For information

SARS Expert Committee

Amoy Gardens Outbreak

This paper gives a descriptive account of the public health management of the Amoy Gardens SARS outbreak. The detailed epidemiological, environmental, and laboratory findings from the investigations are provided in a separate report attached.

Sequence of events

2. On March 26, Kowloon Regional Office (KRO) of the Department of Health (DH) received reports of 15 SARS cases from 7 families seen at the United Christian Hospital (UCH).

3. In the afternoon of March 26, DH medical team conducted a field visit to Amoy E and interviewed units with cases. No common activities or gatherings were reported by residents in the case flats, and they did not know other residents with SARS. Family members of SARS cases were put under medical surveillance, and contact tracing was conducted. Letters were distributed to all Amoy E residents, asking them to contact DH or seek medical attention if they developed symptoms. Pamphlets about SARS were distributed to all Amoy Gardens residents. The building management was instructed to disinfect Block E first, then other blocks. Disinfection of common areas of all blocks in Amoy Gardens was completed by 11PM that day.

4. During March 27-29, DH conducted daily site inspections to Amoy Gardens to identify possible sources of the outbreak and conduct medical surveillance on its residents. A multi-disciplinary team led by DH was formed consisting of the Hong Kong Police Force, Water Services Department, Environmental Protection Department, Electrical and Mechanical Services Department, Food & Environmental Hygiene Department, and Drainage Services Department, etc. The team conducted detailed inspections of Block E's potable water supplies, garbage disposal methods, sewer system integrity

and connections, elevator machine rooms and lift shafts, pest infestations, as well as the ventilation systems and water supply systems in a shopping mall of Amoy Gardens. No major irregularities were detected. Environmental swabs and water samples were taken. Medical staff went from door to door to conduct medical surveillance and interviews with available units in Block E and other blocks.

5. An epidemiological study using an exploratory questionnaire was initiated in collaboration with the WHO team to explore what risk factors were associated with the disease. Medical stations were set up at 2 entrances of Block E, manned by the Auxiliary Medical Services to provide pamphlets, masks, temperature taking and to answer enquiries.

6. By the evening of March 30, there was a cumulative total of 190 suspect / probable cases reported. Block E had the highest number of 93 cases, Block C had 24, Block B had 20, Block D had 15, and the rest were distributed among the remaining blocks. Cases in Block E had earlier onset dates than cases in other blocks.

7. That night, the Administration decided to issue an isolation order for Block E of Amoy Gardens. The decision was taken because of the continued steep rise in the number of cases in Block E, and the isolation order was designed to protect the health of the residents and the community as a whole, by preventing infected persons in Block E from spreading the disease to other places. Blocks B, C, and D were not isolated because residents there were likely infected by Block E residents, and there were much fewer households affected compared with Block E.

8. In the early morning of March 31, the isolation order was served to Block E. The multi-disciplinary team conducted another inspection on the same day. The possibility of virus transmission through dried up U-traps in the bathroom floor drain connected to the soil stack was raised (see details in the investigation report). Epidemiological and environmental investigations were conducted that day to provide evidence for this hypothesis.

9. On April 1, with more preliminary evidence pointing to disease transmission via the above mechanism, 247 Block E residents were evacuated to three holiday camps for isolation until April 10. On April 10, Block E

residents in the holiday camps were allowed to go back to their homes after their homes were rendered safe through the above series of measures undertaken by various government departments and parties.

Government actions

10. Thorough cleansing and disinfection operation was conducted with the cooperation of the Owners' Corporation, residents concerned and the joint efforts of various government agencies for all flats and common areas of Block E, Amoy Gardens between April 7 and 10.

11. Advice was given to residents of other Blocks in Amoy Gardens to disinfect their flats as precautionary measures. Guidelines and disinfectants were provided to residents. In particular, the importance of maintaining water seal at the U-traps of drainage outlets was stressed.

12. The Administration produced a guide to educate the public on the cleaning and disinfection of households, including bathroom cleansing and how to ensure the proper functioning of the water seal in U-traps. The Administration also published guidelines on the proper maintenance and repair of the drainage system and sanitary fitments. The guidelines were distributed to all management companies and owners' corporations.

13. The building management authorities of buildings where confirmed SARS patients reside has been notified of the infection and are required to take proper disinfection measures. Names of these buildings were placed on the homepage of the Department of Health to allow residents to take appropriate precautionary disinfection measures.

14. Major cleansing/disinfection operations were conducted in the surrounding areas of Amoy Gardens by the building management with advice given by FEHD. Pest control efforts were stepped up on a territory-wide basis.

Main findings of the investigation

15. The details of the investigation by the Department of Health are described in a separate report attached, which was submitted to the WHO on

April 18. In addition, a DH/WHO collaborated epidemiological study found that turning on the exhaust fan in the bathroom was a significant risk factor associated with developing SARS.

16. During April 28 through May 16, a WHO team from Health Canada arrived in Hong Kong to assist in environmental investigations in the Amoy Gardens outbreak. The WHO team announced its findings in a press conference on May 16. The conclusions were in line with the DH's investigation report. A copy of WHO's press release is attached with this paper.

17. In its press release on May 16, the WHO team reached the following conclusions:

"It seems highly likely that an unfortunate sequence of environmental and health events happened simultaneously and contributed to the spread of the SARS-related coronavirus in the Hong Kong residential estate of Amoy Gardens."

"At the time of the outbreak, the floor drain traps in many apartments seemed to have not been filled with water for long periods. Thus they had lost their sealing function and generated an open connection to the soil stack. In the case of a running exhaust fan and a closed door, droplets would be drawn from the soil stack into the bathroom through the floor drain. This could have contaminated the bathroom."

"A break of a flush water pipe serving unit 8 on March 21, 2003, led to an overnight shut down of the flush water system. This event most likely decreased the flow in the soil stack and thus would have favored the generation and movement of droplets in the soil stack. In addition, bucket flushing would have increased the generation of droplets in the bathroom."

"The running exhaust fan would have transported contaminated droplets present or generated in the bathroom into the light well. These droplets would have continued to move with momentum in the light well until they had reached a wall. At that point they would have likely moved up due to the natural current within the light well. The droplets would have risen to the top of the building, but might have been disturbed on its way by other active

ventilators discharging into the light well. Should the contaminated air have encountered an open window, it might have entered into other apartments even several floors away from the source."

Department of Health
July 2003

Investigation Report

An Outbreak of Severe Acute Respiratory Syndrome at Amoy Gardens

Kowloon Bay, Hong Kong

April 2003

Department of Health

Hong Kong SAR

Preface

Since 26/03/03, a large outbreak of Severe Acute Respiratory Syndrome (SARS) has occurred in Amoy Gardens in Kowloon Bay, Hong Kong. As of 10/04/03, a cumulative total of 289 cases were reported.

A dedicated investigation into the SARS outbreak in Amoy Gardens was made. Led by Department of Health, this investigation has drawn on professional inputs from Buildings Department, Drainage Services Department, Electrical & Mechanical Services Department, Food and Environmental Hygiene Department, Government Laboratory, Environmental Protection Department, Water Services Department, and Hong Kong Police Force. The purpose of the investigation is to identify the possible modes of disease transmission and factors behind the outbreak, thereby preventing similar outbreaks in the community.

This investigation was conducted under a number of limitations, not least an incomplete understanding of the disease, the paucity of epidemiological research on SARS, and the need to minimize inconvenience and distress to the affected residents. This report therefore does not purport to provide a final and definitive explanation on the outbreak. Nonetheless, it examines systematically the possible causes and mechanisms for the outbreak as well as different modes of transmission based on the available evidence collected. It also raises important points for attention that require more studies by local and international communities.

The outbreak was effectively controlled after deploying a combination of strategies targeted at various modes of disease transmission revealed by this investigation. These control measures learned from the Amoy Gardens experience have been applied throughout Hong Kong to minimize the chance of occurrence of SARS outbreaks. The reported daily number of SARS cases in Hong Kong has now been reduced by 60% since its peak in end of March.

