

The Risk to Health of Microbes in Sewage Sludge Applied to Land

Report on a WHO Working Group

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INTRODUCTION

The WHO Regional Office for Europe, in collaboration with the Government of the United Kingdom, convened in Stevenage from 6 to 9 January 1981 a Working Group on Sewage Sludge to Land: Health Implications of the Microbial Content. The meeting was opened by Dr E.L. Harris, Deputy Chief Medical Officer, United Kingdom Department of Health and Social Security, who referred to the great interest the subject of the meeting had not only within Europe but also in other parts of the world. Dr J. Cuthbert, Director, Stevenage Laboratory, Water Research Centre, offered the participants the use of the Laboratory's facilities for the meeting. Dr R.B. Dean conveyed the greetings of Dr Leo A. Kaprio, WHO Regional Director for Europe, and his thanks for the support of the Department of Health and Social Security.

Dr E.H. Kampelmacher was elected Chairman, Professor E. Lund Vice-Chairman, and Dr E.B. Pike Rapporteur.

The purpose of the Working Group was to cover the range of microbial pathogens known to be present in sewage sludge and review the risks of infection to man. Salmonellae and the human beef tapeworm (*Taenia saginata*) received special emphasis, since they appear to present risks to human health in Europe. Consideration of the effects of toxic metals on human health was outside the scope of the meeting.

The meeting was held shortly after three conferences dealing with cognate topics: a Seminar on Agricultural Use of Sewage Sludge, Basle, 24-26 September 1980 (in connexion with the European Wastewater and Refuse Symposium); the Second European Symposium on Characterization, Treatment and Use of Sewage Sludge, Vienna, 20-24 October 1980 (organized by the Commission of the European Communities); and a Conference on the Present Status of the Salmonella Problem, Bilthoven, 6-10 October 1980 (organized by the World Association of Veterinary Food Hygienists (WAVFH) and WHO).

Certain key factors were apparent from the outset of the meeting. A trend was noted towards an overall increase in the production of sewage sludge within Europe, accompanying the widespread construction of new

sewage treatment plants. Use of sewage sludge on land is often the cheapest method of disposal available, particularly in view of recent rises in the cost of energy, and disposal in this way also makes use of sludge as a valuable fertilizer or soil improver. It has long been realized that sewage sludge contains the pathogens that are prevalent in the community and that its use on land therefore poses a hazard to man by contamination of food or, indirectly, by causing diseases in food animals that are transmissible to man (zoonoses). The major rôle of the Working Group was considered to be that of identifying the diseases that pose a risk to human health and defining the measures that can be taken to reduce the risk. It is evident that the amount of risk varies widely from place to place and that it is therefore reasonable to suggest that local conditions should be taken into account when considering appropriate control measures.

SLUDGE PRODUCTION, TREATMENT, AND DISPOSAL

Sludge is the concentrated particulate organic fraction produced during sewage treatment. Its physical properties and chemical composition vary quite widely according to the source, the stage of sewage treatment from which it is produced, and the way in which it is treated prior to disposal. The first major stage in sewage treatment is that of sedimentation in large tanks, in which up to 70% of the suspended solids may be removed. This primary sludge may have a dry matter content of 40-70 g/l. The settled sewage is then usually treated by an aerobic biological process such as biological filtration or by the activated-sludge process. In each of these processes secondary sludge is recovered by settlement representing surplus biomass from microbial growth. Secondary sludges generally have a lower content of dry solids than primary sludges and are more difficult to dewater, and they are usually combined with primary sludge for treatment. Sludge that does not receive any treatment before disposal is termed raw sludge and is a highly putrescible liquid with an offensive odour. Raw primary and mixed sludges are usually treated in some way to reduce their water content and to render them more stable biologically so as to assist in their disposal. No particular treatment or combination of treatments can be said to be typical, although it is usual for the sludge from the larger works to be treated by anaerobic mesophilic digestion in enclosed tanks maintained at about 35°C for 3-5 weeks. Anaerobic digestion may also be carried out in deep open tanks at ambient temperatures over periods of about 4-6 months. During anaerobic digestion about 35% of the organic carbon and 40% of the dry weight are reduced by the production of methane and carbon dioxide. Sludge may also be stabilized by aeration over a period of several weeks, a method often used to treat surplus activated sludge at small works.

