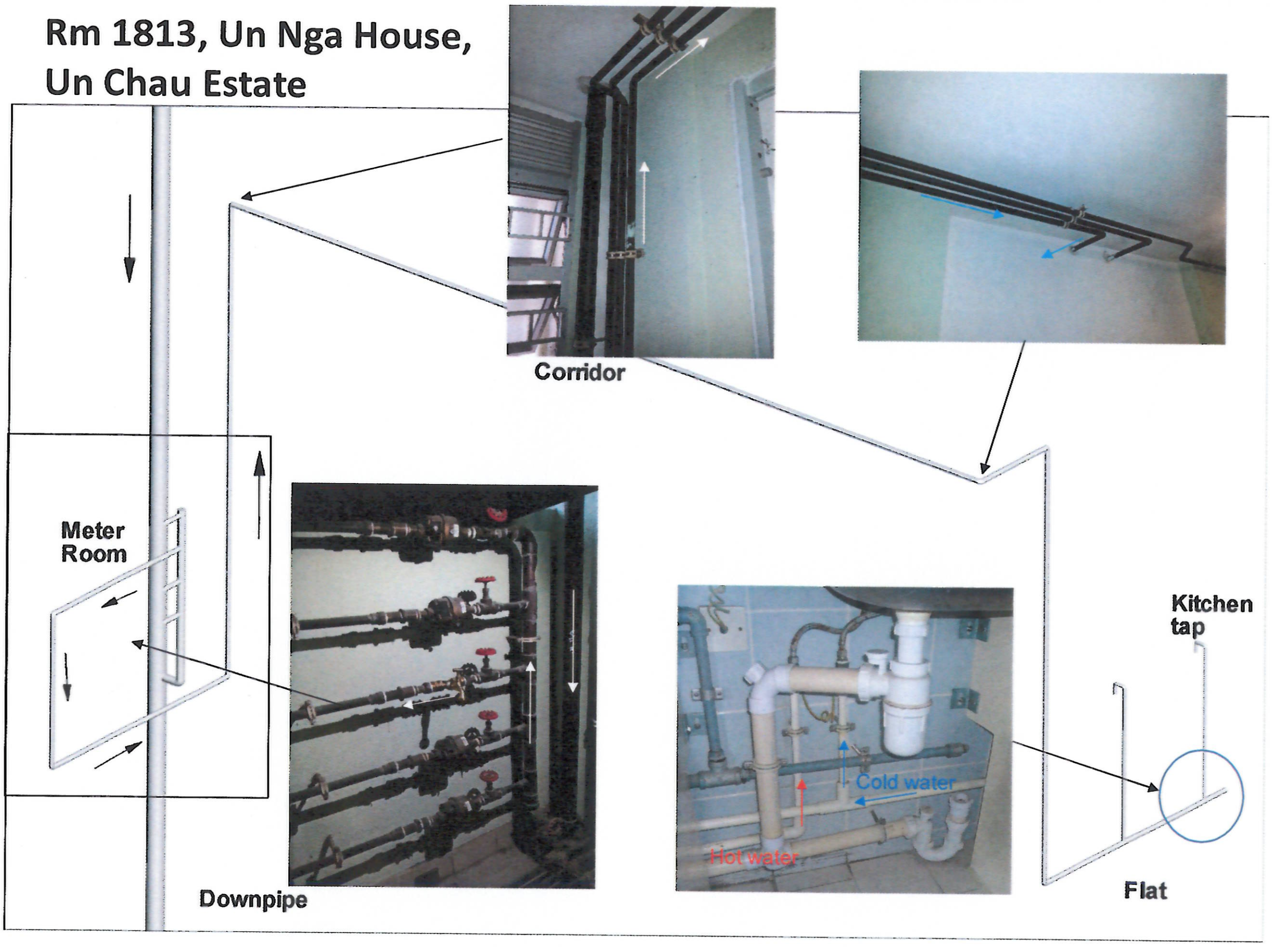


Figure 3 Photos of typical arrangement of water supply chain for a PRH estate flat (Room 1813, Un Nga House, Un Chau Estate)

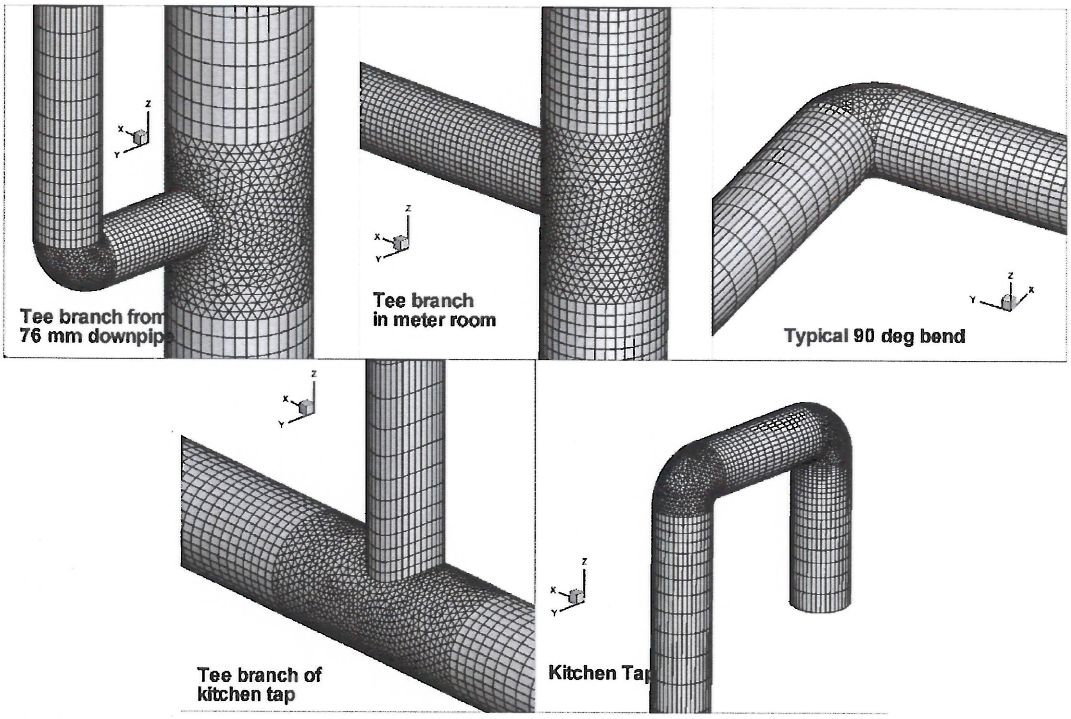


Figure 4 Typical configuration of computational grid at pipe connections in the water supply chain