Background

1.1 The earliest recorded outbreak of Severe Acute Respiratory Syndrome (SARS) in Hong Kong occurred in late-February 2003 (Metropole Hotel). In mid-March 2003, a large outbreak involving some 200 cases took place in a large regional hospital, the Prince of Wales Hospital. As of 10/04/03, a total of 998 SARS cases were known in Hong Kong.

1.2 On 26/03/03, an outbreak of SARS was reported among residents of Amoy Gardens, a private housing estate. As of 10/04/03, a cumulative total of 289 SARS cases were related to this cluster, making it the largest community SARS outbreak in Hong Kong.

1.3 Amoy Gardens is one of the early-generation high-rise private housing estates built in 1981. It is located in Kwun Tong District which is densely populated. The estate is located at the foot of a hill side and is separated from other surrounding housing estates by roads.

1.4 Owing to the steep rise in the number of cases in Block E of Amoy Gardens during the last few days of March 2003, the Director of Health ordered the building to be isolated for a period of 10 days starting from 31/03/03 to prevent spread of the disease. Residents of Block E were moved to holiday camps for temporary accommodation from 01/04/03 until 09/04/03.

1.5 An operation to cleanse and disinfect the flats and common areas of Block E was concluded on 09/04/03. Pest control measures were carried out in Amoy Gardens and the surrounding areas. Waste storage tanks were also cleansed. A crack in the sewage vent pipe located on 4/F, Block E, was repaired. Residents moved back to the building after the Isolation Order expired on 09/04/03.

1.6 A novel coronavirus has been confirmed by the World Health Organization as the causative agent for SARS [1]. As of 16/04/03, a cumulative total of 3293 cases were reported worldwide [2]. SARS affected areas include Canada, Singapore, China, United States of America, United Kingdom, and Viet Nam [3].

1.7 To our present knowledge, the mode of transmission of SARS is by direct close contact or indirect contact via fomites on contaminated surfaces [4]. Airborne spread of SARS has not been demonstrated. The incubation period is typically 2-7 days, but can be as long as 10 days [5].

1.8 Recent laboratory studies in Hong Kong have found that patients with SARS can excrete coronavirus in their feces and urine. The duration of virus excretion in feces in SARS patients may last 20 days or more.

1.9 This report describes the findings of epidemiological, environmental, laboratory investigations in this outbreak, followed by an assessment of the likely routes of transmission based on the available data.

Epidemiological investigations

2.1 A case was defined as a resident of Amoy Gardens who developed the following disease syndrome any time during 10/03/03 through 10/04/03:

a) Presence of new radiological infiltrates compatible with pneumonia;

b) Fever ≥ 38°C, or history of such any time in the last 2 days; and,

c) Presence of at least 2 of the following:

Chills any time in the last 2 days

New or increased cough

New or increased shortness of breath

Typical physical signs of consolidation

The following exclusion criteria apply:

a) Significant bronchiectasis

b) Leucocytosis on admission

c) CXR shows lobar consolidation

d) The pathogen is already known

2.2 For each case, we collected data with respect to date of reporting, date of onset, residential address, and basic demographic data such as age and sex. We administered an exploratory questionnaire to 192 cases with more detailed information on clinical signs and symptoms, travel history, contact history, household conditions, and various other exposures. Following hypothesis generation by the exploratory questionnaire, we initiated a case control study to

identify risk factors for development of SARS. The case control study is in progress at the time of writing this report.

2.3 The first SARS cases in Amoy Gardens were reported on 26/03/03. The number of reported cases peaked on 31/03/03 and declined subsequently (Table 1).

2.4 Figure 1 shows an epidemic curve on 277 cases with known onset dates as of 10/04/03. The earliest onset date in this cluster was 14/03/03, whose patient we refer to as the index case.

2.5 Figure 2 shows epidemic curves by individual blocks. Discounting the index case, cases in Block E appeared 3 days earlier than other blocks (21/03/03-23/03/03). The epidemic curve in Block E (and to a lesser extent, Blocks C and D) resembles a point source outbreak. Cases in other blocks are more evenly spaced out in time and consistent with propagated spread. There is a higher percentage of cases from Block E during the early phase of the outbreak than the later phase.

2.6 As seen in Table 2, Block E accounts for the highest proportion (43%) of cases, followed by Block C (15%), Block B (13%), and Block D (12%). Table 3 shows the percentage of households with SARS cases in each affected block. Block E had the highest percentage of case households (28%), followed by Block C (14%) and Block B (12%). Within Block E, Unit 8 had the highest percentage of case households (73%), followed by Unit 7 (42%) (Table 4).

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Summary Statistics of SARS Cases in Amoy Garden as at 10.4.03

Table 1 – Date of reporting of cases

Date of reporting	No. of cases
26-Mar	7
27-Mar	22
28-Mar	34
29-Mar	22
30-Mar	36
31-Mar	64
1-Apr	52
2-Apr	3
3-Apr	2
4-Apr	8
5-Apr	7
6-Apr	11
7-Apr	10
8-Apr	5
9-Apr	5
10-Apr	1
Total	289

Table 2 –
Number of confirmed SARS cases in Amoy Garden

	No. of cases	Percentage total
Blk A	12	4%
Blk B	39	13%
Blk C	43	15%
Blk D	35	12%
Blk E	125	43%
Blk F	17	6%
Blk G	9	3%
Blk H	1	0.3%
Blk J	1	0.3%
Blk K	1	0.3%
Blk N	1	0.3%
Blk P	1	0.3%
Blk Q	2	1%
Blk S	2	1%
Total	289	100%

Table 3 – Number of households with cases

	No. of households	% of households with cases
Blk A	11	4%
Blk B	32	12%
Blk C	36	14%
Blk D	27	10%
Blk E	75	28%
Blk F	15	6%
Blk G	9	3%
Blk H	1	0.4%
Blk J	1	0.4%
Blk K	1	0.4%
Blk N	1	0.4%
Blk P	1	0.4%
Blk Q	2	1%
Blk S	2	1%

Table 4 – Number of households with cases in Block

	No. of households with cases in Blk E	Percentage of households with cases
Room 1	9	27%
Room 2	7	21%
Room 3	6	18%
Room 4	8	24%
Room 5	2	6%
Room 6	5	15%
Room 7	14	42%
Room 8	24	73%

Table 5 –
Characteristics of cases by sex, age, and symptoms

Characteristic	Percentage
Sex	
Male	45%
Female	55%
Age	
0-14	10%
15-49	74%
50-64	13%
≥65	3%
Symptom	
Fever	95%
Temperature ≥39C	52%
Chills	67%
Diarrhea	66%
Headache	56%
Muscle ache	52%
Cough	44%
Dizziness	38%
Sore throat	28%
Abdominal pain	24%
Vomiting	17%
Runny nose	16%
Shortness of breath	12%
Red eye	5%
Contact with SARS case	4%
Visit to Mainland	8%