Before sludge can be dewatered, some form of chemical conditioning is required, usually with lime, ferrous sulfate, ferric chloride, or aluminium chlorohydrate either alone or in combination, or with organic polyelectrolytes. Heat conditioning under pressure at temperatures of 180-200°C will coagulate sludge and additionally kill all the pathogenic organisms, but it has now been largely abandoned because of the high energy cost and the production of highly polluting liquors of offensive odour. Conditioned sludge may be dewatered either on shallow drying beds or by mechanical pressing or centrifuging to produce a solid cake containing up to 60% dry solids. Sludge cake is suitable for transporting to disposal sites or for incineration. Liquid sludge, which retains much of the original nitrogen, requires transport to disposal sites by tanker, but can be readily and cheaply applied by sprinkling or spraying or by the use of fixed irrigation equipment. Dewatered sludge cake can be dried by hot air and pulverized for use as a fertilizer, but this operation, like incineration, has largely been abandoned because of the very high energy costs.

National disposal policies

It has been estimated (*J*) that the production of sludge in the then nine European Economic Community (EEC) countries in 1978 was about 6 million tonnes dry solids, equivalent to 230 million wet tonnes, and that, because of the growth of population and increased construction of sewage treatment plants, it will rise by about 5% yearly. Sludge production represents about 13% of the total solid waste in the EEC. The per capita contribution is assumed to be 800 kg wet sludge per person per year. Of sludge produced in the EEC, about 29% (as dry solids) is used in agriculture, 45% is dumped in landfills, 19% discharged at sea and 7% incinerated.

Participants in the Working Group provided summaries of the production and disposal practices in their own countries and these are given below.

Denmark. Sludge disposal policy is decided at present by local public health authorities. Draft national regulations exist and it is intended that in their final form they should follow the forthcoming EEC directive on sludge disposal. In the present draft regulations, dated June 1979, "hygienizing" is defined as treatment of sludge at 70°C for 25 minutes or an equivalent treatment. Sludge may be applied to land only if it has either been stored for six months previously or been hygienized. Sludge must be stabilized to such a degree that no significant problems of odour are created during its application. Application by spraying is forbidden. Sludge must be incorporated into the soil within 24 hours from application and it may not be applied to fruit or vegetable crops for human consumption. Sludge from Copenhagen is incinerated. Rules in other Scandinavian countries are enforced by law and are similar to those proposed for Denmark.

France. An inquiry of the Ministry of the Environment about 2000 sewage treatment plants in 62 of the 95 départements has shown the following uses:

Agricultural use only – 24% of works, serving approximately 24% of the population

Agricultural use and dumped – 14%, serving approximately 15% of the population

Dumped only – 60%, serving approximately 45% of the population

Incinerated – 2%, serving approximately 20% of the population.

There is no microbiological standard for sludge used in agriculture.

The recommendations of the Ministry of Health and Social Security are as follows. If sludge is treated the treatment given must be decided on the basis of the use to which the land is put and the requirements for the protection of the health of animals and man. Thermophilic digestion at 50–55°C is preferred for this reason. Spraying of sludge is forbidden. It is also forbidden to use sludge on land used for growing vegetables, whether they are eaten raw or cooked.

Federal Republic of Germany. Treatment of sewage and sludge is the responsibility of individual municipalities. About 85% of sewage currently receives treatment and sludge production exceeds 1 million tonnes of dry solids yearly. Sludge is stabilized by aerobic or anaerobic digestion or by other processes. About 25% of sludge, mostly from smaller works, is used in agriculture. There are proposals to use forests as additional disposal sites. The regulations are in the form of guidelines (2).

Italy. There is much construction of sewage treatment plants, so that sludge production can be expected to increase. Agricultural fertilizer is produced from composting and incineration is little used.

Netherlands. Sludge disposal increased from 13 500 tonnes dry matter per year in 1959 to 201 000 tonnes per year in 1978, a factor of 15. The routes for disposal in 1978 were: direct application to agricultural land, 35%; production of “black soil” fertilizer for public greens, 15%; dumping in landfills, 30%; sea disposal (practised only by The Hague municipality), 13%; others, 7%. There is no legal regulation of sludge disposal, but the Union of Water Boards (Unie van Waterschappen) published guidelines in 1980. These state that raw sludge should not be used on land and that the minimum treatment required is stabilization. A delay of six weeks is required before cattle can be introduced after treatment of grassland with sludge.

