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INADEQUATE PLUMBING SYSTEMS LIKELY CONTRIBUTED TO SARS TRANSMISSION

Geneva and Rome – Inadequate plumbing is likely to have been a contributor to the spread of SARS in residential buildings in Hong Kong Special Administrative Region of China, a World Health Organization (WHO) technical Consultation concluded today. It also contributes to the spread of a number of other infectious diseases in several other countries. In the absence of proper maintenance and without consistent monitoring, reviewing, enforcing and updating of building standards and practices, inadequate plumbing and sewage systems could continue to enhance the potential of SARS and some other diseases to spread. The meeting concluded that it would be relatively easy to interrupt and avoid some diseases, including SARS if it were to return.

The Consultation developed a checklist of environmental hygiene factors in building design and maintenance that, if followed, could contribute to controlling environmental transmission of SARS Coronavirus (CoV) and other viruses. Viruses that can be transmitted by the "faecal droplet" route also include gastro-enteritis virus (such as Norwalk-like viruses), some adenoviruses and enteroviruses responsible for a number of gastro-intestinal and neurological diseases.

"With this Consultation, WHO is helping its Member States appreciate the need to assess and manage the health risks associated with inadequate plumbing and sewage systems. It has documented lessons learned, it has pointed to risk assessment and management tools to be better prepared in case of future outbreaks and it has listed concrete measures and regulatory frameworks for the prevention of faecal droplet transmission of disease-causing viruses, This information will be brought together in a guidelines document," commented Dr Jamie Bartram, Head of WHO's Water, Sanitation and Health Programme at its Geneva headquarters.

It has been suggested that the "faecal droplet" route may have been one of several modes of transmission in Hong Kong during the SARS outbreak in early 2003. In this case, droplets originating from virus-rich excreta in a given building's drainage system re-entered into resident's apartments via sewage and drainage systems where there were strong upward air flows, inadequate "traps" and non-functional water seals.

Meeting in Rome, an international group of WHO experts reviewed the transmission risks related to the current state of plumbing systems around the world and how inadequate construction and maintenance practices could contribute to the spread of SARS.

"In many countries there will be buildings where keeping sewage separate from building occupants is a critical challenge," observed Dr Bartram. "This could result in harmful viruses, including the SARS Coronavirus (CoV), being sucked from the sewage system into the home if, for example, there are strong extractor fans working in a family's bathroom. Fortunately, solutions are simple and already in place in most areas world-wide, but there remain places where short-cuts in design, construction and maintenance continue to compromise safety."

"While the evidence suggests that, under most circumstances, the spread of SARS among people occurred overwhelmingly across a short range of distance through water droplets, there are specific situations where conditions allowed other transmission routes. One of these is through sewage-associated faecal droplets and this Consultation has, therefore, recommended measures to reduce sewage-borne transmission routes of pathogenic viruses," added Dr Bartram.

The Consultation emphasized that the solution – proper plumbing – is a simple public health measure which is often overlooked but can be addressed at minimal extra cost. Nevertheless, it is a significant tool in stopping faecal droplet transmission of disease.

The Consultation resolved that Governments establish or strengthen intersectoral arrangements and mechanisms to enhance joint efforts of ministries of health, building authorities, local governments and architects/designers to both raise general awareness of the risks from inadequate plumbing and sewage systems, and to take concrete actions to address shortcomings in this area.

The experts meeting at the WHO European Centre for Environment and Health in Rome came from nine countries and represented the fields of epidemiology, virology, environmental health, risk assessment/management, building design and plumbing.

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WHO Informal Consultation on the Transmission of SARS CoV and Other Pathogenic Viruses through Faecal Droplets

Rome 23-25 September 2003

Consensus statement

Background

Severe Acute Respiratory Syndrome (SARS) was first described as a new disease in March 2003. Its causative agent is a coronavirus named the SARS-associated coronavirus, SARS CoV. It is generally agreed that the main mode of transmission is from person to person in close proximity. Through outbreaks in Hong Kong SAR, the People's Republic of China, Viet Nam, Singapore and Canada it rapidly achieved notoriety as a readily transmissible infectious disease with a significant mortality rate (currently estimated at 9.5%) and global economic consequences. The costs incurred by the 2003 outbreaks have been estimated at between US$30 and 150 billion.

At the time of the Consultation (September 2003), the global epidemic was estimated to have resulted in 8097 cases of clinical illness with 774 deaths in 27 countries on six continents. There are no reliable estimates of low-severity or asymptomatic infections. In July 2003 the World Health Organization declared the epidemic to have come to an end.