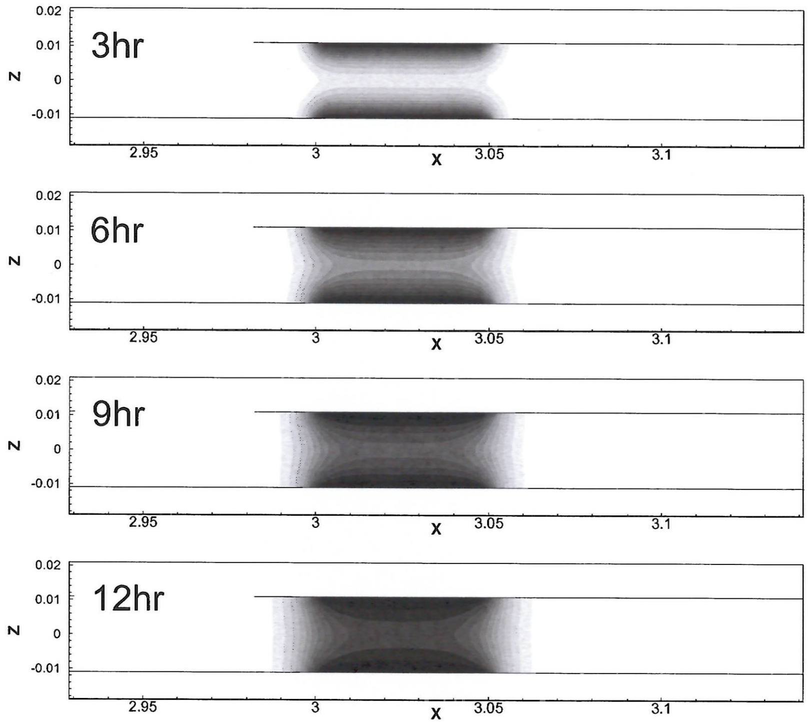


Figure 5 Typical lead distribution in a pipe joint at different times after stagnation

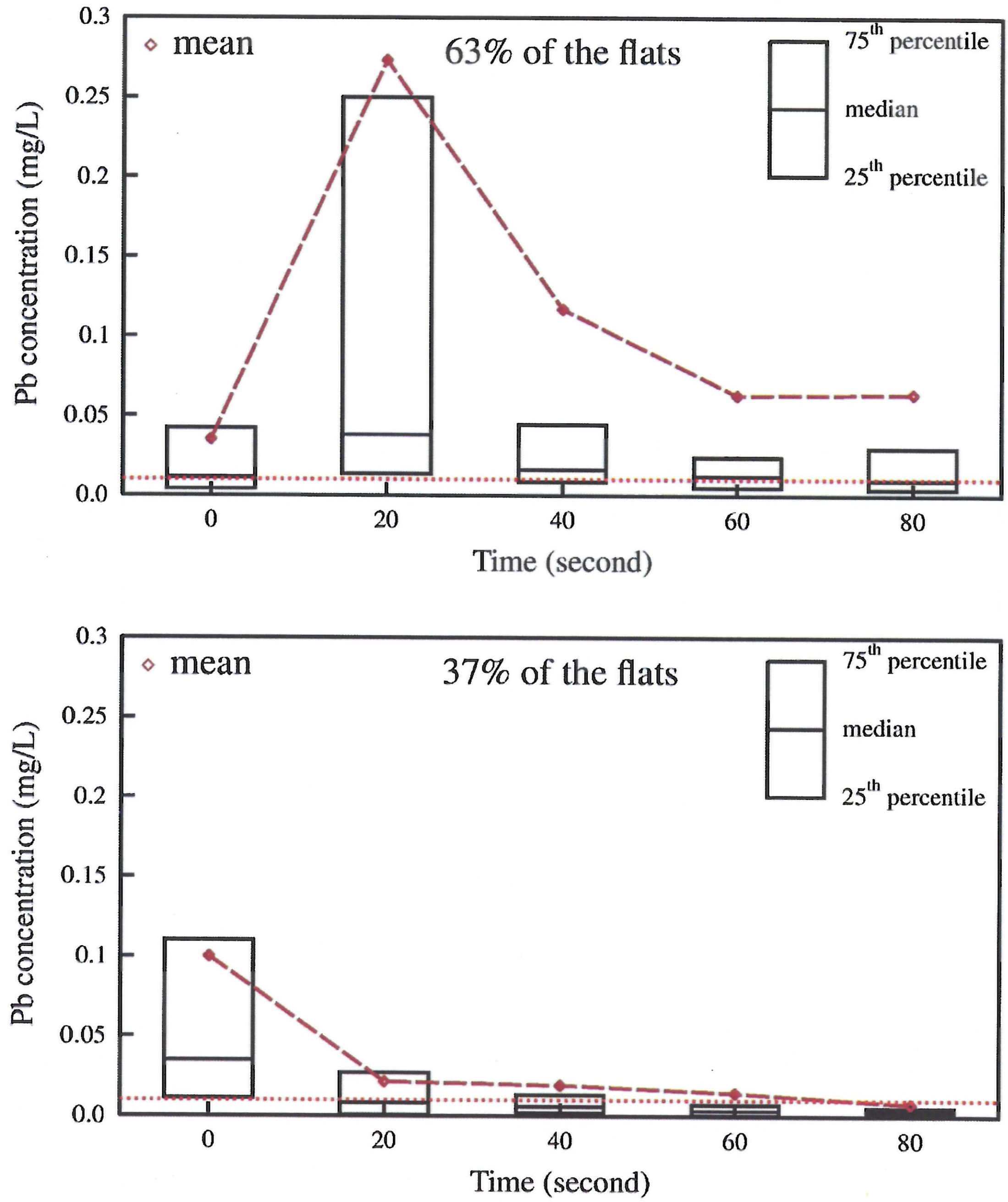


Figure 6 Typical patterns of tap-water lead concentration variation with time

Item No.	Type	Mass of lead deposit in components (mg)	Mass of lead leached per components in 24 hr (µg)	No. of components	Total mass of lead leached in 24 hr (µg)**
Meter Room					
L15	pipe	0.68	4.2	26*	110
L15A	elbow	9.32	28.8	2	57.6
L11	valve	1.20	10.7	1	10.7
L12	stopcock	0.05	25.8	1	25.8
L13	meter	11.46	65.9	1	65.9
L21	pipe	0.37	1.3	5.5*	7.3
L14	elbow	32.00	44.6	2	89.2
L18	elbow	8.36	23.0	4	92
L16	socket		4.0	1	4
Corridor					
L18	elbow	8.36	23.0	4	92
L21	pipe	0.37	1.3	103*	133
L16	socket		4.0	6	24
L17	socket		2.0	1	2.0
L19	socket		1.3	1	1.3
Flat					
L35	valve	0.06	14.9	1	14.9
L36	elbow		3.6	8	28.8
L16	socket		4.0	6	24
L37	pipe		0.7	58*	40
L31	tap		3.5	1	3.5
L31A	tap		5.8	1	5.8

