

Chapter 1

Importance of Negative Pressure Wards

1.1 The Disaster at the Beginning of the Century

At the early beginning of the 21st century, the disaster with airborne infectious diseases appeared in China.

On November 6th in 2002, the first patient with Severe Acute Respiratory Syndrome, or SARS, was diagnosed in the city Foshan of Guangdong Province. On February 11th in 2003, the first formal report about the epidemic was delivered to WHO. At that time, 305 people have been infected and 5 people were dead because of this disease. Till August 7th in 2003, the epidemic has been dispersed into 34 countries and regions within the short period of 6 months. The number of the cumulative suspected cases reached 8347. 916 people were dead. In that period, the freedom of travel for most people was restricted. The activity of economy and trade was severely affected. Take the Far East as an example, the estimated economic loss reached 30 billion dollars [1].

SARS will not affect only patients, but also the medical personnel in ward and related area. The infectious rate of medical personnel in Beijing and Hong Kong reached or exceeded 20%, while that in Taiwan reached as high as 30%. 20% of the infected people in the globe were medical personnel.

The reason for this phenomenon is that little attention has been paid on infectious disease in the globe during the past decades. There exist the following misunderstandings:

- (1) It is believed that the development of economy is helpful to the natural decay of infectious disease. The main treats for human health are cardiovascular disease, tumor and diabetes.
- (2) Infectious disease can be overcome by microbiology technology.
- (3) The fact of long-period existence of infectious disease and the trend to become the first killer for human being are overlooked.

With the above-mentioned misunderstandings, the investment on the infection prevention projects of epidemic disease for public health reduced sharply. The number of hospitals for infectious diseases in the whole nation decreased. The instruments inside were odd. There were no real isolation wards as infectious wards. Even for abroad such as U.S.A., most of the hospitals for infectious diseases were closed in 1950s.

In ordinary ward, indoor air distribution is not good. Polluted air cannot be exhausted outdoors quickly and efficiently at all. Therefore, the safety of medical personnel cannot be guaranteed.

Because the technique to effectively isolate airborne infection was rare and there was no existing standardized isolation ward, only some general provisions can be issued at first. Some temporary emergence measures were enforced or suggested.

In April of 2003, WHO provided principled recommendations on SARS ward in the revised “*Hospital Infection Control Guidance for Severe Acute Respiratory Syndrome*”, including negative pressure, single room with toilet, independent air supply or exhaust.

On April 30th in 2003, the general office at Ministry of Construction of the People’s Republic of China and Ministry of Health of the People’s Republic of China issued an “emergency notice”. It required that central air conditioning system is prohibited in the places where enrollment, isolation and inspection of SARS cases were taken place and where SARS patients were diagnosed. This was meant to prevent the transmission routine of SARS virus. On May 5th in 2003, Ministry of Health of the People’s Republic of China issued “*Guidelines for Infection Control of SARS in Hospital (Trial)*”. It re-emphasized that both fever clinics and isolation observation room should be set relative independently in easily isolated places inside the hospital. Special ward should be set in hospitals where SARS infected patients are received and treated. Natural ventilation for air convection should be guaranteed between indoors and outdoors. Ventilation equipment (such as fan) must be installed for these places where the performance of natural ventilation is poor. Central air conditioning system is prohibited. In the same month, “*Design Highlights for Hospital Buildings Receiving SARS Infected Patients*” were issued, which provided some fundamental general provisions.

1.2 Severity of Airborne Infection

The infectious diseases are mainly transmitted through two ways, including contact transmission and airborne transmission. It should be noted that except for the well-known respiratory transmission pathway, disease can also be infectious through contact transmission. In this case, microbial aerosol may deposit on surfaces including body, hand and other accessible surfaces, if sterilization on air is not performed thoroughly. Then infection may occur when these surfaces contact the susceptible sites of infection. There is a logion from Dr. Hinds that “Viruses are transmitted by direct contact or by inhalation of aerosolized viruses” [2].

There are mainly 41 kinds of infectious diseases, among which 14 kinds are airborne. These airborne diseases rank the first in various specific transmission pathways. In the whole globe, the infectious diseases resulting from respiratory infection by microbial aerosol occupy about 20% of the total diseases. In China, the proportion of respiratory infection occupies 23.3 ~ 42.1% of nosocomial infection, which ranks the first position in various specific transmission routes.