Poland. There are about 400 sewage treatment plants. It is usual for sludge digested in Imhoff tanks or in heated digesters (12% of the total) to be dewatered on drying beds, although some is lagooned. About 50% of air-dried sludge cake is used on agricultural land or on parks and gardens and the remainder is used in landfilling or is lagooned. Sludge production is currently 430 000 m³ per year (55% water content). By 1990 this will increase to 2 million m³ per year because of the construction of new sewage works. There are no specific disposal regulations. There are proposals to institute special farms for receiving digested sludge in the same manner as sewage farms have been extensively used in the past in Poland. Municipal sludge is regarded as a valuable agricultural resource. No hazard to animals has been demonstrated, either with sewage farming or with the use of sludge on land.

At Wroclaw, a farm of 1500 ha is divided into two areas, one periodically flooded with settled sewage and the other irrigated by sprinkling. Cattle are reared on the farm and are introduced to grazing land 14 days after ceasing irrigation. The milk produced from the farm is pasteurized before sale. The health of farm animals, guinea-pigs, and wild rodents feeding on the irrigated land has been examined by the Agricultural University of Wroclaw and no ill effects revealed. Thus, about 800 cattle and 100 horses that grazed on the land and were fed with grass and hay from the farm were examined in 1961-1962, and the conclusion was drawn that sewage farming, as practised, presented no serious risk of tuberculosis, brucellosis, salmonellosis, listeriosis, leptospirosis, or foot-and-mouth disease, in comparison with experiences from control animals on non-irrigated areas (3). Eggs of *Ascaris suum* in sewage applied to soil survived longest when applied in the summer, whereas those applied in spring did not develop to the larval stage (4). When the eggs were exposed to daylight, they became non-viable after 24 hours in the sun and after 4 days in the shade. In the autumn and early spring eggs could remain viable in sunlight for up to 2 days (5).

Switzerland. The total production as liquid sludge is now about 2-3 million tonnes per year. About 30% is incinerated (as in Lausanne and Winterthur) or dumped in disposal landfills, and 70% is used on land, equally divided between arable land and grassland. Guidelines are to be legalized in 1981 and will contain a microbiological standard (not exceeding enterobacteria 100/g) for sludge used on land used for growing fodder or for horticulture. There are specific problems in the case of mountain villages during the winter sports season, because of the difficulty of disposing of the additional load of sewage. The regulations will prohibit the application of sludge to snow-covered or frozen soils, the aim being to avoid polluted snow-melt. It is intended that the microbiological standard should be met by requiring all sludge from installations producing more than 50 tonnes of dry solids per year to be disinfected all the year round. This requirement is regarded as the

only practicable control measure that will eliminate cycles of salmonellosis between farm animals and man. The treatment that has proved most successful in trials is to pasteurize sludge before anerobic digestion.

United Kingdom. In 1975 sludge production was 1.24 million tonnes of dry solids, of which 74% was used on agricultural land and in landfill, 23% disposed of at sea, and 3% incinerated. More than 95% of the population is served by main drainage and, apart from that discharged to sea in coastal areas, all sewage receives full biological treatment (6). The ten regional water authorities in England and Wales and the nine Scottish regional councils control their sludge disposal operations by local codes of practice based on guidelines published in 1977 by the Working Party on the Disposal of Sewage Sludge to Land (7). Raw sludge can be used on arable land if it is ploughed in directly to avoid odour and if it is used only for the growth of crops conserved or cooked before consumption or in forestry or landfill. When raw sludge is used on grassland, cattle or pigs are not permitted to graze for 6 months afterwards as a protection against cysticercosis. Treated sludge can be used on grassland, subject to a delay of 3 weeks before cattle are allowed to graze where milk is pasteurized before sale, or 5 weeks if not pasteurized. This is to minimize the risk of salmonellosis. Revised guidelines were published in July 1981, but the above provisions are not altered.

United States of America. The disposal of sludge is regulated under the Resource Conservation and Recovery Act and the Clean Water Act, passed by the United States Congress and applicable to all States. As required by these laws, the Environmental Protection Agency (EPA) has published "interim final" regulations concerning sludge disposal to land (8). Final regulations are expected in mid 1981; meanwhile the interim final regulations are enforceable by citizen lawsuits. They consider three types of sludge from the viewpoint of public health:

(a) "Not stabilized" (raw sludge). Not for disposal to land; to be incinerated, buried, or heat-dried.