*No. of component in pipe = length of pipe/sample length (~0.2m)
**Total mass of lead leached = Mass of lead leached per components x No. of components

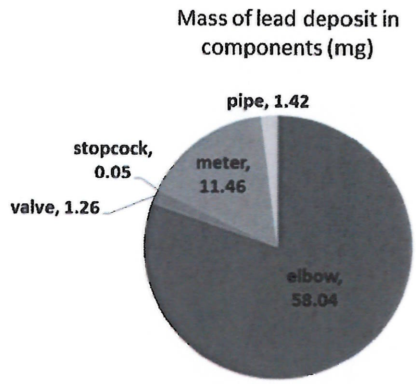
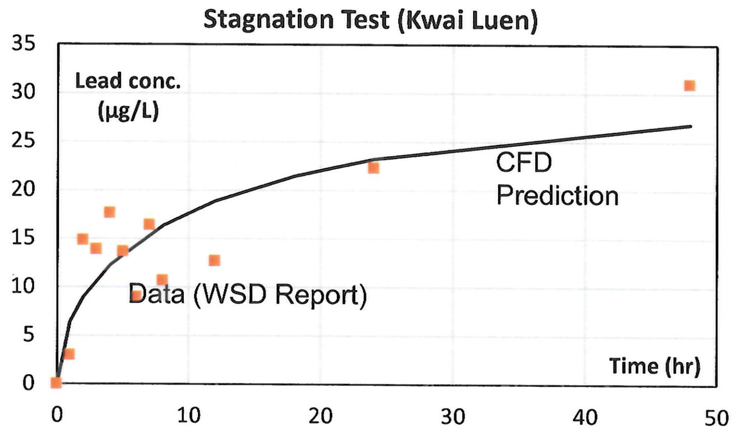
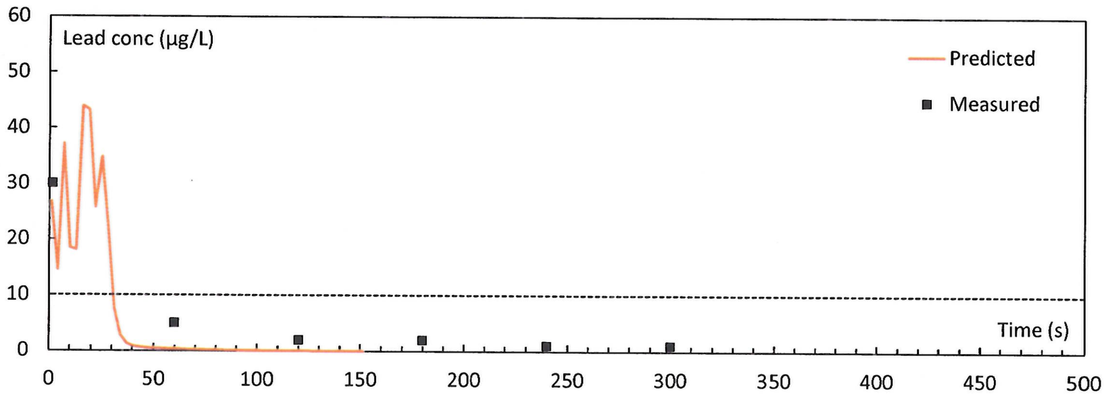


Figure 7 Measured lead deposits (mg) and estimated leached mass in 24 hours (µg) inside the different components of the water supply chain (Luen Yat House, Kwai Luen Estate) – from WSD Task Force Report.

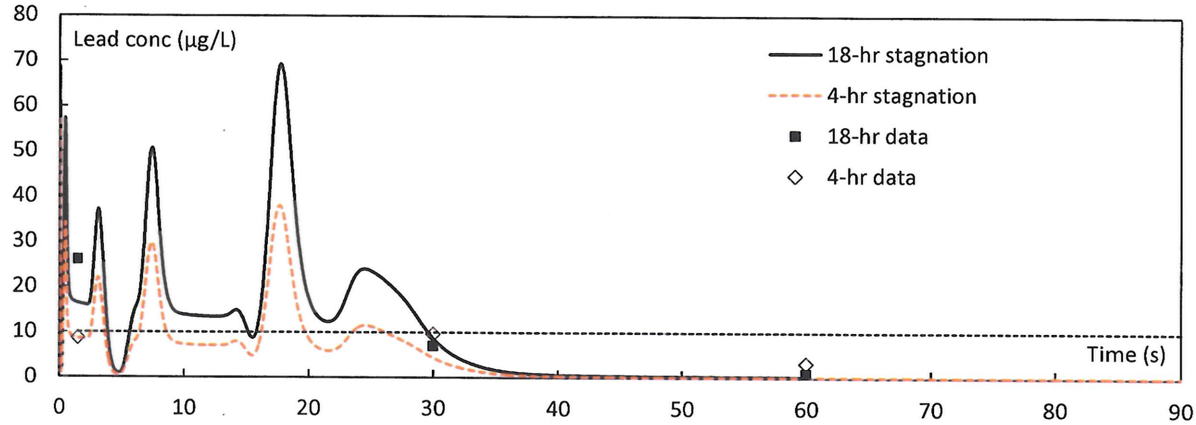


(a) Stagnation Test

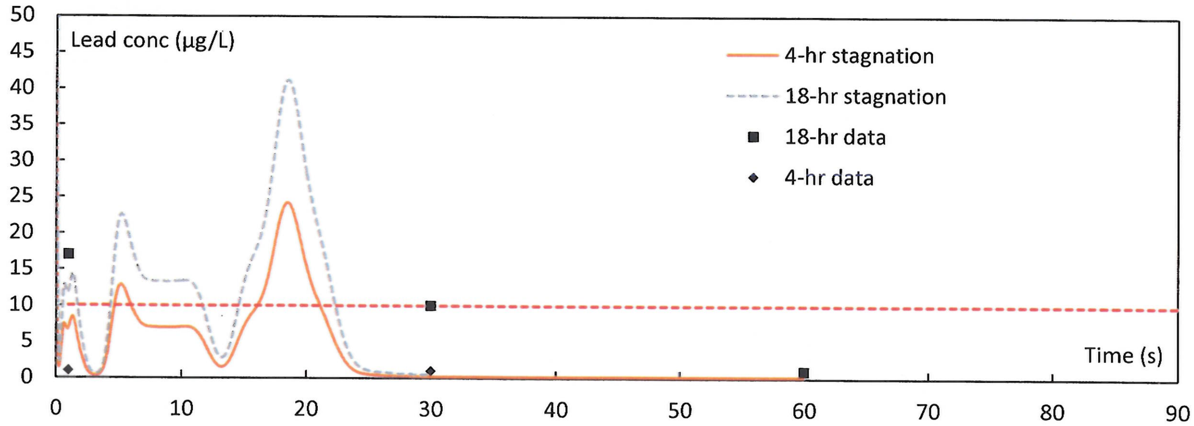


(b) Flushing Test

Figure 8 Comparison of predicted lead concentration at kitchen tap with WSD data (Luen Yat House, Kwai Luen Estate)