There are about 30 kinds of pathogens causing the respiratory infection through airborne transmission.

For bacteria, it includes *Streptococcus Pneumoniae*, *Escherichia Coli*, *Pseudomonas Aeruginosa*, *Klebsiella*, *Serratia Marcescens*, *Salmonella* sp., *Legionella* spp., *Mycobacterium Tuberculosis*, *Staphylococcus Aureus*, *Enterococcus*, etc.

For fungi, it includes Fumagillin, Rhizopin, Trichothecin, *Candida Albicans*, *Histoplasma Capsulatum*, etc.

For virus, it includes Coronavirus, influenza virus, measles virus, varicella-zoster virus, mumps virus, variola virus, Swine vesicular disease virus, Hemorrhagic fever virus, and Coxsackievirus.

For Rickettsia, it includes Q Fever.

For others, it also includes *Mycoplasma* and *Chlamydia*.

The most serious case for respiratory infection should be the pulmonary tuberculosis. In 1994, the Centers for Disease Control and Prevention (CDC) in U.S.A. issued "*Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Facilities*". It pointed out that the new case of tuberculosis infection would become the active tuberculosis quickly. The death rate related to the sudden occurrence of this disease is quite high, which is between 43 and 93%. Moreover, the period between diagnosis and death is quite short. The median of the interval period is from 4 to 16 weeks.

The number of tuberculosis patients from China takes the second place in the world. The number of death because of pulmonary tuberculosis reaches as more as 130 thousands in 2004, which greatly exceeds the total number of death resulting from other infectious diseases.

The severity of the respiratory infection by airborne transmission includes the following aspects:

- (1) explosive epidemic—In a short time, a large amount of people will be infected. Take the incidence of *Legionella* infection happened in U.S.A. in 1976 as an example, the mortality of the people caused by this disease was 29.
- (2) large infection area—The disease can be epidemic in all the country or all the world, which can be evidenced by historical pandemic influenza.
- (3) extremely low infection dose—The dose of infection is much lower than that through other transmission routes. People will be easily infected if only one Q fever deposits onto the respiratory tract. People will be infected if more than 0.1 billion REPECs were ingested, while infection will occur if 10 to 50 REPECs were inhaled. The median infective dose of respiratory by adenovirus is only a half of that by tissue culture. Experiment also shows that even though the inhaled quantity is larger than the minimum infectious dose when the

inhalation period is prolonged, there is still no infectious effect. Therefore, in terms of the dose for infection control, except for “the concentration of airborne droplet nuclei to prevent transmission and reduce infection” required in “*Guidelines for Preventing the Transmission of Mycobacterium tuberculosis in Healthcare Facilities*”, special attention should also be paid on the virus dose which has the infection effect. It should also be noted that the initial exposure airborne virus concentration plays the leading role.

- 4) cross infection—Although *Salmonella* sp. is the bacteria for infections of the digestive tract symptoms, respiratory infection case appears in the pediatric surgery ward. Venezuelan equine encephalitis virus and yellow fever virus are arboviruses, but they can cause respiratory infection. Other people can be infected by hepatitis virus and syphilis through microbial aerosol generated from dental drill with high rotation speed [2].

Based on the investigation of infectious disease in a neonatal ward lasting for 11 months, it was found that the outbreaks of seven Gastroenteritis cases by *Salmonella typhimurium* (Bacteriophage T2) were not from contaminated food, but from collected dust contaminated by this bacteria in a vacuum cleaner. In ten months after the occurrence of the last infection case, *Salmonella typhimurium* can still be separated from dust.

In the past, it was believed that the Measles was caused by direct contact infection with airborne droplet nuclei. However, during an outbreak of Measles in a pediatric clinic in a hospital located in State of Michigan in U.S.A., it was found that three out of four infected children had no history of direct contact. It was the cough from infected children that may cause airborne infection. It could emit 144 infectious virus particles per minute during cough [3].

There is also evidence of infection through airborne transmission for Hepatitis B Virus which spreads mainly through digestive tract infection. Therefore it is reasonable to consider that it is more likely to cause environmental contamination for Hepatitis B Virus through saliva and airborne droplet nuclei than that through contact by hands. Table 1.1 illustrates the positive detection rate of virus in air sample [3].