Figure 1

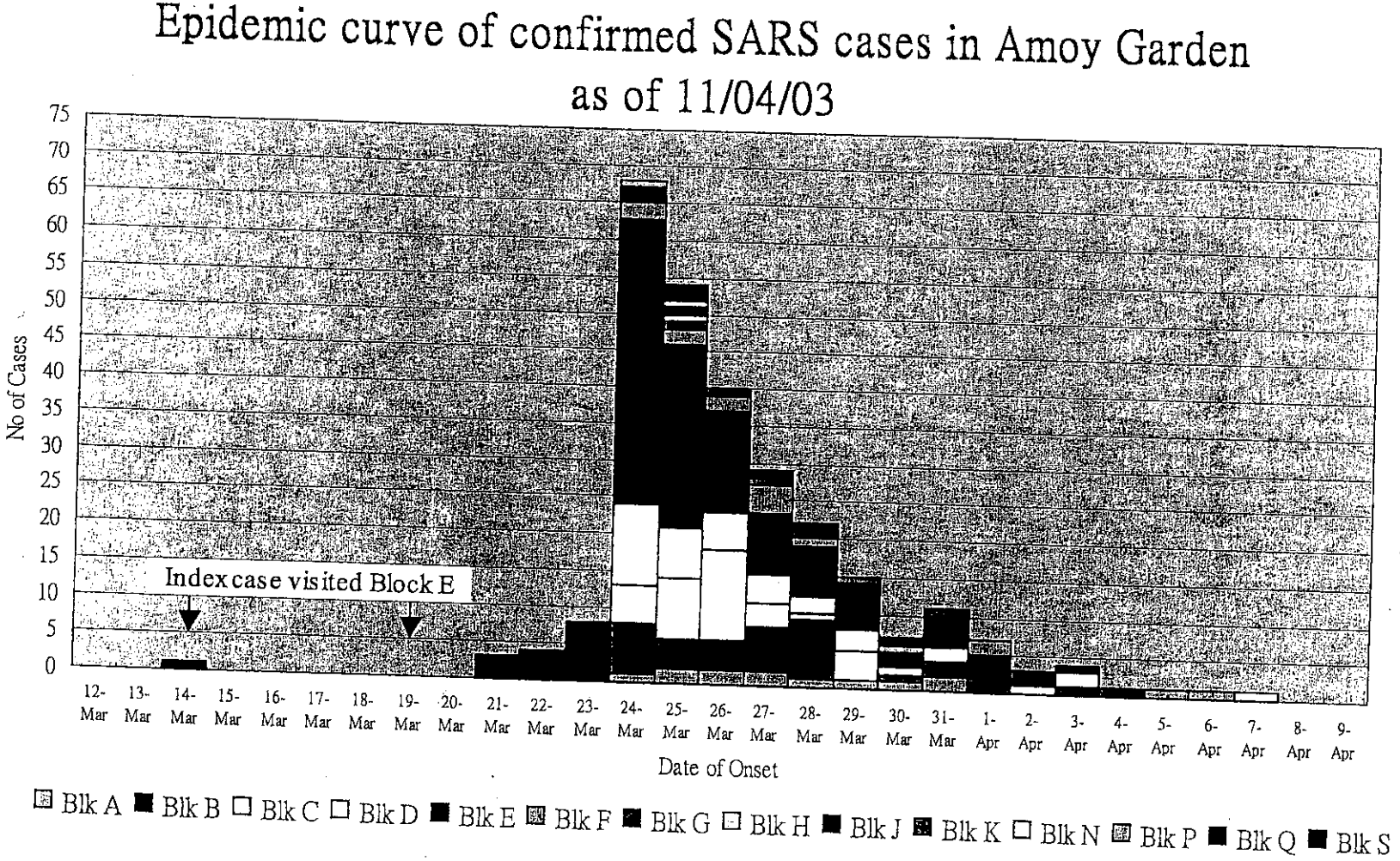
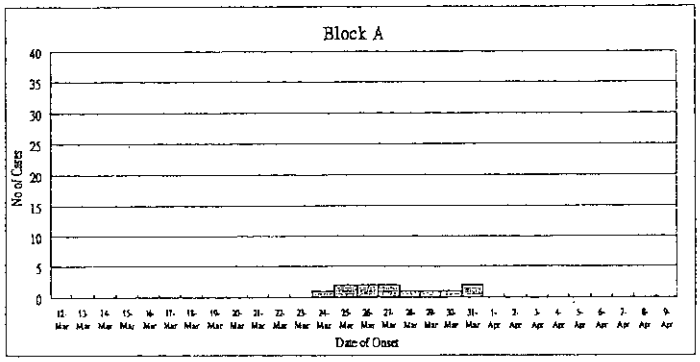
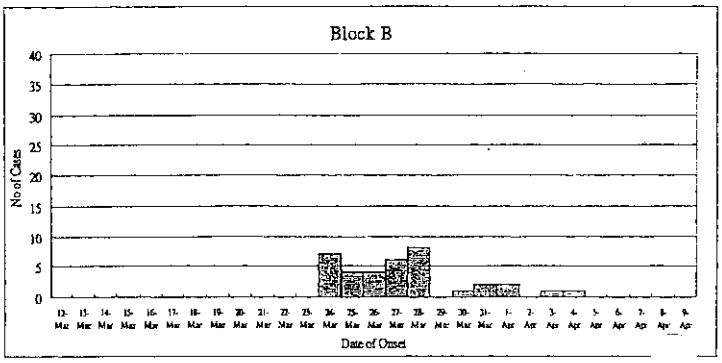
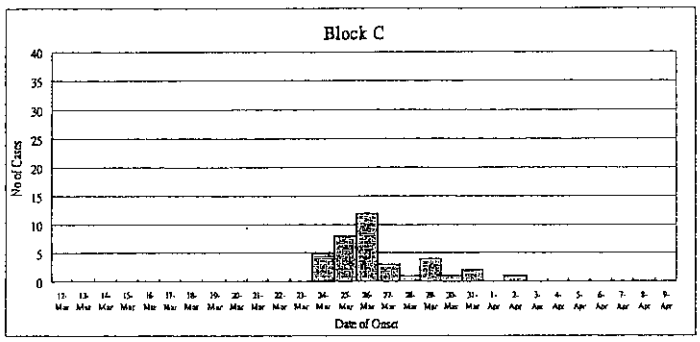

Epidemic curve of confirmed SARS cases in Amoy Garden as of 11/04/03
No of Cases
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Index case visited Block E
12-Mar
13-Mar
14-Mar
15-Mar
16-Mar
17-Mar
18-Mar
19-Mar
20-Mar
21-Mar
22-Mar
23-Mar
24-Mar
25-Mar
26-Mar
27-Mar
28-Mar
29-Mar
30-Mar
31-Mar
1-Apr
2-Apr
3-Apr
4-Apr
5-Apr
6-Apr
7-Apr
8-Apr
9-Apr
Date of Onset
Blk A
Blk B
Blk C
Blk D
Blk E
Blk F
Blk G
Blk H
Blk J
Blk K
Blk N
Blk P
Blk Q
Blk S

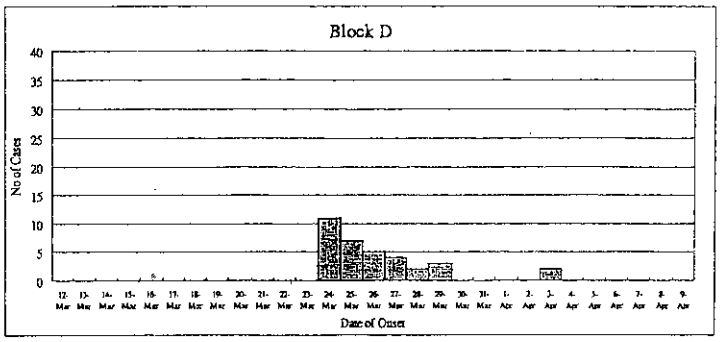
Figure 2

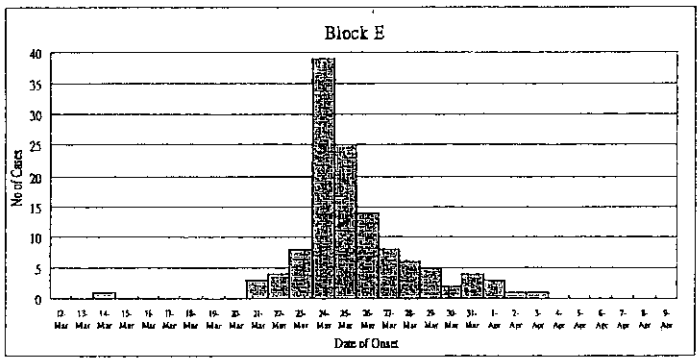
Epidemic curve of SARS cases by Block A-G in Amoy Gardens (10/04/03)(N=277)