(a) Room 3607, Luen Yat House, Kwai Luen Estate



(b) Room 1813, Un Nga House, Un Chau Estate

Figure 9 Comparison of predicted lead concentration at kitchen tap with HKUST data (Kwai Luen and Un Chau Estates)

APPENDIX III

Tables and Summaries

Table	Description
1	List of "affected estates" sampled by Water Supplies Department during July – September 2015: (a) number of samples with excess lead; (b) distribution of lead concentration (total number of samples = 1325)
2	List of PRH estates and houses covered by independent sampling (2-22 December 2015
3	Distribution of measured lead concentrations for 3,806 samples in "unaffected estates" completed in or after 2005
4	Distribution of measured lead concentrations for 2,639 samples in "unaffected estates" completed before 2005
5	Comparison of excess lead data of WSD and HKUST – "fully flushed" vs first draw samples
6	Classification of buildings based on the HKUST sampling results
7	Measured lead concentrations (mg/L) in meter room, entry to flat, and kitchen tap for vacant flats

Table 1 List of "affected estates" sampled by Water Supplies Department during July – September 2015: (a) number of samples with excess lead; (b) distribution of lead concentration (total number of samples = 1325)

(a)

Estate	Year of completion	No. of buildings	No. of samples	No. of samples with excess lead
Kwai Luen Estate Phase 2	2014	2	122	5 (4.1%)
Kai Ching Estate	2013	6	327	8 (2.4%)
Wing Cheong Estate	2013	2	64	2 (3.1%)
Lower Ngau Tau Kok Estate Phase 1	2012	5	163	7 (4.3%)
Shek Kip Mei Estate Phase 2	2012	2	79	8 (10.1%)
Tung Wui Estate	2012	2	52	4 (7.7%)
Hung Hom Estate	2011	3	74	18 (24.3%)
Yan On Estate	2011	3	69	6 (8.7%)
Choi Fook Estate	2010	3	92	13 (14.1%)
Un Chau Estate Phase 2 and 4	2008	5	138	23 (16.7%)
Ching Ho Estate	2008	3	145	12 (8.3%)
Total		36	1325	106 (8.0%)

(b)

Lead concentration (μg/L)	Number of samples	Percentage
< 1	403	30.4%
1-4	623	47.0%
5-9	193	14.6%
10-19	70	5.3%
20-29	14	1.1%
≥ 30	22	1.7%
Total	1325	

Table 2 List of PRH estates and houses covered by independent sampling (2-22 December 2015)

Date of Survey (2015)	Estate	House	Flat
2-Dec	Hung Hom (A)	Hung Yan	910, 1715, 3905
		Hung Yat	107, 3207*, 3811
		Hung Yiu	317, 1917, 3610
	Yan On (A)	Yan Chung	408, 2403, 3702
		Yan Hei	206, 1906, 3512
		Yan Yuet	920, 2508, 3405
3-Dec	Kwai Luen (A)	Luen Yat	303, 2506, 3804
		Luen Yuet	310, 2205, 3201
	Shek Kip Mei (A)	Mei Leong	803, 1510, 4004
		Mei Wui	310, 2308, 3007
	Wing Cheong (A)	Wing Chun	213, 1718, 3405
		Wing Kit	1305, 2610, 3815
4-Dec	Ching Ho (A)	Ching Chung	108, 1209, 3815
		Ching Hin	114, 2202, 2908
		Ching Yu	1612, 2107, 3513
	Choi Fook (A)	Choi Hay	518, 2124, 4006
		Choi Lok	615, 1920, 4010
		Choi Sin	620, 3010, 4005
7-Dec	Lower Ngau Tau Kok (A)	Kwai Fai	106, 1810, 3715
		Kwai Hin	210, 2309, 4115
		Kwai Leung	209, 2213, 3609
		Kwai Sun	214, 2720, 4411
		Kwai Yuet	406, 1718, 4506
	Sau Mau Ping (South) (U)	Sau Sin	304, 2304, 3414
8-Dec	Choi Tak (U)	Choi Shing	211, 2106, 3914
	Kwai Chung (U)	Hop Kwai	1009, 2419, 3501
		Pak Kwai	919, 2413, 3916
	Tung Wui (A)	Wui Sum	103, 1220, 2807
		Wui Yan	916, 1603, 3303
9 Dec	Kai Ching (A)	Hong Ching	605, 2402, 3113
		Lok Ching	421, 1806, 3212
		Mun Ching	221, 1916, 3410
		Sheung Ching	116, 1022, 4022
		Yan Ching	219, 1913, 3605
		Yuet Ching	508, 1908, 3107
10-Dec	Un Chau Phase 2 & 4 (A)	Un Chi	217, 1906, 3902
		Un Hei	205, 1501, 3406
		Un Kin	403, 1003, 1802
		Un Lok	1004, 1805, 3402
		Un Nga	513, 2112, 3703
	Un Chau Phase 5 (U)	Un Wai	416, 2204, 3503
17-Dec	Yee Ming (U)	Yee Yan	1124, 2315, 3015
22-Dec	Shui Chuen O (U)	Hei Chuen	316, 1303, 2108

(A) Affected Estates, (U) Unaffected Estates

*A vacant flat

Table 3 Distribution of measured lead concentrations for 3,806 samples in "unaffected estates" completed in or after 2005

	No. of estates	No. of buildings	No. of samples	No. of samples with Pb concentrations			
				< 1 μg/L	1–4 μg/L	5-9 μg/L	≥ 10 μg/L
All samples with Pb < 1 μg/L	5	9	128	128 (100%)			
All samples with Pb < 5 μg/L	17	42	926	872 (94.2%)	54 (5.8%)		
All samples with Pb < 10 μg/L	18	73	1801	1544 (85.7%)	221 (12.3%)	36 (2.0%)	
At least one sample with Pb ≥ 10 μg/L	5	39	951	740 (77.8%)	175 (18.4%)	25 (2.6%)	11 (1.2%)
Total	45	163	3806	3284 (86.3%)	450 (11.8%)	61 (1.6%)	11 (0.3%)

Table 4 Distribution of measured lead concentrations for 2,639 samples in "unaffected estates" completed before 2005

	No. of estates	No. of buildings	No. of samples	No. of samples with Pb concentrations			
				< 1 μg/L	1–4 μg/L	5-9 μg/L	≥ 10 μg/L
All samples with Pb < 1 μg/L	109	225	2009	2009 (100%)			
All samples with Pb < 5 μg/L	20	56	440	412 (93.6%)	28 (6.4%)		
All samples with Pb < 10 μg/L	9	27	190	178 (93.7%)	3 (1.6%)	9 (4.7%)	
Total	138	308	2639	2599 (98.5%)	31 (1.2%)	9 (0.3%)	

* A total of 2,656 sample results is available; 17 of them are obtained from 9 schools and have been excluded.