There remain considerable gaps in our understanding of the sources, transmission dynamics and routes of infection of the pathogen. These hamper our full understanding of how the epidemic evolved and, in particular, how and to what extent environmental factors contributed to the propagation of disease. As a result, we lack a complete insight into the extent to which environmental control measures could play a role in containing future outbreaks of this disease and diseases caused by other pathogenic micro-organisms with similar routes of transmission. What is clear, however, is that in any outbreak situation effective disease control will be essential to contain and eliminate the epidemic, while preventive environmental measures will help reduce the risk of outbreaks to occur, limit the extent of outbreaks when they occur and enhance the impact of control measures.

Available evidence suggests that SARS CoV originated from animal populations and that intensive human-animal contact was instrumental in its transfer to the human population. Such intensive contacts occur, for example, at marketplaces where live animals are traded and slaughtered. The SARS CoV responsible for the outbreak in humans in 2003 shows slight genetic differences from the virus found in animal populations (also referred to as SARS CoV). The latter appears to be responsible for sero-positivity among animal handlers. At the time of the Consultation it was unclear whether the circulation of a SARS CoV in human populations had led to establishment of a modified virus in animal reservoirs that may be more infectious or virulent to humans.

This Consensus Statement addresses the risks of transmission of SARS CoV amongst human populations associated with the design and operation of sanitation facilities for the management of human excreta. It does not give further consideration to the transfer of the agent between animal and human populations; this issue is dealt with in another WHO publication under preparation: *Water-borne zoonoses: understanding their identification, causes and control.*

There is evidence that, once established in human populations, SARS CoV is excreted by symptomatic persons in faeces, vomit, respiratory secretions and urine (ranked in the approximate order of quantity of virus shedding). Virus shedding peaks between days 7 and 10 after the onset of symptoms. The most severely affected cases have been associated with especially intense transmission, and have been referred to as "super-transmitters". This status is more likely linked to the innate capacity of the host to mount an immune response than to possible genetic differences between virus strains. Asymptomatic or mild disease appears to have occurred, yet there is no evidence that chronic infections or prolonged asymptomatic carrier states are part of the syndrome.

In most areas, disease transmission during the epidemics has been overwhelmingly across short distances, i.e. less than 1 meter. In a number of well-documented specific cases, however, there is compelling evidence of virus-containing droplets travelling over a longer distance (tens of metres) and leading to human infection. In one outbreak cluster (the Amoy Gardens in Hong Kong) this trans-mission route was associated with inadequate maintenance of bathroom plumbing and drainage systems combined with inappropriate ventilation of bathrooms. In another, the Metropole Hotel, transmission might have been associated with droplets generated by vomiting (a route which is well recognised in the transmission of other viruses such as norovirus). Data limitations prevent the

spread dominated. These two clusters may be considered important 'sentinel events' in the first flush of the epidemic, in relation to both the control of this specific disease and more general issues of disease control.

The Amoy Gardens outbreak, which affected 329 persons and caused 42 deaths, was characterised by extensive and rapid spread of the infection between occupants of apartments in a multi-towerblock complex. Modelling and simulation studies revealed the high probability that this transmission pattern was linked to faecal droplet transmission. The formation and transport of faecal droplets could be traced back to inadequately maintained water-traps and reduced water use for bathroom cleaning, resulting in non-functional water locks of floor drains. This, combined with air movement instigated by over-powered bathroom extractor fans, created conditions that were highly conducive to this route of transmission. The likelihood of re-entry of extracted air containing faecal droplets into other dwellings through mainly upward air circulation in the narrow light-wells between apartments was also demonstrated. There were confounding factors, such as the movement of people between apartments and housing blocks, but these do not explain the specific distribution pattern of cases in the buildings, in particular in housing block E (41% of all cases) in a very short time span. There is little or no evidence for the hypothesis that rodents and cockroaches may have played a vectorial role in this outbreak cluster. Whilst not implicated in this outbreak, they may play a role in the transmission of some viruses (potentially including SARS CoV) and their control and elimination is a component of good public health and hygiene practice.

In the case of the outbreak in the Metropole Hotel there is less evidence to allow a full appreciation of the role and relative importance of droplets in the transmission and infection routes. The source of infection was an infected hotel guest who may have vomited, as a result of which droplets containing the virus might have dispersed through the building.