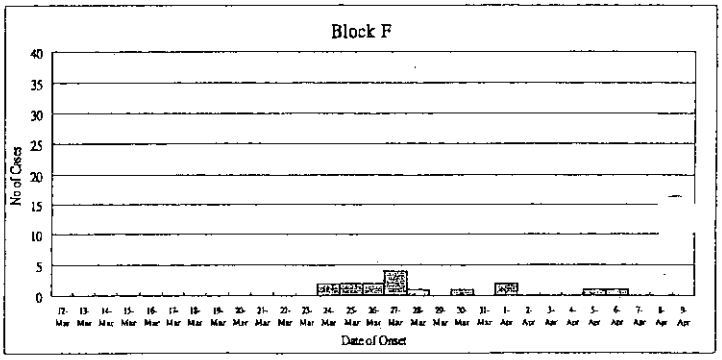


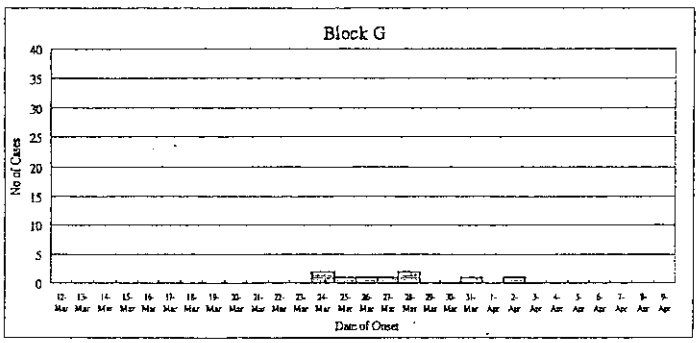












2.7 Annex 1 details the spread pattern and dates of onset by individual units on different floors and blocks. In Block E, the mean number of cases per affected household was higher for Unit 7 and 8 compared with other Units (2.1 vs. 1.2). Among affected households in Block E with ≥2 cases, 90% of them had case onset dates spaced ≤2 days, implying common exposures rather than secondary spread. The percentage of affected households above 10/F was significantly higher than those 10/F and below (34% vs. 7%, p<0.001). In other blocks, both the number of affected households and the mean number of affected members per household were lower than Block E.

(Annex / not attached)

2.8 Table 5 shows the characteristics of the cases by sex, age, common symptoms, contact with known SARS cases, and visit to Mainland China. Fifty-five percent of the cases were female. Almost three-quarters of cases were adults aged 15-49. The commonest reported symptoms were fever (95%), chills (67%), diarrhea (66%), and headache (56%). High fever (≥39C) was noted in half of the cases. Except for the diarrhea, the prevalence of symptoms was by and large comparable to an earlier SARS cohort at PWH [6]. The exploratory questionnaire did not find a common exposure shared by most cases in terms of a common event, gathering, trip, or visit to a specific place.

2.9 Block E cases did not differ significantly in age and sex from cases in other blocks. Block E cases reported a higher percentage of being in close contact with someone outside the family who has had pneumonia (10% vs. 2%). Also, a higher percentage of Block E cases reported problems with the sewer systems (13.4% vs. 2.7%). In particular, 20.6% of cases living in units 7 or 8 of Block E reported sewer system problems, compared with 6.1% among cases

living in units 1-6 of Block E.

2.10 The index case was a 33-year-old man who traveled between Hong Kong and Shenzhen. He required hemodialysis for chronic renal failure due to systemic lupus erythematosus, and he was followed up at Prince of Wales Hospital (PWH). On 14/03/03, he had onset of fever, malaise, chills, rigor, and diarrhea. He visited his brother's family in Unit [redacted], Block E of Amoy Gardens, stayed overnight and used the toilet there. On 15/03/03, when he was followed up at PWH, he had a fever of 38 degrees Celsius, white cell count of 6.1, lymphocyte count of 0.5, and right lower zone haziness on chest X-ray. Nasophyrangeal aspirate was positive for influenza A. Upon hospital discharge on 19/03/03, he stayed at his brother's flat and passed stools in the toilet. On 22/03/03, he was re-admitted to PWH due to shortness of breath. Two nurses who cared for him subsequently developed SARS. His brother and sister-in-law were also diagnosed to have SARS on 23/03/03 and 28/03/03 respectively.

Environmental investigations

3.1 The estate consists of 19 residential blocks (Blocks A – S) of 33-storey sitting on a podium with three levels of shopping arcade underneath. Each residential block has 33 floors (4/F-36/F) and each floor has eight units. The size of each Unit is approximately 48 sq. meters. The eight units are built around a rectangular-shaped central core containing three passenger lifts. Air ventilation system of each individual unit is independent (i.e., no central air-conditioning system). Each unit is furnished with one toilet and one kitchen together with living and bedrooms. The bathroom unit is small in size, about 3.5 square meters. Units of the same stack in different floors are served by plumbing and drainage piping systems running vertically along the external wall. Adjacent units (e.g., unit 7 and 8) were separated by a narrow 1.5-meter light well (or "canyon"), where bathroom windows, exhaust fans, master bedroom windows, air conditioners, and laundry drying racks faced one other. The estate accommodates an estimated 19,000 residents. The location map of Amoy Gardens and the floor plans of an individual block are shown in Figures 3A and 3B respectively. On the northeast of Amoy Gardens, there is a construction site on a hill slope for senior citizen residences development at Jordan Valley.

Figure 3A – Location map of Amoy Gardens

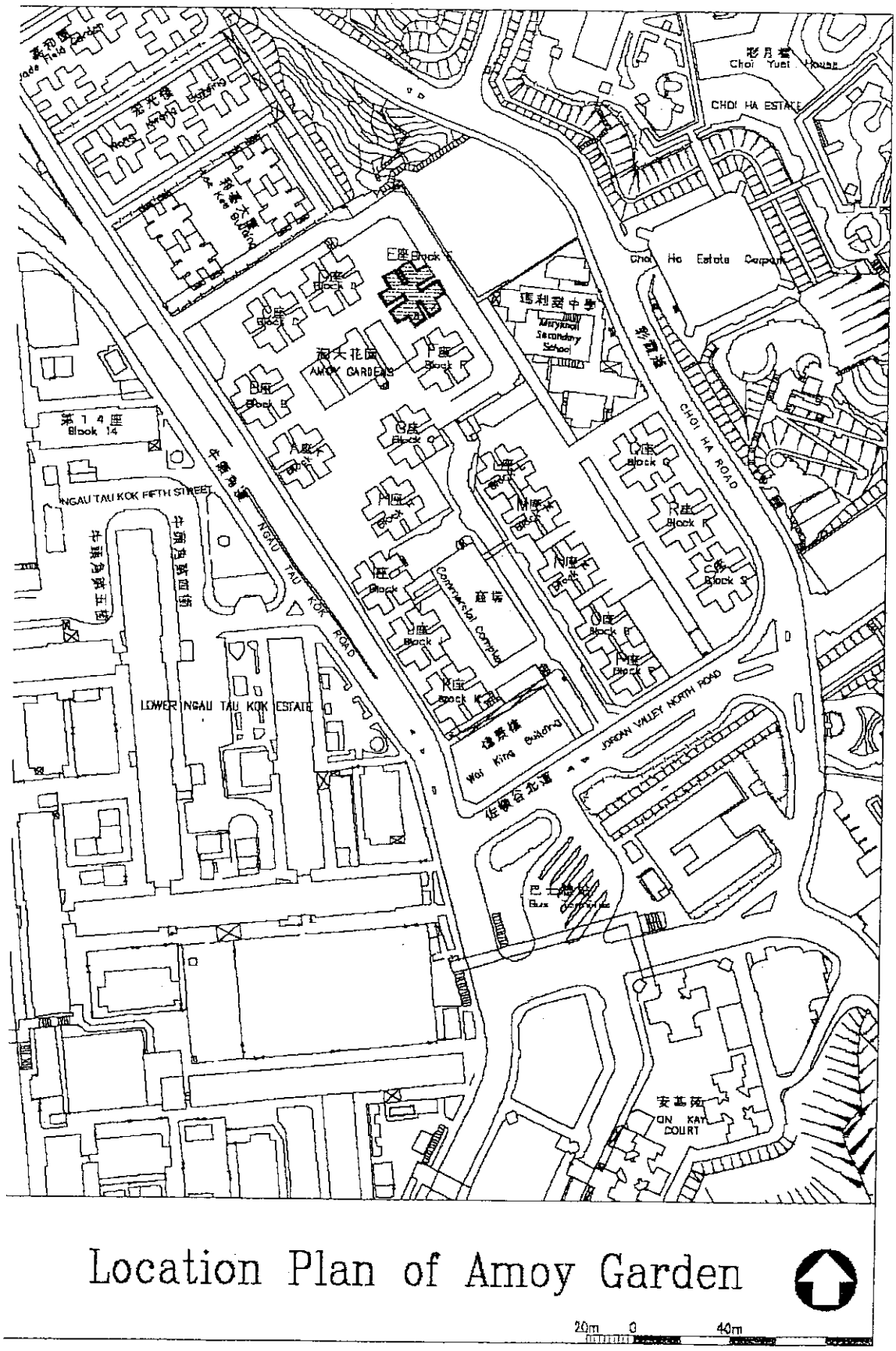
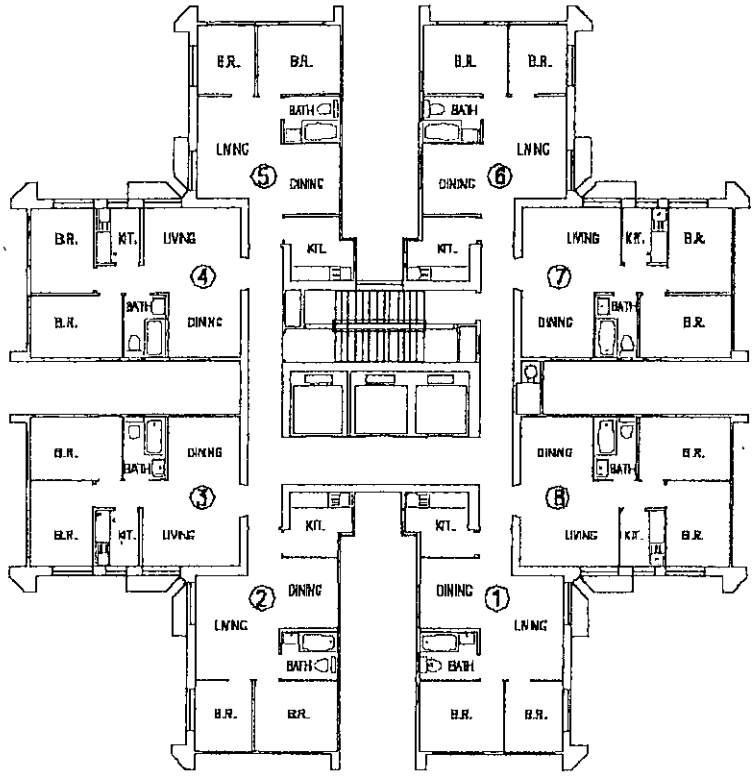