Table 5 Comparison of excess lead data of WSD and HKUST – "fully flushed" vs first draw samples

Estate	No. of buildings	WSD/HD		HKUST	
		No. of samples	No. of samples with excess lead	No. of samples (flats)	No. of first draw samples with excess lead
Kwai Luen Estate Phase 2	2	122	5 (4.1%)	6	5 (83.3%)
Tung Wui Estate	2	52	4 (7.7%)	6	5 (83.3%)
Shek Kip Mei Estate Phase 2	2	79	8 (10.1%)	6	6 (100.0%)
Wing Cheong Estate	2	64	2 (3.1%)	6	3 (50.0%)
Kai Ching Estate	6	327	8 (2.4%)	18	14 (77.8%)
Un Chau Estate Phase 2 and 4	5	138	23 (16.7%)	15	5 (33.3%)
Hung Hom Estate	3	74	18 (24.3%)	9	6 (66.7%)
Lower Ngau Tau Kok Estate Phase 1	5	163	7 (4.3%)	15	5 (33.3%)
Yan On Estate	3	69	6 (8.7%)	9	1 (11.1%)
Ching Ho Estate	3	145	12 (8.3%)	9	1 (11.1%)
Choi Fook Estate	3	92	13 (14.1%)	9	0 (0.0%)
Total	36	1325	106 (8.0%)	108	51 (47.2%)

Table 6 Classification of buildings based on the HKUST sampling results

Estate	No. of class 1 buildings	No. of class 2 buildings	No. of class 3 buildings	Total no. of buildings
Choi Tak	1	0	0	1
Sau Mau Ping	1	0	0	1
Shui Chuen O	1	0	0	1
Un Chau Phase 5	1	0	0	1
Choi Fook	2	1	0	3
Ching Ho	1	2	0	3
Kwai Chung	1	1	0	2
Yan On	1	2	0	3
Hung Hom	0	1	2	3
Lower Ngau Tau Kok	0	2	3	5
Yee Ming	0	0	1	1
Kwai Luen	0	0	2	2
Shek Kip Mei	0	0	2	2
Tung Wui	0	0	2	2
Wing Cheong	0	0	2	2
Un Chau Phase 2 & 4	0	0	5	5
Kai Ching	0	0	6	6
Total	9	9	25	43

Table 7 Measured lead concentrations (mg/L) in meter room, entry to flat, and kitchen tap for vacant flats

Estate	House	Flat	Date	Meter	Entry	t = 0s	t = 30s	t = 60s	t = 120s	t = 180s	t = 300s
Un Chau	Un Nga	1813	12/12/15 10:30	0.007	0.017	0.017	0.010	<0.0025	<0.0025	<0.0025	<0.0025
				0.004*	0.008*						
			12/12/15 14:00	0.011	0.008	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
				0.005*	0.004*						
			12/17/15 11:05	0.008	0.008	0.002	<0.002	0.004	<0.002	<0.002	<0.002
				0.005*	0.006*						
Kwai Luen	Luen Yat	3607	12/12/15 11:53	0.017	0.033	0.026	0.007	<0.0025	<0.0025	<0.0025	0.011
				0.004*	0.003*						
			12/12/15 14:45	0.013	0.019	0.009	0.010	0.003	<0.0025	<0.0025	<0.0025
				0.005*	0.010*						
			12/17/15 11:45	0.014	0.022	0.012	0.011	<0.002	<0.002	<0.002	<0.002
				0.009*	0.002*						
Kai Ching	Mun Ching	2221	12/17/15 10:15	0.010	0.031	0.018	0.003	0.004	<0.002	<0.002	<0.002
				<0.002*	<0.002*						
			12/17/15 13:00	0.006	0.013	0.008	<0.002	<0.002	<0.002	<0.002	<0.002
				<0.002*	0.002*						

* samples were collected again at the meter room and the pipe entry to the flat about 5 minutes after the "t = 300s" sample was taken.

Sampling Protocol
(affected and unaffected estates)

Introduction

In view of the inadequacy of the sampling by the Water Supplies Department and Housing Department, independent and planned sampling was carried out by the Hong Kong University of Science and Technology (HKUST). The purpose of the field sampling was to provide (i) an independent dataset for identification of the sources and causes of excess lead in drinking water, and (ii) a basis for general health risk assessment. The sampling activity covered 36 buildings in the 11 “affected estates” and 7 buildings in 6 selected “unaffected estates”. In each building, 3 flats at upper, middle and lower levels were randomly selected by the Housing Department (HD). In total, 129 flats were sampled. **Table 2 of Appendix III** shows the details of all flats sampled.

Sampling protocol

The field sampling activities were all conducted by trained HKUST researchers. Coordinator of the field sampling was Dr. NT Lau of the Division of Environment of HKUST. There were 6 sampling teams. Each team consisted of two members; at least one member could speak and understand Cantonese well enough to communicate with the HD staff and the residents. Each team was responsible for sampling one building (three flats) each day. All team members were briefed and received training before the commencement of the survey on 30 November, 2015. The training was provided by Dr. Samuel Yu of HKUST Health, Safety & Environment Office (HSEO) Laboratory, which is accredited under the Hong Kong Laboratory Accreditation Scheme (HOKLAS).

The field sampling activity was conducted during 2-22 December 2015. The schedule of sampling is shown in Figure IV-1.

Preparation work by Housing Department (HD)

The resident was informed by HD staff to flush the kitchen and wash basin taps the night before sampling for 5 minutes before going to bed, and not to use the kitchen tap afterwards before the sampling. In case a filter was installed, the filter was removed by a contractor appointed by HD the day before sampling.

Briefing

A briefing session was conducted at 4pm the day before every sampling day. Sampling teams obtained the sampling bottles (provided by HSEO Lab) together with sampling forms and other apparatus (one 1 litre bottle and one 250 mL measuring cylinder for flow rate measurement), and the contact points and details of the next-day sampling from the field program coordinator Dr. Lau.

Sampling

Field samplings were conducted between 6:30 am – 9:00 am. The teams would meet with the Housing Department staff for briefing before commencement of the sampling.