Airborne transmission mainly depends on aerosol and airborne droplet nuclei. During the conversation, cough and sneeze of patient, not only aerosol but also spittle and droplet nuclei after evaporation can be generated.

Table 1.1 Detection rate of HBsAg in air sample from public place

Sampling position	Sample number	Positive sample number	Positive rate (%)	Sampling position	Sample number	Positive sample number	Positive rate (%)
Hospital clinic department	10	3	30	Waiting room	8	2	25
Karaoke room	8	2	25	Outskirts	5	0	0

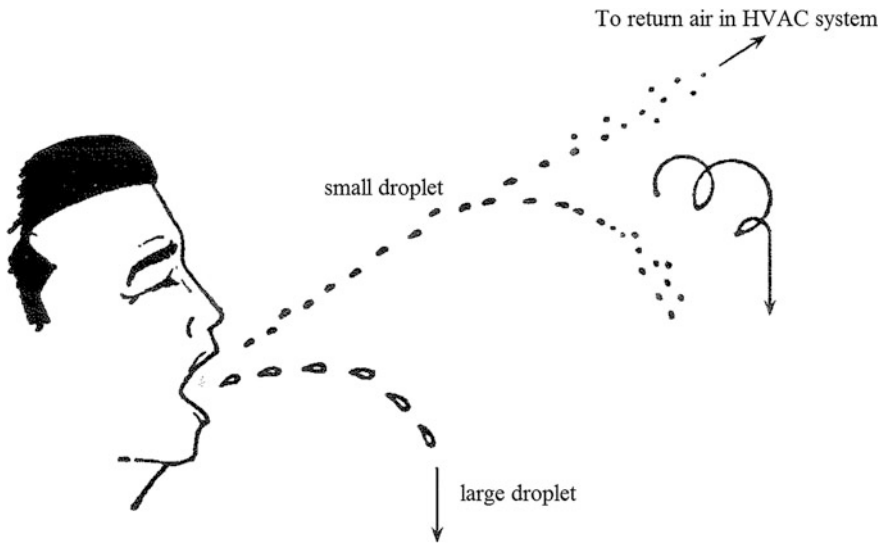


Fig. 1.1 Droplet nuclei and aerosol generated during sneeze

Figure 1.1 and 1.2 shows the situation of sneeze. Figure 1.3 illustrates the number of particles released during sneeze, which can reach as more as 300 thousands. The number of aerosol released from respiration of patients depends on the expiratory velocity. The number in common case is not too much. Although