Enveloped viruses, such as the coronaviruses, are generally considered to be highly sensitive to environmental stresses, including visible light and UV radiation, desiccation due to low relative humidity, temperature ranges and physico-chemical conditions. They become rapidly inactivated but traces of their genetic material may remain detectable by molecular-based (PCR) methods for long periods. Survival of enveloped viruses is, on the other hand, enhanced by factors such as high humidity, the presence of particulates (e.g. adsorption or inclusion) and of some chemicals – for coronaviruses organic compounds and magnesium. There is, however, a great deal of variability between different genera of enveloped viruses, as well as between enveloped and non-enveloped viruses. Some enveloped viruses can survive dozens of days in suitable conditions. Limited studies of the SARS CoV suggest survival for a relatively low number of days even under suitable conditions. Some of the other viruses that may be transmitted through faecal droplets – for example some adenoviruses and noroviruses – persist longer in an infectious state.

Context

SARS and SARS CoV have focused interest on some aspects of links between sewage/sewerage and health. This interest may usefully contribute to furthering the control of health risks associated with inadequate sewerage and especially of pathogenic viruses that are amenable to droplet transmission. Disease transmission via sewage droplets is, in general, likely to be a small but significant contributor to the overall burden of sewage-related disease (which includes disease associated with environmental contamination with untreated or under-treated sewage/excreta as well as its introduction into the domestic environment). A large part of the burden of disease associated with inadequate water, sanitation and hygiene (an estimated 2,213,000 deaths and 82,196,000 DALYs lost annually) is borne by populations in developing countries (children in particular), with the lack of access to adequate sanitation a major determinant (Pruess *et al.*, 2002). Approximately 1.9 billion people or 31% of the global population use water-based sanitation, both in developed and developing countries (WHO/UNICEF, 2000). Underlying trends – most importantly population growth, urbanisation, increasing affluence and a general preference for water-borne sanitation - suggest that the total population exposed to sewage/sewerage related risks will increase in numbers and as a proportion of the total global population.

The majority of the world's population uses some form of dry sanitation and this dominates amongst the rural poor and poor populations in peri-urban and slum areas of cities in developing countries. There is insufficient evidence, however, to support meaningful statements on the risk of SARS transmission through the environment in areas with dry sanitation; it appears that the principal environmental risk is associated with water-borne sanitation.

Lessons learnt

There is limited reliable information available concerning SARS CoV. There is a need, therefore, to combine information from different sources in order to arrive at useful conclusions. Relevant sources of information include our knowledge and experience with other viruses known to be transmitted via the faecal droplet route; it also includes our knowledge of the characteristics and behaviour of virus particles, experience with other droplet or aerosol-transmitted infections such as legionellosis and validated mathematical models that allow a systematic

Sources, transmission and routes of infection
It can be reasonably assumed that, in general, in the 2003 SARS outbreaks more than one source-transmission-exposure combination contributed to the total disease outcome. It is therefore appropriate to consider all reasonably credible routes and to assess the controls acting on them.

The principal **sources** of human derived SARS CoV in the built environment appear to be respiratory secretions, human excreta (faeces and urine) and vomitus. The role of animal-human exchange is recognised but not considered here.

The principal potential **transmission routes** for SARS CoV in the environment include droplets and aerosols generated from secretions and excreta, sewage and perhaps vectors. These routes may interact with one another – droplet deposition on surfaces is an example.

Plausible routes of **infection** include inhalation and mucosal/conjunctival contact – the latter especially through hand contact. Available evidence does not support ingestion as a route of infection.

Objectives and control measures
Control of transmission of SARS CoV (and of viruses with related transmission patterns) in human populations depends on interrupting source-transmission-infection route combinations. In connection with faecal droplet transmission, four principal objectives are:

- To effectively remove suspended faecal droplets containing viruses from the built environment
- To prevent (re-)entry of faecal droplets (from sewage) to the human/built environment.
- To minimise inhalation of air from occupied rooms
- To remove virus contamination from (human contact) surfaces (i.e. cleaning)

To prevent entry of faecal droplets from sewage into the human/built environment, principal barriers include effective sealing of all connections to sewerage from the dwelling. Water seals in toilets are highly effective but leaks enabling droplets to escape may occur in pipes routing through buildings and from vent stacks without evidence of liquid leakage and are a matter of concern. Pressure differences caused by ventilation or air-conditioning between rooms or between the inside and outside of an apartment may exacerbate the risks associated with such leaks. Whenever possible, venting systems should be free of mechanical devices.