Sampling procedure:

1. The sampling team briefed the residents the sampling exercise. The residents were asked two questions - (i) if kitchen and wash basin taps have been flushed for 5 minutes the day before; and (ii) if kitchen and wash basin taps have been used again after the flushing.

2. The kitchen tap was turned fully open to the cold water side with the first sample (250 mL) collected immediately at time zero. The tap remained open throughout the sampling.

3. The second, third, fourth and fifth samples (50 mL each, except the fifth sample of the third flat of each building, which was a 250 mL sample for quality control purpose) were collected at 20, 40, 60 and 80 seconds after the tap was turned on.

4. The sample identification number was recorded on the sampling form. Any potential contamination and other relevant information were also recorded.

5. A photo of the kitchen tap was taken using smartphone or camera.

6. Flow rate measurement: Water was collected using the 1 litre bottle provided; the time required to collect approx. 1 L of water was recorded. The exact volume of the water collected was measured using the 250 mL measuring cylinder provided.

An illustration of the sampling survey is shown in **Figure 1 of Appendix II**.

Post-Sampling and analysis of samples

After the sampling, the samples were transported back to HKUST. All apparatus and log sheets were returned. The teams reported any unusual circumstances to the coordinator and clarified the information on sampling forms in debriefing sessions held every morning on sampling days. All samples were preserved and logged in by HSEO Lab, and then selected samples were sent to the Government Laboratory (GL) around noon time by HSEO staff. The water samples were analyzed for lead, copper and nickel.

A total of 645 samples (excluding vacant flat and control flat samples) were collected; 290 samples were analyzed by GL and 269 samples by HSEO Lab. The unanalyzed samples were stored in HSEO Lab's calibrated refrigerator for future analysis. Results of analyses by GL were sent back to HKUST once available. Eighteen samples analyzed by both GL and HSEO Lab of HKUST were used for cross checking. For samples with lead concentration less than or equal to around 0.01 mg/L, the differences were typically less than 0.001 mg/L (1 μg/L); the mean difference of lead concentration over the range of 0.05 mg/L is 0.0022 mg/L (Figure IV-2).

Sun	Mon	Tue	Wed	Thu	Fri	Sat
29 Nov	30 Nov Training at HSEO	01 Dec	02 Hung Hom Estate Yan On Estate	03 Kwai Luen Estate Wing Cheong Est. Shek Kip Mei Estate	04 Ching Ho Estate Choi Fook Estate	05
06	07 Lower Ngau Tau Kok Estate Sau Mau Ping South Estate	08 Tung Wui Estate Kwai Chung Estate Choi Tak Estate	09 Kai Ching Estate	10 Un Chau Estate	11	12 Un Chau Estate* Kwai Luen Estate* * Vacant flat
13	14	15	16	17 Yee Ming Estate Kai Ching Estate* Un Chau Estate* Kwai Luen Estate*	18	19
20	21	22 Shui Chuen O Est.	23	24	25	26

Figure IV-1 Calendar for HKUST field sampling program.

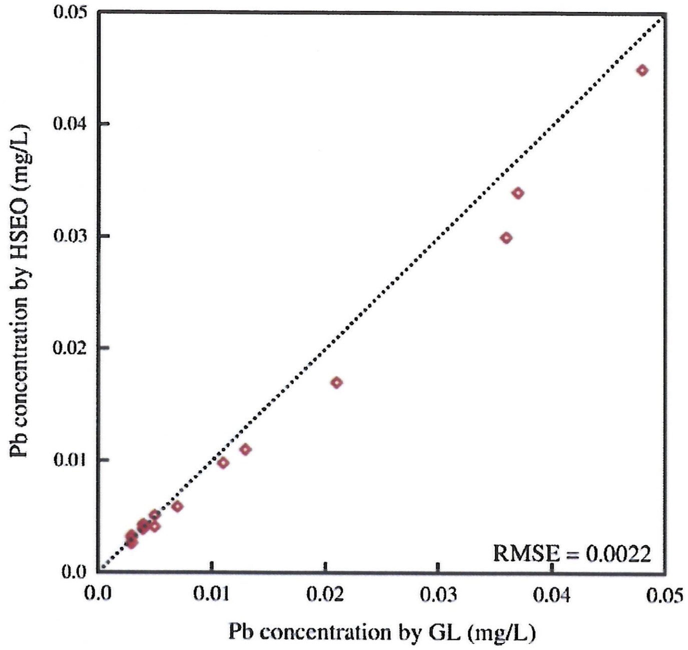


Figure IV-2 Cross checking of lead concentration analyzed by Government Laboratory (GL) and HKUST HSEO Lab.

APPENDIX V

Sampling Protocol
(3 Vacant Flats)

Special sampling surveys were also conducted in 3 vacant flats of three estates. Two sampling taps were installed: (i) at the water meter position inside the meter room; and (ii) at the location of pipe entry inside the flat. The kitchen and wash basin taps were flushed by HD staff for 5 min the day before. Samples were taken at the sampling and kitchen taps (Figure V-1). The vacant flat sampling was carried out by one sampling team. The pipe configuration of each flat was also measured on site for further analysis.

Vacant flats:

- Room 1813, Un Nga House, Un Chau Estate
- Room 3607, Luen Yat House, Kwai Luen Estate
- Room 2221, Mun Ching House, Kai Ching Estate

Sampling dates and estates sampled:

- 12 Dec 2015 (Sat), 10:00-15:00, Un Chau, Kwai Luen
- 17 Dec 2015 (Thu), 9:30-13:30, Kai Ching, Un Chau, Kwai Luen

Sampling procedure:

1. One 250 mL sample was collected at the meter room tap.
2. One 250 mL sample was collected at the tap at the entry of the water supply pipe to the flat.
3. The first sample (250 mL) at the kitchen tap was collected when the tap was opened. The tap remained fully open throughout the sampling.
4. The second, third, fourth, fifth and sixth samples (50 mL each) were collected at t = 30, 60, 120, 180 and 300 seconds at the kitchen tap.
5. The kitchen tap flow rate was measured using 1 L bottle and measuring cylinder.

6. After the flow rate measurement (which took around 5 minutes), one 250 mL sample was collected again at the meter room tap.

7. One 250 mL sample was again collected at the tap at the pipe entry to the flat.

8. After around 3 hours, the vacant flat was revisited and steps 1-7 were carried out again to collect one more set of samples (except for the second day of sampling for Un Chau Estate and Kwai Luen Estate vacant flats).

After the sampling, the samples were transported back to HKUST. All apparatus and log sheets were returned. All samples were preserved and logged in by HSEO Lab and then selected samples sent to the GL for analysis. A total of 80 samples were collected for vacant flats; 40 samples were analyzed by HSEO Lab and 40 by GL.