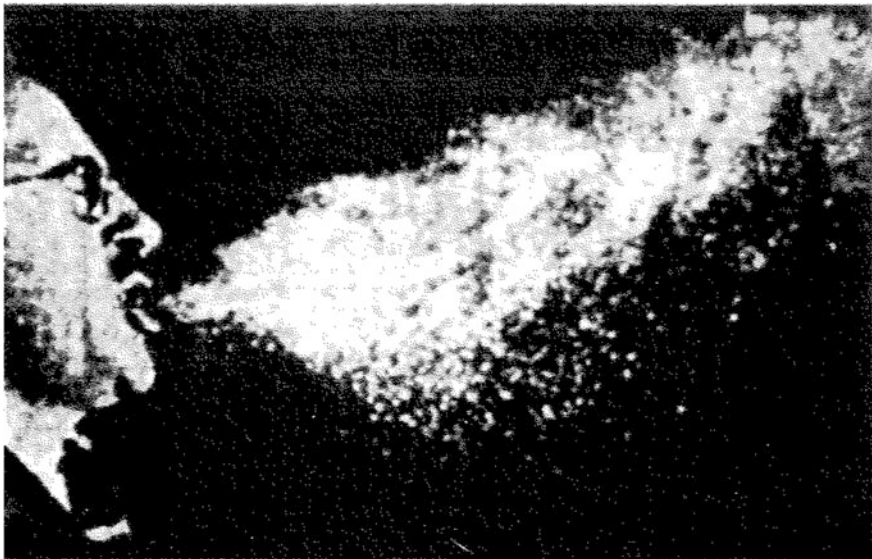


Fig. 1.2 Photograph during sneeze

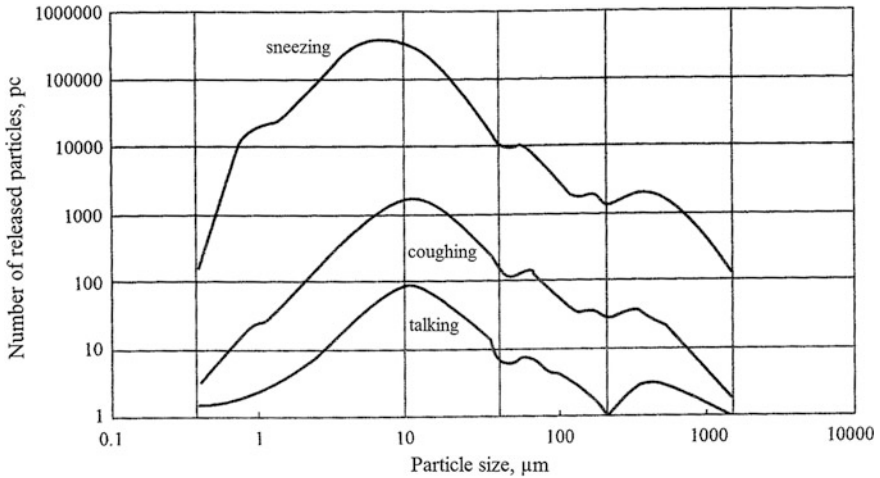


Fig. 1.3 Particle size distribution of generated aerosol released during sneeze

only thirteen infectious droplet nuclei could be released from a tuberculosis patient per hour, twenty seven people could be infected within four weeks [2].

The airborne droplet aerosol is spread in the following way:

Spittle will migrate under the influence of airflow, gravitational force and drag force. Therefore, the distance of movement is very small, which is less than 0.9 m [4].

However, the influence of gravitational force on aerosol is very small. Aerosol will move under the influence of airflow mainly. When it is near the return air outlet, it will be sucked towards the outlet. Therefore, aerosol can disperse to further place.

Therefore, the transmission characteristics between spittle (large droplet) and aerosol (small droplet and droplet nuclei) are distinct. But most of large spittle will become droplet nuclei eventually, i.e., aerosol. As for the Coronavirus, it exists mainly in secretion and droplet. So except for the transmission from direct contact, the route of airborne transmission is also very important.

The outbreak of Severe Acute Respiratory Syndrome (SARS) at Amoy Gardens in Hong Kong proved that SARS Coronavirus can spread through the route of airborne transmission. According to the investigation report of SARS outbreak at Amoy Gardens, which was issued by Department of Health in Hong Kong on April 17th in 2003, and based on test with oil droplet aerosol by Hong Kong Polytechnic University, it was found that droplet will move upwards with the airflow of “fume”, and it will also disperse transversely, which was influenced by the exhaust and return air from the exhaust fan at external window inside the bathroom at each floor. It took only several seconds for this kind of flow to reach the upper ceiling.

Therefore, it is not acceptable to reach the conclusion that it is safe to stay three feet away, which is based on the fact that the transmission distance of spittle is less than 1 m [5].

Whether pathogen can be spread through spittle or aerosol (droplet nuclei) depends on the degree of dependency on the water content and the nutrition provided by the carrier. If the degree of dependency is large, aerosol with small diameter may not be able to provide enough water content and nutrition for its survival. In this case, the movement of aerosol cannot be the transmission route of infection.

Previous studies have shown that the maximum diameter of droplet and spittle can reach 100 μm . It is reasonable to consider the size to be continuous. After evaporation, they will become aerosols with smaller diameter, i.e., the so-called airborne droplet nuclei. When they enter into the flow stream of recirculation air, the complexity and risk of transmission for Coronavirus will be increased. Therefore, it is necessary to control the exhaust air in the long distance, such as the influence of exhaust air from sewerage at Amoy Gardens in Hong Kong. It is also necessary to isolate in short distance or take primary isolation measures, which can be proved by the reality that most medical personnel close to SARS infected patients got infected.

It is usually beyond the expectation that microbial aerosol can also be generated from the flush toilet [2]. American scholar named Wallis reported the research result about the aerosolization of poliovirus during the usage of the flush toilet in 1985. Air was sampled during the flush of water after virus was injected into the urinal manually. Results were shown in Table 1.2.