(b) "Process to significantly reduce pathogens", e.g. anaerobic or aerobic digestion treatment with heat, lime, or chlorine, composting, and lagooning. The restrictions in the final regulations are expected to be: no public access for 12 months; no grazing for 6 months; no growth of crops for human consumption that come in contact with sludge for 3 years.

(c) "Process to further reduce pathogens". No restrictions on the use of the sludge. These processes are expected to be new approaches such as high-energy irradiation and thermal processes, e.g. pasteurization, heat treatment, thermophilic digestion, and composting.

The Metropolitan Sanitary District of Greater Chicago (MSDGC) has a large commitment to the utilization of sludge on land for the fertilization of crops, the major utilization project being on land reclaimed from strip-mining in Fulton County, Illinois, where digested sludge is received from its largest treatment plant (the West-Southwest) (9). The MSDGC currently owns over 6075 ha of land approximately 320 km south of its 2240 km² drainage area. Liquid digested sludge containing approximately 4% dry solids is carried by barge down the Illinois River and then pumped for 17.3 km to holding basins on the site. Sludge is applied to the land mainly from April to October, by soil incorporation. So far the application rates have been up to 67 dry tonnes per ha per year to fields where maize is the principal crop. Currently about 5400 wet tonnes per day of sludge are transported to the site. The total equivalent population served by sewage treatment is about 10 million and, of the total sludge produced, about 40% is used directly in agriculture and 60% in land filling, parks, and horticulture. The rule governing application to land is to avoid contamination of food chains, so that grain grown on land receiving sludge is only used for feeding cattle.

Because of the extent of the sludge disposal activities, microbiological monitoring and survey work has been carried out for many years (9). The average level of salmonellae in raw sludge from the West-Southwest plant was 49 per 100 ml (20 observations) and over the period 1975-1977 salmonellae could not be recovered in annual samples from four test fields that received approximately 20 dry tonnes per ha per year and had received cumulative applications of 47-174 tonnes per ha. *Taenia* eggs have not been recovered from the sludge, about two thirds of parasite eggs recovered being of *Toxocara* species. Studies have shown that enteroviruses are inactivated in the mesophilic digestion of sludge at Chicago (10) and none have been recovered since late 1975 from three streams draining the Fulton County site (9).

MICROBIAL HAZARDS AND PUBLIC HEALTH

Sewage sludge contains a wide variety of pathogens, including bacteria, viruses, fungi, and eggs of parasites. Their significance is discussed by Alderslade (11). They are derived from the population served by the sewerage system, and the prevalence of any particular pathogen reflects the current incidence of disease in the community. Pathogens may also enter the sewerage system from abattoirs and farm drainage, domestic animals, the rodent population of the sewers, and surface waters. The load of most pathogens in sewage is considerably reduced by treatment, particularly biological treatment. However, many pathogens appear in the raw

sludge in numbers greater than in the original sewage contributing to the sludge, because of the concentrating effects of sedimentation and adsorption.

The Working Group considered that sludge and its use on land pose a potential hazard to the health of man and food animals. However, there would only be a significant risk of infection when a combination of circumstances occurred involving, for example, the nature of the pathogen, the sludge disposal practice, the use made of the land, and a variety of local geographical, climatological, and demographic factors. Because of this, to assess the risks to human health each potential class of pathogen was examined critically by the Working Group in the light of the epidemiological information existing. The epidemiological information for some pathogens, notably the salmonellae, exists in a variety of forms such as data from national surveillance of case histories or outbreaks, or from investigations on carrier rates. Both bacterial and viral infections may exist in the carrier state in animals or man without any clinical manifestations. The carrier state in a herd can serve as an effective focus for spreading infection.

Bacteria other than salmonellae

Escherichia coli. Certain serotypes are pathogenic to man, animals, or both and are particularly virulent in infants. Problems are caused by plasmid-mediated transfer of drug resistance to other Enterobacteriaceae, particularly salmonellae, in the gut. As these serotypes are always present in sewage it is possible that sludge may play a role in their dissemination, although there is no actual evidence for this; further research is needed. Methods to prevent the transfer of drug resistance should be directed in the first instance to stopping the misuse of antibiotics.

Other Enterobacteriaceae and Pseudomonas aeruginosa. These organisms are all ubiquitous in the natural environment and therefore should not be considered in particular. The presence of *P. aeruginosa* in the natural environment is closely associated with human pollution, although its multiplication only occurs at higher temperatures, as in indoor microclimates.