Figure 3B – Floor plan of a residential block at Amoy Gardens



Block E

Typical Floor Plan of
Block E at Amoy Garden

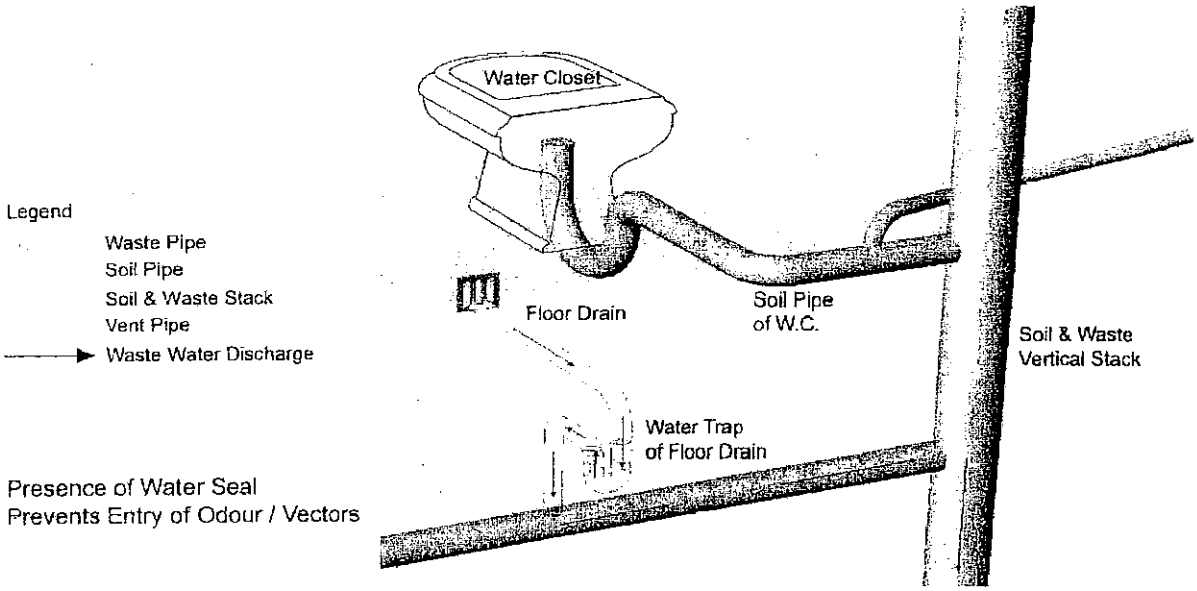
Drainage and sewer systems

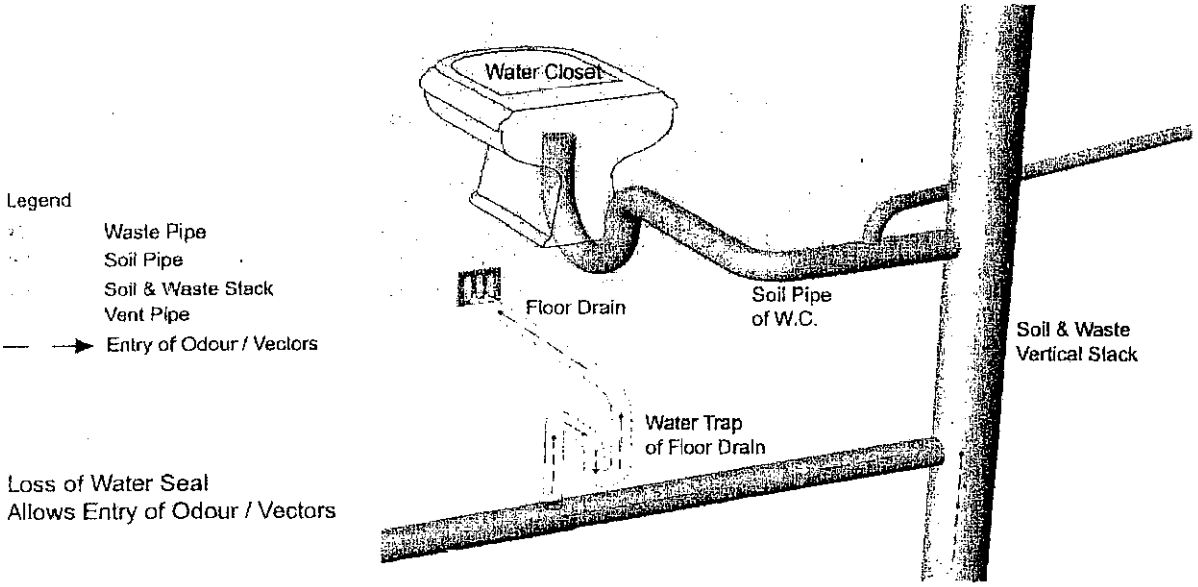
3.2 The sewerage system at Amoy Gardens comprises an unplasticised polyvinychloride (uPVC) soil stack of 100mm running from the top floor to the 4th floor where it is joined by a uPVC waste pipe of 80mm diameter from kitchen units also extending through the height of the building. For the soil stack, there is a parallel air vent pipe of 55mm in diameter re-joining the soil stack at the roof level. The water closet, the floor drain, the bath tub, and wash basin in the bathroom are all connected to the external soil stack which is ventilated at the top (Figure 3C). The kitchen sink and kitchen floor drain are connected directly to the waste water pipe inside the kitchen, which is also vented at the top.

3.3 One soil stack collects effluent discharge for the same Unit number on all floors in the same block. Soil stacks from different units do not cross until they join at the podium level and subsequently connected up at the manholes at the ground level of the building.