Table 1.2 Aerosolization situation of poliovirus during the usage of the flush toilet

No.	Dose of injected virus	Number of collected virus with microporous membrane
1	3.8×10^8	1545
2	4.3×10^9	1383
3	6.1×10^9	775
4	4.8×10^9	455
5	5.0×10^9	1270
6	2.4×10^9	563
7	3.0×10^9	1600
8	3.0×10^9	704

Table 1.3 Generation of aerosol during flush of water on the fresh faeces containing virus

Mass of faeces (g)	Total amount of virus (PFU)	Virus in water from urinal (PFU/mL)	Recycled virus (PFU)
24	2.4×10^7	2040	65
50	4.5×10^7	480	6
64	4.8×10^7	180	0
22	5.9×10^7	28	0

Sampling results with the flush of water on the fresh faeces containing virus are shown in Table 1.3.

In short, the following environmental factors may be responsible for the spread of aerosol and spittle:

- (1) The space is relative small and closed, where infectious particle will accumulate.
- (2) There are no enough local or overall ventilation rates. The infectious particles cannot be diluted, whose concentration (so-called infection dose) is high enough to be epidemic.
- (3) For recirculation air containing infectious particles, the risk of infection increases.
- (4) Under the effect of pressure difference, infectious particles can penetrate from one side to another. They may migrate from one side to another with the influence of airflow. These provide the opportunity to increase concentration.

Therefore, all the measures taken to control the transmission of aerosol and spittle are reducing the concentration.

Reference [6] provides the theoretical analysis for the transmission of aerosol and spittle.

1.3 Requirement for Negative Pressure Ward

There are four classification levels of infectious isolation wards, according to the contagious strength of the disease from patients [7].

Class 1: Contact isolation, such as for Hepatitis A patient.

Class 2: Droplet isolation. The difference from Class 1 is the operational procedure.

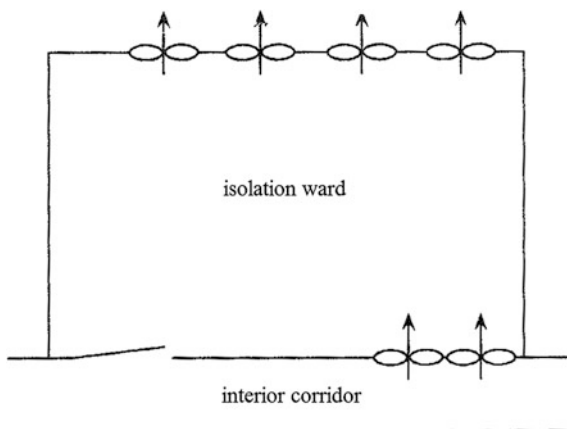
Class 3: Air isolation, such as for Tuberculosis patient.

Class 4: Sealing isolation, such as for patient infected by Ebola virus fever, Ebola hemorrhagic fever, SARS, Staphylococcus aureus. This kind of isolation has the dual functions of contact isolation and air isolation.

During the early stage for the outbreak of SARS, the most urgent task was to relocate these confirmed and suspected patients into isolation ward as soon as possible, which was meant to avoid cross infection. However, the consciousness of isolation among medical personnel was weakened these years. They were not wary and showed contempt for infection with airborne transmission. This caused the weakened situation for the scientific research in the field of health care with infectious disease. The scientific study on construction of isolation ward was totally vacant.

In order to face the emergent event, common wards were reconstructed into isolation wards in mainland China, Taiwan, Hong Kong and other regions. In other places, only some simple measures were taken.

Fig. 1.4 One of the most simplest isolation forms in emergency situation



For example, in order to meet the urgent needs during the early stage of the outbreak of SARS in March, 2003, window-type exhaust fans were added in renovated ward in some public hospitals in Hong Kong. Air from corridor could enter into the ward, and was then discharged outdoors after passing through the sickbed.

The same method was adopted in Guangzhou Eighth People's Hospital during the epidemic of SARS in 2003. Five to six exhaust fans were installed on exterior window of the ward. Two supply fans were set on interior wall connecting the corridor and the ward. In this way, indoor air could not flow reversely towards the corridor, and then went outside of the ward area. The effect of isolation with airflow was achieved, which is shown in Fig. 1.4.

The application showed that there was no cross infection inside ward area. However, because of the large velocity, patients felt cold even when the quilts were used during the early spring period.