Suspended droplets containing virus may arise in the built environment from a variety of sources in addition to excreta/sewage droplet formation. These include respiratory secretions and vomitus. The role of these in disease transmission has been highlighted for other viruses (e.g. *Norovirus*). There is a generic set of interventions that is effective against droplets regardless of source. These will contribute to the interruption of transmission and are of concern primarily in environments where virus-containing droplets are most likely to be generated. This focuses attention on healthcare facilities and toilets/bathrooms. Removal of potentially virus-containing droplets from the built environment must be accompanied by measures to ensure that the exhausted droplets are not then reintroduced to the built environment. This phenomenon appears to have played a critical role in the Amoy Gardens outbreak. In this connection, a number of effective building design and management measures can be readily identified, such as vertical separation of vents and separating inlet from outlet vents. Some of these measures may be costly and there is generally little evidence to define exact standards for design parameters. This area has been identified as a research priority. While lessons may be learnt from experience with legionellosis outbreaks, virions are about one hundredth the size of *Legionella* bacteria and could therefore behave differently under similar conditions. In high risk settings, such as healthcare facilities with symptomatic individuals, it may be appropriate to treat exhaust air to reduce the potential viral load e.g. through heat, filtration and/or impact. The extent to which these control measures would be effective in reducing viral load is, however, still inadequately understood and requires further investigation.

The importance of inhalation of (potentially virus-contaminated) air exhausted from rooms will depend on infectious virus loads and therefore prevailing sources and environmental conditions. Air originating from toilets/bathrooms used by and other spaces occupied by symptomatic persons is of specific concern. Limited evidence suggests that this mechanism has contributed to SARS CoV transmission in some circumstances and it is likely to be relevant for several other viruses. The principal prevention and control measures include re-entrant and light well design, separation of inlet and outlets to and from built environments and effective dispersal of exhaust air. The building and design specifications are to be supported by regular sanitary inspection and proper maintenance, and by cleaning and disinfection of installations.

Surfaces may be contaminated by viruses through droplet deposition, contact with infected persons and through vectors and fomites. Such viruses become a cause of health concern when carried to a site of infection; apparently transmission by hand contact from contaminated surfaces to, for example, conjunctivae is of particular importance. Measures described above will contribute to minimising droplet presence in the built environment and general vector/vermin control will further contribute to minimising contamination and pathogen spread. Of primary importance, however, is surface cleaning (and where appropriate disinfection). Moreover, such hygiene measures contribute to the control of a variety of pathogens causing gastrointestinal and respiratory infections. Control of infection arising from surface contamination also depends significantly on personal hygiene behaviour. Uninterrupted access to water in sufficient quantities for hygiene purposes is necessary for effective control of a wide range of infections including interruption of SARS transmission from surfaces to sites of infection.

Settings

The selection of appropriate control measures will depend on the settings in which they are to be applied. The principal settings of interest include the health care environment (including residential care) and multi-storey residential accommodation (which, for all practical purposes, also reflects the concerns over other multi-storey buildings). Local or national characteristics, such as cultural practices, will also determine which control measures are likely to be effective and feasible to implement. The development of control strategies should take full account of these. Where public health policies prescribe the isolation of potential SARS patients in residential settings, consideration must be given to applying prevention and control measures designed for health care setting to affected household settings, as appropriate.

In the countries affected by SARS in 2003, infections acquired in health care settings figured significantly and health care workers constituted an important vulnerable group. Some association has been reported between the implementation of procedures involving the generation of infectious droplets and transmission risk, but there are insufficient data to verify and firmly establish the fraction of risk attributable to this mode of transmission as compared to the predominant close-range spread. In health care settings aspects of concern include sluice rooms, the handling of soiled surfaces and linen, the ventilation of toilets and bathrooms (including the proximity of ventilation outlets to air intakes including windows) and the role of humidifiers in droplet transmission. Training and explicit infection control strategies (including 'Water Safety Plans') to reduce or eliminate faecal droplet risks are crucially important. Many controls should be routinely applied, yet where SARS CoV is of potential concern their planning and management merit special attention and re-assessment. Complementary measures include the use of personal protection measures in high risk settings.

In multi-storey residential (and other) building settings implementation of commonly-recognised standards of good practice in plumbing, drainage and ventilation will contribute significantly to the control of faecal droplet transmission. Failures of water seals/ traps and other faults that create a direct air link between occupied rooms and sewer are of special concern because of the associated health risk. Sewage odour provides a sensitive yet non-specific indicator of substantive concern meriting prompt attention for this detail.