(a) (b) (c)

Figure V-1 Sampling at (a) installed tap in meter position; (b) tap at the water supply pipe entry to flat; and (c) kitchen tap.

APPENDIX VI

Summary on Computational Fluid Dynamics (CFD) Modelling

A three-dimensional (3D) unsteady computational fluid dynamics (CFD) model is used for investigating the accumulation of dissolved lead in stagnation and its mixing and transport in flowing condition.

Stagnant condition

In stagnant condition, the leaching of lead from the pipe wall and fixture surface into the water is governed by molecular diffusion. It is assumed that immediately adjacent to the pipe wall, the dissolved lead concentration is in the maximum equilibrium condition (Kuch and Wagner, 1983; Van der Leer et al, 2002). The three-dimensional diffusion process in the water supply chain can be described by a Fickian diffusion equation:

$$\frac{\partial C}{\partial t} = D\left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2}\right)$$

where $C(x,y,z,t)$ is the lead concentration in water; (x,y,z) are the spatial coordinates; t is the time; D is the molecular diffusivity of lead in water, taken as 10^{-9} m2/s (Kuch and Wagner, 1983; Van der Leer et al, 2002). At the location immediately adjacent to the pipe surface, a fixed lead concentration C_{eq} is prescribed as the equilibrium concentration. In this formulation, the leaching rate of lead is not a constant but decreasing with time as the water becomes more saturated with lead. In the absence of any better information, the equilibrium lead concentration for a given pipe joint or component is taken to be the measured maximum lead concentration determined in the 24-hour leaching test for a corresponding component for the vacant flat on 33/F, Luen Yat House, Kwai Luen Estate (WSD Task Force Report).

Flowing condition

With the water tap turned on, it is assumed that the flow in the relatively short water supply chain (in the order of 15-30 m) attains steady state condition immediately after the tap is open. The dissolved lead accumulated during the stagnation period will then be transported by the turbulent pipe flow to the open tap. Besides being transported by the flow, the lead will be mixed over the cross-section by the turbulence in the flow; the lead cloud will also disperse longitudinally due to transverse velocity shear. The mixing and transport of dissolved lead in the steady pipe flow is governed by the advective-diffusion equation:

$$\frac{\partial C}{\partial t}+\frac{\partial(uC)}{\partial x}+\frac{\partial(vC)}{\partial y}+\frac{\partial(wC)}{\partial z}=\frac{\partial}{\partial x}\left(E_T\frac{\partial C}{\partial x}\right)+\frac{\partial}{\partial y}\left(E_T\frac{\partial C}{\partial y}\right)+\frac{\partial}{\partial z}\left(E_T\frac{\partial C}{\partial z}\right)+S$$

where $C(x,y,z,t)$ is the lead concentration in water; $[u,v,w]$ (x,y,z) is the velocity field and E_T is the turbulent diffusivity determined by a two-equation turbulence model (k-ε model). E_T is typically in the order of 10^{-2}-10^{-3} m²/s. Lead leaching rates at different locations along the water supply chain (corresponding to different pipe joints and sections) are prescribed as mass sources S - defined as the leaching rate of lead per unit pipe wall surface area. S is taken as the measured lead leaching rate from 24-hour leaching tests for the flat on 33/F, Luen Yat House, Kwai Luen Estate (WSD Task Force Report). This modelling methodology for predicting lead distribution in the stagnant fluid and moving flow is similar to the approaches of Kuch and Wagner (1983) and Van der Leer et al (2002). The present method represents however a significant advance over the 1D modelling adopted in the earlier works, as 3D modelling allows a more accurate depiction of the complex flow and solute transport in the water supply chain pipe network.

Numerical solution

The solution of the above governing equations was obtained numerically using the FLUENT 3D CFD code. Key information of the water supply chain of the three vacant flats studied is given in Table VI-1. The model grid is generated based on the actual pipe system geometry directly measured on-site. The pipe section between the downpipe and the kitchen tap for a typical flat is studied, excluding less important details such as the branches to other flats, and branches to washroom, and heaters (see **Figure 2 of Appendix II** for the vacant flat in Un Chau Estate). Mixed tetrahedral and hexagonal grid cells are used to fit the boundary of various components (elbow, tees) in the system, with minimum grid cell size of about 1 mm (**Figure 4, Appendix II**). Meters, valves are modelled similar to a short pipe section of 5 cm; the lead leaching rate/equilibrium concentration (based on WSD measurements) is prescribed at the pipe wall. For a typical water supply chain of a Public Rental Housing (PRH) estate flat, 800,000 to 1,000,000 grid cells are used.

For stagnant condition, zero velocity is prescribed in the whole pipe system. For flowing condition, a steady-state solution of the velocity field is first predicted with the total flow rate prescribed at the inflow boundary and zero-pressure at the open kitchen tap. The computed 3D velocity field in the pipe system is then used for predicting the lead transport. The time step for the molecular diffusion computation is 20 s, while that for transport in flowing water is 0.02 s.

Stagnation Test

The data from stagnation test by WSD Task Force is used for calibration of the leaching rate and equilibrium concentration of the components in the water supply chain. Three vacant flats and one management office in Kai Ching Estate and Kwai Luen Estate were used for the test on stagnation and flushing. The stagnation test was conducted by first thoroughly flushing the water supply chain for 15 hours. Water then remained stagnant in the water supply chain and water samples were taken at 0, 1, 2, 3, 4, 6, 8, 24 and 48 hours for determining the lead contents. The numerical prediction is carried out in a similar way for the vacant flat at Room 3607, Luen Yat House, Kwai Luen Estate. **Figure 5 of Appendix II** shows the molecular diffusion of lead at a pipe socket at different times after stagnation. It can be seen that the dissolved lead concentration gradually builds up by molecular diffusion, and fills up the cross-section. Considering the limited available data and the complexity of the problem, the predicted lead concentration is in good agreement with data – the increasing concentration with stagnation time is well predicted (**Figure 8(a) of Appendix II**).

Flushing test

Flushing test is carried out after a certain period of stagnation to determine the variation pattern of lead concentration at the consumer tap after the tap is opened. In the investigation carried out by the WSD Task Force, flushing test was carried out immediately after 48 hours of stagnation test and samples were taken at 1, 2, 3, 4, 5, 10 and 30 minutes to determine the lead content. In this numerical study, the flushing test was carried out after around 4 and 18 hours of stagnation. Samples were taken at the time when the tap was opened, and after 30 s, 60 s, 120 s, 180 s and 300 s. The flushing tests were simulated numerically; the predicted lead concentration variation with time is compared with the measured data for Kwai Luen Estate vacant flat. The result shows that during the course of flushing, the lead concentration can vary greatly due to local accumulation of dissolved lead at the elbows, joints and pipe fixtures. However, the lead concentration in general drops to a very low level after 30 – 60 seconds; this is supported by both data of this study and the WSD Task Force Report (**Figure 8(b) and Figure 9 of Appendix II**).