Yersinia enterocolitica. The epidemiology of this organism is not yet fully understood, although it is excreted in faeces and can multiply at low temperatures. It is primarily associated with food poisoning. Further studies are needed to determine whether sludge is an agent of infection in, for example, the recontamination of cooked foods by raw vegetables or other materials brought into the kitchen that carry sludge-treated soil.

Clostridium perfringens. The clostridia are mainly soil organisms. Because of their long-lived spores, the addition of sludge can increase their background level in soil and therefore, in theory, their numbers in certain

foods. In practice, the normal level of spores in the soil is so high that the application of sludge is unlikely to increase significantly the risk of food being contaminated.

Clostridium botulinum. Apart from being primarily a soil organism, *C. botulinum* can be introduced into the farm by brewer's grain contaminated with the organism. Pastures fertilized with the manure from cows fed on this material can be contaminated, and so can silage made from the pastures (12); the bacteria have been shown to multiply and produce toxin in poor-quality silage (13). *C. botulinum* produces one of the most potent toxins known. It would appear that there is no specific risk to public health from sludge, but sludge can increase the level of spores in the soil. Public health is protected by detailed attention to the preparation and processing of canned foods and cases of botulism in man are extremely rare. Similar considerations also apply to other clostridia, which can be opportunistically pathogenic in certain circumstances.

Bacillaceae. These aerobic spore-forming bacteria, other than *Bacillus anthracis*, are so ubiquitous that sludge containing them cannot be considered as having any specific role in the etiology of food poisoning. Anthrax is mainly a disease of animals and is sporadic. In man, the principal cause of anthrax is the handling of carcasses, hides, wool, and other animal products containing the spores of *B. anthracis*. The main problem is with the carcass unrecognized as infected and with wastewater from tanneries and wool-processing establishments treating materials imported from the few parts of the world where anthrax is still endemic. There is no evidence available implicating sludge as a source of human anthrax.

Listeria monocytogenes. This organism can be regarded as an opportunistic pathogen, since it is carried regularly in the gut by healthy persons and animals. In one study (14), it was isolated from 35 out of 38 samples (92%) of treated sewage effluent. Cases of listeriosis in man are sporadic and the epidemiology is poorly understood. It is a psychrophilic organism. Sludge disposal will add to its load entering the environment, but the significance of this is not known and its incidence is not of great concern.

Vibrio species. Cholera, caused by *Vibrio cholerae*, is waterborne. Enterotoxigenic strains of *V. cholerae* survive poorly in the environment and thus treated sludge is not involved directly in the spread of cholera. It is now known that food animals, such as cows and pigs, can act as carriers. *V. parahaemolyticus* is a marine organism, so sea foods are its principal agents of infection. Sludge applied to the land cannot be considered an agent.

Mycobacterium species. Unlike that of the foregoing organisms, the epidemiology of tuberculosis is well understood. Sludge can transmit the organism to farm animals, but the disease has now been virtually eradicated from many regions, so that this route of infection is no longer of any significance. Waste from sanatoria is a special case and should be disinfected before discharge. Heat treatment of sludge is the only practicable measure known of killing these bacteria.

Leptospira species. These organisms can survive relatively well in alkaline water. There is no evidence that sludge is an agent of infection. The number of clinical infections in man is very small and the disease is an occupational one affecting farmers, veterinarians, and others in contact with animals.

Campylobacter species. The epidemiology of infection with these organisms is not yet understood, but they have similarities with salmonellae in the way they affect man and animals. They are now recognized as a common cause of gastroenteritis in man. It is thought that sewage sludge is unlikely to be concerned significantly in their spread in the environment or in the incidence and extent of their carriage in animals.

Salmonellae

Experience in Switzerland

In Switzerland there has been a consistent increase in human cases from 23 in 1955 to 3629 cases in 1979 (both figures are certainly underestimates). Over the same period there have also been increases in the *Salmonella* carrier rate in pigs and cattle and in the frequency of isolations from meat, meat products, and butcher's shops. Recent surveys carried out by the Institute of Veterinary Hygiene, University of Zurich, as reported by Dr Breer, have shown the following positive incidences of isolation:

From normally slaughtered pigs, 1978: 63/500 (12.3%)

From healthy cattle slaughtered at four abattoirs, 1977: 63/2515 (2.5%)

From monthly hygiene control examinations in butcher's shops, 1979: 56/290 (19.3%)

From sewage sludge samples from 205 treatment plants, 1980: 383/396 (96.6%).