In recognition of the possibility of sewage droplet-associated transmission, some specific settings have attracted particular concern in affected countries. These include:

- Locations where sewage is treated and/or discharged. This relates to both occupational exposure (i.e. workers in sewage treatment plants) and to exposure of local populations. For the 2003 outbreaks no association of infection with this exposure route was reported and the limited information concerning the likely survival of SARS CoV and similar viruses in the environment suggests that dilution was very extensive and inactivation was likely to have occurred before exposure. Assessment of risks from more robust and prevalent viruses in highly exposed populations may provide useful insights (e.g. incidence of adenovirus infections in sewer treatment plant workers).
- Water treatment plants. Some water treatment processes may concentrate pathogens from raw water and some processes used may also be associated with droplet formation The presence of viable coronavirus in source waters is, however, most unlikely and even if the virus were present, it would be subject to extensive dilution. The risks to workers in water treatment plants can be safely assumed to be orders of magnitude below the risks workers in sewage plants may be exposed to, and appear to be negligible on the basis of available evidence.

Effective supportive regulation and good practice

Many of the interventions/controls that will contribute to the reduction or elimination of the spread of virus-laden droplets are long term in nature. Their deployment is best achieved through interventions in design, construction, operation, licensing and certification and these are important components of overall national strategies.

- **Design** interventions centre upon review of designs for compliance with health-based regulations and standards, and subsequent approval. This procedure is supported by the existence of regulations and standards and by the inclusion of disease control in the training of architects and engineers.
- In many countries there are procedures for building inspection at various stages of construction or rehabilitation, as well as at final commissioning. These provide opportunities to ensure that **construction** work has complied with design and followed health-based regulations and standards. Such procedures are supported by the existence of corresponding regulations and standards and by the existence of appropriately-trained professionals charged with conducting the inspections.
- Responsibility for **building safety** should be assigned to a specified authority (e.g. owner, manager) under appropriate legislation. Whilst specific arrangements will respond to local/national circumstances it would normally be appropriate for public and multi-occupancy buildings to require a declared 'Water Safety Plan' with a defined strategy towards safety (definition of hazards and controls), a monitoring regime and a management plan, including responses to deficiencies in defined controls and communication.
- Several **professional groups** and especially building managers and plumbers play a critical role in the ongoing assurance and upgrading of building safety. The effective contribution of such groups is best secured through **in-service training** and through **licensing schemes** linked to maintaining and updating knowledge of good practice. Licensing schemes are best oriented towards accessibility to as many active practitioners as possible and not towards the creation of a 'two tier' system in which unlicensed practitioners are common.
- Inadequate and insufficient devices and products may be readily available and attractive to purchasers (both professional and householder) because of lower cost. Their wide-spread use may contribute significantly to increased health risks to populations. **Certification schemes** linked to health-based regulations and standards, where they are effective, may contribute to controlling associated risks. Experience with SARS has highlighted the importance of matching devices and appliances (e.g. appropriate power of exhaust fans). Certification may relate to the adequacy and comprehensibility of guidance on the use of appliances as well as to the characteristics of devices *per se*.

All of the above depend upon the existence of a suitable regulatory framework, including specific measures (both incentives and sanctions) to put them to effect, and a commitment of the authorities to enforce them.

Priority research issues for effective management

A limited number of issues were identified where targeted research is necessary to provide information of immediate relevance to increasing the effectiveness of controls and minimising likelihood of costly over-engineering:

- The degree of separation between air inlet and outlet structures and vertical separation to sewer vents or building exhausts may be usefully studied through air movement modelling combined with information on pathogen infectivity. The costs associated with amending guidance on this could be significant and research could contribute to rapidly refining standards of good practice appropriate for health protection
- It is unclear whether the presence or use of toilet lids contributes to or reduces overall risk. It is not relevant in cultures where squat plates are used and in some countries lids are discouraged in public buildings. Given the risk of droplet generation by the act of toilet flushing insight into designs or measures that would reduce this and/or minimise dispersal of droplets would provide useful clarification.
- Research into disease transmission through virus-contaminated droplets has been very limited and simple questions such as the range over which droplets from a flushed toilet spread and deposit remain unclear.
- Much of the available information concerning SARS CoV and indeed concerning other viruses transmitted through droplets is qualitative in nature (e.g. infectivity, inactivation) and this inhibits the application of quantitative methods to assess the effectiveness of actual and potential control measures.
- The pro's and cons of toilet bowl disinfection by means of additives to flush water, and its potential contribution to reducing droplet infectivity would merit research because it is frequently advocated without a clear and reliable evidence base.

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