3.4 The floor drain in the bathroom is linked to the soil stack, separated by a U-shaped trap designed as a water seal. When the water seal dried up, there is a direct pathway between the soil stack and the bathroom space.

Figure 3C





Floor Drains at Amoy Gardens

3.5 Interviews with Amoy Gardens residents revealed frequent complaints about foul smell in toilets, which suggest that the U-trap arrangement might not be functioning properly in some units. As the water closets, the basins and the bathtubs were frequently used, their U-traps should be charged with water and should have been functioning properly. However, as most households had the habit of cleaning the bathroom floor by mopping instead of flushing it with water, the U-traps connected to most floor drains were likely to be dry and would not have been functioning properly.

3.6 An experiment carried out in one of the units in Block E clearly showed reflux of air from the soil stack into the bathroom through the floor drain when the exhaust fan in the bathroom was switched on, creating negative air pressure in the small bathroom (videotape available). Such reflux could bring droplets of contaminated sewage present in the soil stack, dispersed inside the bathroom, and extracted by the bathroom exhaust fan into the light well between adjacent units. The contaminated droplets could then enter other units through open windows along both sides of the light well between Units 7 and 8.

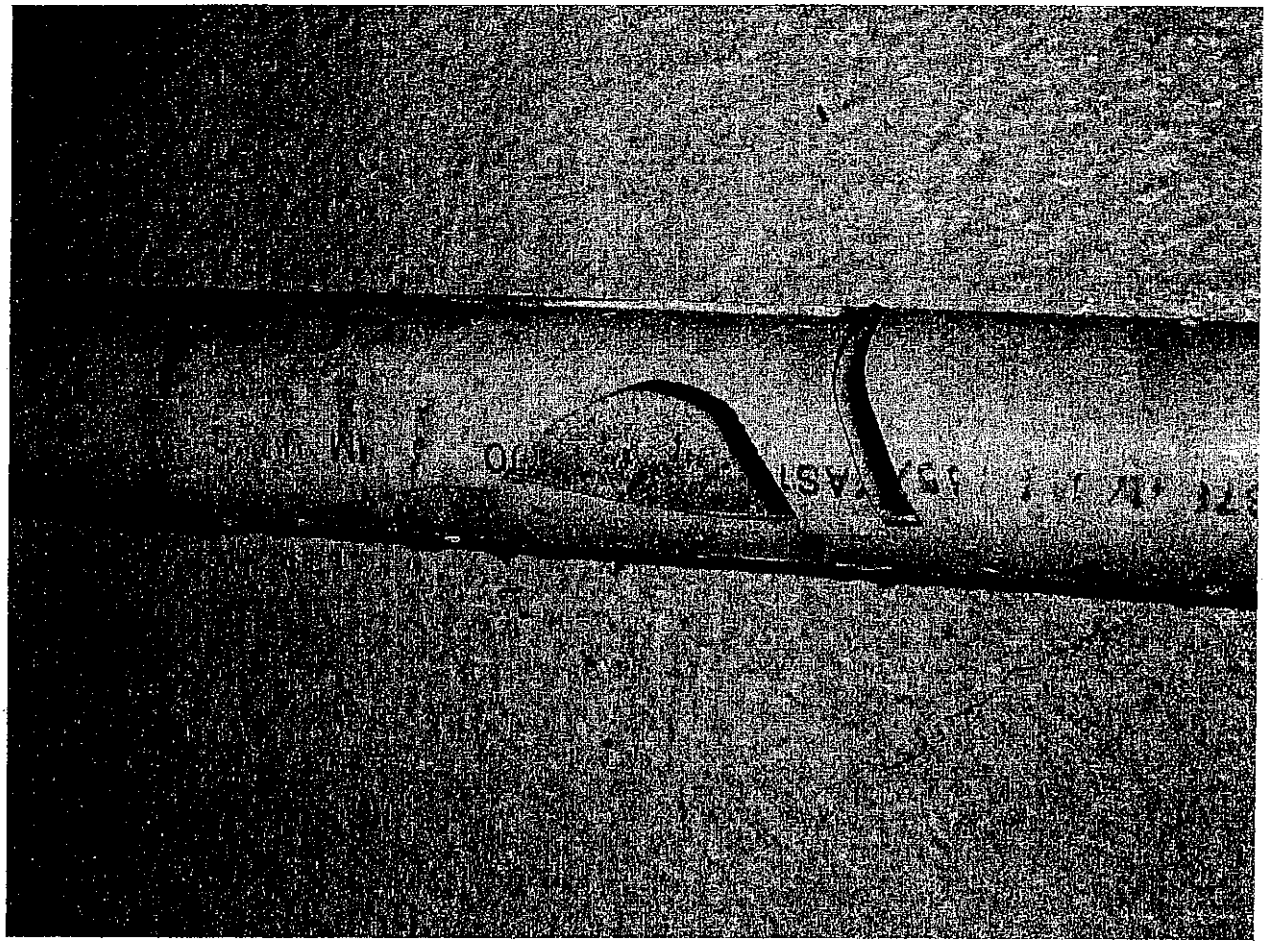
3.7 Testing of the soil stacks for 6 units of Unit 7 and 8 using a tracer dye did not show visible leakage. Stains were observed at the junction between the wall and external pipe, probably related to sewage seepage or rusting of metal brackets. A large crack was found on a sewage vent pipe on 4/F upon examination of the accessible portions of the duct (Figure 4). A smoke test was performed using oil-based droplets at ambient temperature to simulate aerosol movement. During the smoke test, smoke released into the soil stack at the roof level was observed to leak from this broken vent at 4/F

into the light well between units 7 and 8. In theory, the cracked sewer vent pipe could result in the emission of droplets carrying contaminated sewage into the light well every time a toilet was flushed.

3.8 When a smoke test (oil-based emulsion at ambient temperature) was performed between the 1.5-meter wide light well between Units 7 and 8, the aerodynamics of the light well demonstrated a "chimney effect". The puff of oil droplets was shown to rise inside the light well, expanding laterally as it traveled up the height of the building in a matter of minutes under prevailing wind condition (video available). Furthermore, a SF6 tracer gas test was conducted by releasing the tracer gas at Unit [redacted] and measuring the dispersed gas at Unit [redacted] and at Unit [redacted]. The level of SF6 at Unit [redacted] showed a dilution of 100 times while at the 7th floor, it was not detectable. This "chimney effect" could thus create an upward force that acts on droplets coming into the light well between Units 7 and 8 (and perhaps explain why there were more cases on the upper floors). However, it was not known what quantity of virus, if any, would be dispersed through this mechanism.

3.9 An underground sewage drain joins Blocks F, E, D and C in Amoy Gardens at the ground level. Another underground sewerage drain joints Blocks G, A and B. They are joined together between Block B and Block C before entering the public sewer, after passing through the Amoy Gardens' terminal manhole which is incorporated with a U-trap.

Figure 4 – Broken vent pipe at 4/F, Block E, Amoy Gardens



Water supplies

3.10 The three water tanks (fresh water, flushing water and fire service) were located on the top of Block E. Manhole covers on top of the water tanks were locked. There were 3 mains trunks down fed pipes supplying 4/F-13/F, 14/F-23/F, and 24/F-36/F respectively. Except for a missing flap on the overflow pipe of the fresh water tank, no irregularities were found on inspection. No irregularities were found at the sump tanks inside the pump room of Block E and F.

Vectors

3.11 Considerable numbers of dead American cockroaches (*Periplaneta americana*) were found along the surface drainage channels on ground level of Amoy Gardens. Some dead American cockroaches were also found in the car park underneath Block E one day after insecticidal treatment. Cockroach infestation was detected in 5 out of 10 inspected licensed food premises in the shopping mall of Amoy Gardens (as of 10/04/03). Live cockroaches were successfully trapped near drain holes in the podium of Block E where some 20 large refuse collection bins were kept nearby.