Quantitative evidence has demonstrated high levels of salmonellae in sludge and their survival for many weeks in sludge, on grassland, and in stored grass (15, 16). The seasonal incidence from 1969 to 1978 of *Salmonella* isolations from cattle (26 646 samples) has been related to the times of year at which sludge was applied, and evidence from studies of carrier rates and serotypes in cattle grazed on sludge-treated pastures has indicated a positive

association and a cycle of infection existing (man-sludge-animals-man). It has not been possible to control this cycle by improvements in meat inspection at slaughterhouses. Accordingly, the Swiss authorities have decided that sludge must be hygienized before being used on land. The most suitable process is pasteurization prior to anaerobic digestion (17), and in January 1981 there were three plants in operation.

Experience in the Netherlands

Salmonellosis is an important public health problem in the Netherlands, reported cases in 1976 reaching 12 000 in the population of about 13.5 million. In the period 1951-1970 the three commonest serotypes in human cases were *S. typhimurium* (60%), *S. panama* (10%), and *S. infantis* (5%) (12). Since 1960 the epidemiology of salmonellosis has been extensively studied by Edel, Kampelmacher, and others (18-22) and they have shown that foods of animal origin, particularly meat, are the most important source of infection in man, that a relatively high number of clinically healthy food animals, including poultry, are carriers, and that infected feedstuffs, particularly imported fish meal, are responsible for the introduction of new serotypes. In experiments in which pigs were fed heat-treated pelleted food and kept in housing from which all sources of contamination except environmental sources were excluded, they became carriers of salmonellosis, whereas pigs in a control group from which environmental contamination was excluded remained healthy and uninfected. Since 1971, extensive studies on cycles of transmission of salmonellosis have been carried out on the former island of Walcheren, where there are about 200 pig farms, 2 slaughterhouses, 60 butcher's shops, and 14 sewage works serving 90 000 people. These have demonstrated that complex cycles of transmission exist involving animals infected from the environment and from feedstuffs, meat, patients, healthy carriers, effluent from sewage works, surface water, insects, birds, rodents, and food animals. A major piece of evidence for this cycle is the high incidence of isolation of a single phage type, *S. typhimurium* II 505, from most of the classes of samples examined (19, 21). Two of the main conclusions from this work (20) are that it must be considered very unlikely, except on a relatively small scale, that salmonella-free foods and feeds can be produced in the near future and that, for direct protection of the consumer, education about and improvement of hygiene in the kitchen are important. The pelleting of animal feed, particularly for pigs, will reduce contamination on the farm. However, a reduction in environmental contamination may help to break the cycles of infection.

Experience in the United Kingdom

An extensive system for reporting cases of human salmonellosis has existed in England and Wales since 1941 and for the reporting of outbreaks in

food animals since 1958. Isolations from human cases and incidents are recorded by the Communicable Disease Surveillance Centre (Public Health Laboratory Service) and notifications of cases are received independently by the Office of Population Censuses and Surveys and by the Department of Health and Social Security. Since 1975 salmonellosis of food animals has been notifiable under the Zoonoses Order (23). This level of recording has been widely used to ascertain trends in infection by different serotypes and to enable appropriate control measures to be taken (24). There were over 11 000 reported human cases in 1978, amounting to a rate of 16 per 100 000 population (11). Prior to 1941 it was rare to find other than about 14 "native" serotypes, but changes in feeding patterns, agricultural practices, and food importation have introduced serotypes not previously encountered. A feature of incidents in food animals has been a reduction in outbreaks caused by host-adapted serotypes such as *S. dublin*, *S. pullorum*, and *S. gallinarum*. There has, however, been an increase in the incidence of *S. typhimurium* and "exotic" serotypes such as *S. hadar* and *S. agona* (24). Some of these exotic serotypes may have been introduced originally by infected imported feedstuffs, since when they have been increasingly identified as the cause of human food poisoning cases; an example is *S. agona*. In 1978, 1428 outbreaks were reported in cattle in England, Wales, and Scotland, the commonest serotypes being *S. typhimurium* (48%) and *S. dublin* (30%). The value of surveillance has been shown in two recent examples: the now widespread distribution of multiple resistant strains derived from *S. typhimurium* phage type 204 (R-type CSSuT) in cattle and man, which was traced to a single farm with an extensive calf trade; and the tracing of *S. hadar* infection of turkeys to a few producers of turkey poults (25).