References

Kuch, A. and Wagner, I. (1983). A mass transfer model to describe lead concentrations in drinking water. *Water Research*, 17(10), 1303-1307.

Van der Leer, D., Weatherill, N.P., Sharp, R.J. and Hayes, C.R. (2002) Modelling the diffusion of lead into drinking water. *Applied Mathematical Modelling*, 26, 681-699.

Table VI-1 General Information about the drinking water supply chain from the downpipe in meter room to the kitchen tap in the vacant flats for this study

	Room 1813, Un Chau Estate, Un Nga House	**Room 3607, Kwai Luen Estate, Luen Yat House**	**Room 2221, Kai Ching Estate, Mun Ching House**
Total length of pipe (m)	14	17	29
No. of bends	8	10	19
No. of tees	5	6	6
Measured flow rate (L/s)	0.25	0.35	0.27

* The pipe from the corridor first enters the kitchen for Un Chau Estate vacant flat. The pipe first enters the toilet for vacant flats in Kwai Luen and Kai Ching Estates.
** Meter room located at end of corridor for Un Chau and Kwai Luen Estate vacant flats. Meter room located at lift lobby for Kai Ching Estate vacant flat.

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COMMISSION OF INQUIRY

into Excess Lead Found in Drinking Water

Rules of Procedure and Practice

(made at the Preliminary Hearing on 20 October 2015)

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1. In accordance with the Commission's Terms of Reference, Commission proceedings will address the following matters –

   (i) the causes of excess lead found in drinking water in public rental housing developments;

   (ii) the adequacy of the present regulatory and monitoring system in respect of drinking water in Hong Kong and;

   (iii) recommendations with regard to the safety of drinking water in Hong Kong.

I. General

Public hearings

2. Unless otherwise directed, the hearings of the Inquiry will be open to the public.

Prohibition on photograph, audio/video recordings without the authorization of the Commission

3. Without the authorization of the Commission, no photographs may be

taken or audio/video recordings made in the hearing room, the overflow room or the other rooms in the Former Court of Final Appeal Building ("the Building") used for the purposes of this Inquiry.

Language

4. The proceedings will be conducted in Cantonese, although witnesses may give their evidence in any language or dialect that they wish to do so. Testimony given in English will be translated into Cantonese. The Commission will provide consecutive/simultaneous interpretation services when appropriate.

Access to documents

5. The Commission Secretariat has compiled, and will update regularly, an index of all documents and material provided to the Commission for the purpose of the Inquiry. Any involved party who wishes to gain access to such documents or material may apply in writing to the Commission Secretariat. At its discretion the Commission shall determine whether or not and to what extent access may be permitted.

6. Any involved party who wishes to obtain soft copies of documents to which access has been permitted by the Commission may apply to the Commission Secretariat to be provided with such copies. At its discretion the Commission shall determine whether or not such copies are to be provided. The cost of obtaining such copies shall be borne by the party obtaining such copies.

Use of materials provided by the Commission

7. All materials supplied by the Commission to any of the involved parties or any of them shall be used only for the purposes of the Inquiry. Public dissemination of any of such materials shall not be allowed until and unless

they have been adduced as evidence and expressly referred to in the Inquiry.

II. Standing

The participation and legal representation of other parties

8. Parties who have been directed by the Commission to provide written statements shall provide such statements by the date specified by the Commission, subject to applications for extension of time to be considered by the Commission.

9. Any party (apart from the parties referred to in paragraph 7 above), who wishes to (1) participate in the Inquiry (if leave to participate has not yet been granted by the Commission); (2) call any witnesses; and/or (3) adduce any witness statements and/or materials for the purpose of the Inquiry, shall apply in writing to the Commission within 7 days from today.

10. If the Commission decides that an application referred to paragraph 8 above be granted, the party in question shall (unless otherwise directed by the Commission) provide the witness statement(s) of the witness(es) to be called and/or material(s) to the Commission within such period as the Commissions may consider appropriate.

III. The hearing procedure

Opening addresses

11. Counsel for the Commission may make an opening address. Counsel for the parties permitted to participate and be legally represented (the "involved parties") may apply to the Commission to make their own opening addresses. If the Commission accedes to such application, the addresses will be made immediately after the address of counsel for the Commission. The Commission may determine the sequence and length of such addresses.

Evidence

12. The Commission notes that section 4 (1) of the Commissions of Inquiry Ordinance, Cap. 86 provides that in conducting the inquiry it may:

> "(a) receive and consider any material whether by way of oral evidence, written statement documents or otherwise, notwithstanding that such material would not be admissible as evidence in civil or criminal proceedings;".

The examination of witnesses

13. Oral evidence will be given under oath or affirmation.

14. The procedure by which the Commission will receive oral evidence is as follows:

(1) The Commission shall determine the sequence in which oral evidence be given in the Inquiry.

(2) Counsel for the Commission will lead the evidence of witnesses called by the Commission; Counsel for any involved party may apply to the Commission for leave to question a particular witness; Counsel for the Commission may re-examine the witness.

(3) Unless otherwise directed by the Commission, Counsel for an involved party may lead the evidence of witnesses who testify on behalf of such a party, after which Counsel for the Commission may question such witness; thereafter, Counsel for the other involved parties may apply to the Commission for leave to question such witness; finally, Counsel for that involved party may re-examine such witness.

(4) Unless otherwise directed by the Commission, insofar as any

witness wishes to adopt his or her witness statement as his or her evidence (with or without modification or elaboration), the contents of his or her witness statement are to be read out either by the witness or by his or her counsel.

(5) At any stage of the Inquiry the Commission may ask questions of any witness.

(6) The Commission may give directions to each party limiting the length of examination of witnesses and submissions.

(7) The Commission shall inform all involved parties as and when the witness statements and/or expert reports of the witnesses to be called by the Commission become available.

(8) The Commission may recall any person who has given oral evidence to answer further questions.

"Witnesses" referred to above shall include factual and expert witnesses.

<u>Closing addresses</u>

15. Counsel for the Commission and counsel for the involved party may make closing addresses. The Commission may determine the sequence and length of such addresses.

<u>The Substantive Hearing</u>

16. The Substantive Hearing of the Inquiry shall commence on 2 November 2015 at 10 am in the Building.

17. The Substantive Hearing shall, subject to any adjournments that the Commission may consider necessary from time to time, continue until 18 December 2015 and shall resume from 4 January 2016 until all evidence and

submissions are heard.

18. Unless otherwise directed, the Substantive Hearing will be held from 10 am to 1 pm and from 2:30 pm to 4:30 pm every day.