3.12 Rodent infestation was found at the ground level and in the shopping mall of Amoy Gardens. Rodents and rodent droppings were detected at the car park and refuse collection Units on the ground floor. Signs of rodent infestation were also found in 5 out of 10 inspected licensed food premises in the shopping mall of Amoy Gardens (as of 10/04/03). Rodent droppings and sight of live rats were noted in the suspended ceiling in some of the licensed food premises. However, signs of rodent infestation were not detected in the

residential blocks. Eleven out of the 12 live rodents collected were sewer rats that were active in the ground level and lower floors of a building.

Garbage and elevators

3.13 One garbage cleaner was responsible for collecting refuse for one whole block beginning around 9:30 PM every day. Garbage collection started from the top floors down. Passenger lifts were used to transport large garbage bags placed by the households in the back staircase awaiting collection by cleaners. Garbage collected from Blocks A – G was taken to a refuse collection point on the podium level in Block F. There was no mixing of garbage cleaners in different blocks just before the outbreak. No SARS case was reported among the garbage cleaners.

3.14 Each block is served by 3 elevators. Each floor is served by one elevator which stops every 3 floors. No obvious clustering of cases was observed along flats served by the same elevator. Smoke test for air flow in Block E elevators did not yield any pattern that explained the clustering of cases in units 8 and 7. The bottom lift shaft showed old newspapers and other rubbish.

Construction site at Jordan Valley

3.15 The construction site had a 26-storeyed building on a hill slope on the northeast of Amoy Gardens. Approximately 200 construction workers worked there. One worker was confirmed to have SARS with onset date 25/03/03, shortly after the peak of the outbreak. He had history of visiting Amoy Gardens during the incubation period. No other workers were hospitalized with SARS.

3.16 Inspection did not find machinery or work processes that generated fine dust particles or aerosols, e.g., drilling or hydraulics. Mobile toilets were provided on every 3 floors (G/F, 3//F, 6/F, etc), but toilets above 15/F did not arrive until end of March. Notices were put up asking workers to use the mobile toilets. The worker with SARS claimed to use them all the time. The site suspended operation since 01/04/03 because of the Amoy Gardens outbreak.

Laboratory investigations

Laboratory investigations

4.1 All laboratory specimens were tested at the Public Health Laboratory Center of the Department of Health.

4.2 A total of 61 air samples were collected from inside the residential units, on the roof top, inside lift cars, lift plant Unit, exhaust of lift chamber, and at various locations near the sewage drain systems in six blocks (including block E) of Amoy Gardens. The air samples were collected using an impactor type air sampler. One hundred liters of air were sampled onto filters which was cultured for bacteria using McConkey and lauryl sulphate agar. All the collected air samples were negative for *E. coli*. One air sample plate on Block E near a toilet was positive for the coliforms *Klebsiella spp* and *Citrobacter freundii*. Some bacteria of no outbreak significance were isolated in kitchen, such as *Ewingella Americana, Aeromonas hydrophilia*, and *Serratia plymuthica*. Fungal cultures of air samples have also been performed, and the results are pending at the time of writing this report.

4.3 Fourteen water samples were taken from the fresh water tank on the roof, the water taps of various flats, and the sump drain tank at the pump room. Sterile bottles of at least 500 ml capacity each (with added sodium thiosulphate to inactivate available chlorine) were used to collect the samples. They were examined for *E. coli* and fecal coliforms. Results were negative for these organisms.

4.4 Over a hundred environmental swabs were collected from various sites, including floor drains in the bathroom, toilet rim, toilet fan, and outer wall, and outer surfaces of sewer pipeducts. One environmental swab collected from a toilet inner rim was positive for coronavirus by RT-PCR. That Unit was an infected household ([redacted]) with onset date 26/03/03. All other environmental swabs were negative.

4.5 Urine samples were taken from toilets of the Jordan Valley construction site. They were negative for coronavirus by RT-PCR.

4.6 Approximately 200 samples consisting of throat/pharyngeal swab, anal/rectal/fecal swab, body surface swab, urine samples, droppings, and serum were taken from domestic cats, domestic dogs, rodents, and cockroaches in Amoy Gardens. These were tested for coronavirus by RT-PCR using the primer for human SARS cases. Positive results were obtained from swabs taken from domestic cats and dogs, rodents (droppings and throat swabs), and cockroaches (body surface, gut swab). Genetic sequencing showed the coronaviruses from these samples were >99% similar to those detected in patients. The cats and dogs were kept inside households with SARS cases. The rodents and cockroaches were collected near refuse collection room and sewer drains. The rodents did not display signs of disease, and autopsies showed that their tissues were free from infection and also negative for coronavirus on RT-PCR.

Routes of transmission

Probable explanation for the outbreak

5.1 Given the unique spatial distribution pattern of cases in Block E and taking into account of the contact of SARS patients and the reported large number of patients with diarrhea symptom, we observe that environmental factors played a major role in this outbreak.

5.2 It has been postulated that some people with compromised immune system can infect a large number of people by excreting copious amounts of viruses. The index case in this outbreak, who suffered from SLE and chronic renal failure, was highly infectious as his brother, sister-in-law, and attending healthcare workers all came down with SARS.

5.3 Recent laboratory studies in Hong Kong have shown that many patients with SARS excrete coronavirus in their stools which can survive for prolonged periods. Overseas studies have reported that some patients had diarrhea during the febrile syndrome [5]. In this outbreak, a relatively high percentage of cases had diarrhea, and they contributed to a significant virus load being discharged into the sewer system and the environment.

5.4 The index case was suffering from diarrhea as he defecated in his brother's flat in Unit [redacted] Block E on 14/03/03 and 19/03/03. Between 23/03/03 and 26/03/03, a cluster of SARS cases appeared in Unit 7 between

13/F and 20/F, directly above and below the flat of the index case in Unit 7, [redacted] (Annex 1). It is probable that the index patient initially infected a small group of residents within Block E and subsequently the infection spread to other residents through the sewage system, person-to-person contact and the use of shared communal facilities. This is supported by the observation that Block E cases appeared 3 days earlier than other blocks.

(Annex / not attached)

5.5 The spread of SARS by contaminated sewage is supported by the finding of coronavirus by RT-PCR in a toilet rim in an affected household in Block E. Furthermore, the spatial distribution of the cases in Block E in parallel with soil stacks and the higher incidence of reports about sewer drain problems in Block E (particularly Units 7 and 8) provide additional pointers to the role of sewage contamination.

5.6 The bathroom floor drains with dried-up U-traps provided a pathway through which residents came into contact with small droplets containing viruses from the contaminated sewage. These droplets entered the bathroom floor drain through negative pressure generated by exhaust fans when the bathroom was being used with the door closed. Water vapor generated during a shower and the moist conditions of the bathroom could also have facilitated the formation of water droplets. The chance of exposure was increased given the small size of bathrooms (3.5 square meters) in apartment units of Amoy Gardens (Figure 5). Contaminated droplets could then deposit virus on various surfaces, such as floor mats, towels, toiletries and other bathroom equipment.

Figure 5 – Small bathrooms in Amoy Gardens

5.7 The actual sequence of events leading to disease propagation from Block E to other blocks is difficult to reconstruct, but is probably attributable to a combination of factors including person-to-person spread between cases and their close contacts, vectors carrying the virus, and environmental contamination. Disease transmission among close contacts of cases such as family members was observed in this outbreak, and it was not uncommon for families in Amoy Gardens to own flats in different blocks. Laboratory tests have found that cockroaches and rodent droppings in Amoy Gardens contained coronavirus. Such vectors probably played the role as mechanical carriers for the virus since the rodents did not display signs of disease and autopsy showed that their tissues were free from infection and negative for coronavirus.

Unsubstantiated hypotheses

5.8 Airborne transmission is not compatible with the epidemiological picture. Strong signs of spatial clustering were present in certain blocks and Units which is not explainable by airborne transmission. The outbreak came down steadily after its peak without showing a second wave one incubation period after, which would be expected of airborne transmission. The overall attack rate among all Amoy Gardens residents is about 1.5%. The attack rate would have been higher in a densely populated place such as Amoy Gardens if airborne transmission had occurred.

5.9 Waterborne transmission is unlikely. If the water tank of Block E were contaminated, all floors and units would have been equally affected, in contrary to the observed spatial clustering of cases in Units 7 and 8. Waterborne spread also could not explain why blocks other than Block E were

also affected. Moreover, no sign of fecal contamination was found from all the water samples collected.