The main factors in Great Britain affecting salmonellosis in food animals by *S. typhimurium* and other serotypes not host-adapted to specific animals are thought to be animal-to-animal transmission, the effects of intensive rearing (as, for example, the widespread and extensive movement of calves from dealer's premises and cattle markets) and, in the early 1970s, the importation of low-grade protein for compounding animal feedstuffs. There are several well-documented cases of salmonellosis in cattle caused by contamination of pasture with crude sewage or septic tank wastes, but there is no evidence, despite the compulsory reporting of incidents, for a link with the application of sludge to grazing land (7, 11, 26). It is thought that the use of sludge in accordance with the United Kingdom guidelines provides advantages to agriculture outweighing any possible disease risk in animals (7).

Infections of cattle by the host-adapted serotype *S. dublin*, rarely transmitted to man, have been endemic for many years in certain well-defined localities, typically those with low-lying poorly-drained grazing land. Transmission is from animal to animal.

The main reservoirs of human salmonellosis in Great Britain are considered to be meat, dairy products and, in particular, poultry. The principal reason for the spread of the disease is faulty food hygiene in the home and in catering establishments.

Risks to animal and human health from salmonellae on sludge applied to agricultural land

Although the initial scope and purpose of the Working Group did not include an examination of the risks to food animals from the use of sludge in agriculture, the topic was examined in some depth because meat and dairy products are an important source of salmonellae in human food poisoning. There appears to be a discrepancy between the lack of evidence in the United Kingdom implicating the application of sludge to land in salmonellosis of food animals and the evidence that it does so in the Netherlands and Switzerland. This discrepancy (26, 27) was examined in depth by the Working Group.

The United Kingdom experience is based on analyses of reports of clinical infection and outbreaks made under the Zoonoses Order (23), whereas the evidence from the Netherlands and Switzerland is from extensive epidemiological surveys to detect carriers of salmonellae (15, 16, 18-22). One view expressed was that the detection of carriers provides a more certain index of risk, since carriers are responsible for spreading infection to other animals and to man via food, and since lower numbers of salmonellae are required to establish a carrier state than to establish clinical infection. Comprehensive national surveillance of outbreaks over many years in the United Kingdom too, has enabled newly introduced serotypes and trends in the sources of infection to be noted and control measures to be taken (11, 24). It was recognized by the Working Group that properly planned and controlled epidemiological experiments are expensive to carry out and, because they would be designed to prove hypothetical factors — perhaps suggested by surveillance — they ought to follow surveillance.

Another key factor considered by the Working Group was the effect local or national differences might have on the transmission of salmonellae from sludge to food animals. Such differences include the density of human population, the incidence of human salmonellosis, the extent to which full biological treatment of sewage is provided, the treatment and handling of sludge, the application of guidelines covering the application of sludge to land, agricultural practices, the stocking density of animals, and the climate.

The Working Group agreed that:

(a) Sewage sludge contains salmonellae that contribute to overall environmental contamination, but it is not the only source of such salmonellae. The contribution of sludge to background levels should be assessed along with the contributions of salmonellae from other sources to the environment.

(b) Surveillance is needed as a first priority to reveal the extent and likely causes of salmonellosis and to suggest appropriate epidemiological studies and control measures.

(c) Surveillance will not necessarily reveal the extent or importance of the carrier state or its importance in determining the risk of infection from environmental sources, but it will detect major trends in the sources and incidence of infection with different serotypes and the factors responsible for them.

(d) Epidemiology is expensive and epidemiological experimental design likely to be complex. Properly controlled experiments can only test specific hypotheses and should follow surveillance.

(e) Changes in the rate of carriage of salmonellae by animals are not likely to be followed by directly proportionate similar changes in the incidence of human ill-health. The relationship will be complex and uncertain, and its determinants have not been estimated.

(f) Elimination of all sources of environmental contamination, although theoretically desirable, may be impracticable and would not, in the absence of measures designed to eliminate other routes of infection (e.g. juvenile infection and contaminated feedstuffs), have an immediate impact on the burden of salmonellae in animal and human populations.

(g) Suitable control measures should be dictated by local conditions and the availability of funds.

(h) A major factor in human food poisoning is contamination of the kitchen, whether introduced by infected meat and dairy products or by infected soil on vegetables (even though these are later cooked). It is accordingly cost-effective to improve hygienic practices in the kitchen.