In fact, it is not necessary to install five to six exhaust fans, because the room is not large. Additionally, the supply fan is also unnecessary. It is fine if one louver were installed above the door.

Of course, the influence of exhaust air on atmosphere was not considered. This is only one of the simplest isolation forms in emergency situation. At the late stage of SARS epidemic, it was required that HEPA filter must be installed in exhaust air pipeline during the formal design process in Hong Kong.

Moreover, staffs including operators, laboratory technicians and medical personnel will directly face the recipients, i.e., the pollution source. They may be the first victims. As mentioned before, about 20% of infected people were medical personnel during the epidemic of SARS in 2003. In Hong Kong, the proportion reached 22%.

In order to protect operators (medical personnel) from infection, the measures taken was termed as Primary Isolation.

Setting of exhaust hood near the head of sickbed is one of the isolation methods with physical barriers.

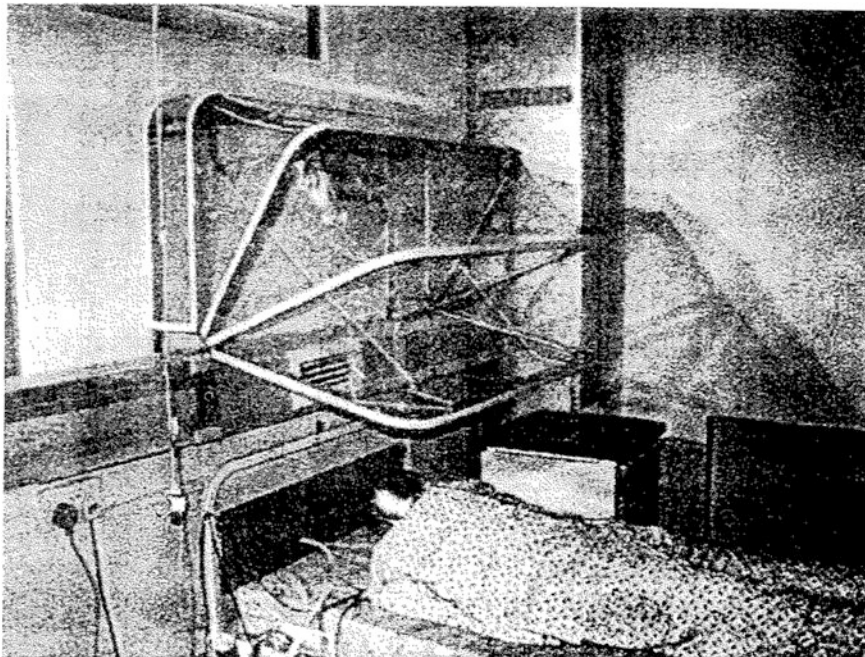


Fig. 1.5 Movable exhaust hood near the head of the sickbed

The exhaust hood near the head of sickbed should be flexible. During the SARS period in Hong Kong, one movable exhaust hood was tested [8], which is shown in Fig. 1.5. The transparent hood was used to isolate the exhaled aerosol. Air was exhausted through the exhaust air outlet near the head of the sickbed or through the exhaust fan on the hood. However, practice showed that this kind of isolation was not welcomed, because it limited the movement of patients including lying down and getting up (shown in Fig. 1.6) and it also influenced the draft sensation of patients. Therefore, it was not promoted during the SARS epidemic period.

In brief, according to the practical cases of isolation wards investigated by author at home and abroad at that time, few of isolation wards of this kind can meet the fundamental requirements for the control of airborne infection. The fundamental requirements include the following aspects:

- (1) To protect other patients and medical personnel from infection.
- (2) To protect outdoor environment from infection.
- (3) To prevent cross infection between patients.

Isolation wards which meet the above requirements are negative isolation wards, which are different from the protective isolation wards with positive pressure.

In 2009, the A/H1N1 influenza virus outbreak in the world. With the conditions of continuous appearance of novel infectious disease and re-appearance of



Fig. 1.6 Photograph for getting up of patient

existing/old infectious disease, the local standard DB 11/663-2009 “*Essential construction requirements of negative pressure isolation ward*” was issued in Beijing, which plays an important role in guiding the design of isolation ward in Beijing and other places and controlling the disperse of infectious disease.

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