5.10 The hypothesis implicating aerosolized dust containing virus particles being carried from the construction site to Amoy Gardens faces many questions. The predominant wind direction before the outbreak was south-easterly, which was not in the right direction from the construction site to Amoy Gardens (though incidental change in wind direction is possible). Except for one worker with SARS, there is no other proven focus of infection in the construction site. Other unsolved questions include the lack of a visible means to generate aerosolized dust particles, and the infective dose required for the massive outbreak. It is also difficult to explain why Block F is relatively spared despite its closeness to Block E.

Conclusion

6.1 The epidemiological, environmental, and laboratory evidence suggests that the SARS outbreak in Amoy Gardens was primarily caused by sewage contamination associated with the index patient and other infected persons excreting coronavirus that gained entry to households through the bathroom floor drain with dried U-traps. Other modes of transmission include person-to-person transmission through close contact with cases, vectors acting as mechanical carriers for the virus, and environmental contamination. Airborne and waterborne transmission is not compatible with the observational data.

6.2 As always, reconstruction of the outbreak has proved difficult and it is not possible to find a single cause that explains the outbreak completely. The conclusion in this investigation report is based on the best knowledge available, and is subject to refinement in light of results from new studies.

6.3 With the cooperation of Block E residents and the joint efforts of various Government agencies, an operation to thoroughly cleanse and disinfect the flats and common areas of Block E, Amoy Gardens, was concluded on 10/04/03. The disinfection focused on the kitchen and toilet of each flat. Particular attention was paid to sinks, bathtubs and drainage points. Pest control measures were undertaken in Amoy Gardens and the surrounding areas. Waste storage tanks were also cleansed. Subsequent tests for *E. coli* showed that the disinfection of the drainpipes was effective.

6.4 The Food & Environmental Hygiene Department (FEHD) advised residents of other Blocks to disinfect their flats, particularly sinks, bathtubs, washhand basin, toilet bowls and floor drains in the toilets and kitchens.

Guidelines and disinfectants were provided to residents. Residents of Amoy Gardens were advised to keep water seal at the U-traps of drainage outlets to ensure proper functioning.

6.5 The management company of Amoy gardens has repaired the crack in the sewer vent pipe found at the 4th floor level of Block E. The Administration has also asked the management company to carry out a comprehensive inspection of the drainage system of all blocks within the development.

6.6 To minimize the likelihood of similar outbreaks in future, the Administration has produced a guide to educate the public on the cleaning and disinfection of households, including bathroom cleansing and how to ensure the proper functioning of the water seal in U-traps. Improvements to environmental hygiene will be made and pest control stepped up on a territory-wide basis.

6.7 The Government has published a set of guidelines to draw the public's attention to the proper maintenance and repair of the drainage system and sanitary fitments. The guidelines are available from the Buildings Department website and are being distributed to all management companies and owners' corporations.

6.8 The management of buildings where confirmed SARS patients reside is notified of the infection and is required to take disinfection measures. FEHD will inspect these buildings to see if they meet the required standard. Names of these buildings are placed on the homepage of the Department of Health. Residents of these buildings are thus also alert to the need to take preventive disinfection measures.

6.9 Major cleansing and disinfection operations were conducted in the surrounding areas of Amoy Gardens by the building management with advice

given by FEHD. Pest control measures were also undertaken in the area.

6.10 It would appear that this outbreak arose from an infrequent combination of events as there has been only one such massive outbreak in the whole community. The outbreak was effectively controlled after deploying the above combination of strategies targeted at various modes of disease transmission revealed by this investigation. These control measures learned from the Amoy Gardens experience have been applied throughout Hong Kong to minimize the chance of occurrence of SARS outbreaks. The reported daily number of SARS cases in Hong Kong has now been reduced by 60% since its peak in end of March.

-- END --

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WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR THE WESTERN PACIFIC

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MISSION

To investigate risk factor involved in the possible environmental transmission of 'Severe Acute Respiratory Syndrome' (SARS) in specified residential buildings in the Special Administrative Region of Hong Kong. The investigation is conducted in the context of assisting the Hong Kong authorities.

SITE - AMOY GARDENS ESTATE

BACKGROUND

Around March 21, 2003, an unusual cluster of SARS cases occurred in Block E of the Amoy Gardens Estate with apartment units 7 and 8 most affected. The initial epidemiological investigation and the unusual high number of cases affecting these two units prompted the hypothesis that environmental factors may have been involved in the transmission of the SARS-related coronavirus.

ACTIVITIES

Site visits were performed to evaluate the building as situated in its surroundings, to study in detail the mechanical building systems including water supply, wastewater disposal and ventilation systems serving all occupancies in various fashions, and to take environmental samples for laboratory testing.

DESCRIPTION OF TARGET BUILDING

- General Features

- High-rise private housing estate built in 1981
- 'Cruciform' towers built on a podium harbouring a shopping mall and park decks.
- Living space for approximately 20,000 residents
- Each tower has more than thirty floors with eight living units each (approx. 48 m^2 per unit)
- Units are separated by light wells (see footnote) (6 meters deep; 1.5 meters or 2.3 meters wide)
- Light wells are open-air utility channels between living units and contain plumbing risers connecting to all bathrooms.
- Light wells act as a light source and a ventilation plenum; bathroom and living room ventilators discharge exhaust air into the light well; combustion gases of gas fired hot water heaters discharge into the light well.

- Plumbing System

- Potable water supply system distributing water from a roof mounted storage tank and serving all fixtures except the water closet.
- Potable hot water is generated using gas-fired instant water heaters.

- Water closet flush water system uses seawater.
- Wastewater stream is divided into separated 'grey' (kitchen) and 'black' (bathroom) systems; each condominium stack is vertically connected to the same riser.

- Heating

- Space heating is not required and no facility has been installed for that purpose.

- Ventilation / Air Conditioning

- Windows of each unit can be opened; powered ventilators and air conditioning units are installed at the option of the owner.

RESULTS

- The physical condition of the building structure is generally good and meets international standards.
- The building management provides the necessary administrative and technical support.
- The existing plumbing system meets the needs to contain waste within piping provided it is operated by the multitude of users as per original design intent.
- The air exhaust system in the bathrooms discharges copious quantities of droplets in the bathroom into the light well and ultimately into the outer building boundary layer where the droplets can re-enter the building at other locations.
- There is no strong enough evidence to link the broken vent pipe discovered at the bottom of the light well to the spread of the virus.
- All attempts to recover live virus from collected swabs were negative. In addition, all attempts to find genetic material ('footprints') of the SARS-related coronavirus were also negative.

CONCLUSIONS

- At the time of the outbreak, the floor drain traps in many apartments seemed to have not been filled with water for long periods. Thus they had lost their sealing function and generated an open connection to the soil stack. In the case of a running exhaust fan and a closed door, droplets would have been drawn from the soil stack into the bathroom through the floor drain. This could have contaminated the bathroom.
- A break of a flush water pipe serving unit 8 on March 21, 2003, led to an overnight shut down of the flush water system. This event most likely decreased the flow in the soil stack and thus would have favoured the generation and movement of droplets in the soil stack. In addition, bucket flushing would have increased the generation of droplets in the bathroom.
- The running exhaust fan would have transported contaminated droplets present or generated in the bathroom into the light well. These droplets would have continued to move with momentum in the light well until they had reached a wall. At that point they would have likely moved up due to the natural current within the light well. The droplets would have risen to the top of the building, but might have been disturbed on its way by other active ventilators discharging into the light well. Should the contaminated air have encountered an open window, it might have entered into other apartments even several floors away from the source.

- Laboratory testing showed no evidence for live virus still being present in Amoy Gardens. Nor did it show any evidence for remaining genetic material ('footprints') of the SARS-related coronavirus.

CONCLUDING REMARK

It seems highly likely that an unfortunate sequence of environmental and health events happened simultaneously and contributed to the spread of the SARS-related coronavirus in the Hong Kong residential estate of Amoy Gardens.

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*Note: In construction terms, the light well is actually a re-entrance