The Working Group noted that the WAVFH/WHO conference on food poisoning had considered that salmonellae are so ubiquitous that proper control of human salmonellosis is through improved food hygiene and that attempts to remove salmonellae from the environment are not likely to succeed. Three lines of attack are therefore suggested.

1. The rearing of *Salmonella*-free animals. This is at present only possible under controlled experimental conditions.

2. Heat treatment, including pasteurization. This could be used for milk and egg products but not for foods eaten raw.

3. Education of food handlers and kitchen personnel in good food hygiene.

Parasites

Eggs of a variety of helminths and protozoan cysts can be found in sludge and in raw and partially treated sewage. The reduction in their count

during sewage treatment depends on sedimentation and may not be great. The relative densities and settling velocities of helminth eggs and protozoan cysts vary, but may not be sufficiently greater than the density of sewage and the upward flow velocity (surface loading rate in rectangular tanks) for sedimentation to be effective. Nevertheless they will be concentrated in primary sludge. In the case of the parasites that have man as a specific host, sludge and other faecal contamination represent the only way in which they can enter the environment.

Taenia saginata. The larval, or cysticercus, stage in cattle causes economic loss to farmers because of condemnation or downgrading of carcasses. The only true test of viability of eggs in sludge is the ability to infect cattle after ingestion. Table 1, from data presented by Professor H.J. Bürger, shows that grassland treated with sludge containing eggs of *T. saginata* becomes non-infective for test calves 17-18 weeks after applying the sludge (28).

Table 1. Numbers of cysticerci and presence of sarcosporidia at autopsy after test grazing of parasite-free calves on grassland that had received sludge containing eggs of *T. saginata* and cysts of sarcosporidia

Treatment of plot	Period between application of sludge and test grazing		
	5-6 weeks	9-10 weeks	17-18 weeks
200 l sludge/m ²	211+	15-	0-
	147+	13-	0-
	65+	5-	0-
200 l sludge/m ² , grass mowed after 5-6 weeks	NT	3+	1-
		2+	1-
		0-	1-
No sludge applied	3-	NT	NT
	2-		
	0-		

+ = sarcosporidia isolated - = sarcosporidia not isolated NT = not tested with calves

Note: Testing for infectivity of grass was carried out by allowing three parasite-free test calves to graze for two weeks in each case, followed by slaughter and extensive examination of the carcass.

Ascaris lumbricoides and *Toxocara* species. Man can be infected by eggs of both these helminth parasites. The definitive host of *A. lumbricoides* is man himself, and of *Toxocara* both cats and dogs. The contribution from eggs of these organisms in sewage sludge to human ill health is unknown.

Echinococcus species. These pose little problem in countries north of the Alps. *E. granulosus* exists in a well-defined cycle involving dogs (tapeworm stage), particularly working dogs on sheep farms, and sheep (larval stage). In addition, *E. multilocularis* exists in a similar cycle involving foxes and voles and, in the USA, cats and house mice. Man can be the intermediate host (larval stage). It is possible for eggs from cats and dogs to enter sewers from surface water, although the significance of this is unknown.

Toxoplasma gondii. Infection via sludge can only occur if sporocysts from cat faeces enter the sewerage system. Other routes of transmission such as direct infection with sporocysts from cats and infection with schizonts are probably more important than transmission via sludge.

Sarcocystis species. Infection rates in cattle and pigs are high but the epidemiology is poorly explored, particularly the role of sludge in spreading infection.

Gastrointestinal nematodes. These are present in slaughterhouse waste and farm runoffs. The eggs do not develop further under anaerobic conditions but may hatch after the spreading of sludge on pastures. Slurry is a vehicle in animal infections.

The Working Group considered that the parasites for which sludge is significant as a vector are *T. saginata*, *Ascaris* species, *Toxocara* species, and sarcosporidia. Cysts of *Entamoeba* and *Giardia* species also occur in treated effluents. For all of these parasites transmission can involve routes other than sludge. The control of infection by these parasites in sludge requires long storage of the sludge before it can be applied, or long periods after applying it before grazing animals are reintroduced. Sludge must not be applied to growing vegetables or to crops eaten raw.

The risk of infection to man from parasites associated with the use of sludge needs evaluation. The risk to food animals from parasites transmitted by sludge disposal did not fall within the scope of the Working Group.

Viruses

The categories of viruses that can be present in sludge are: enteroviruses, polioviruses, coxsackie viruses A and B, echoviruses, enteroviruses No. 68-71,

possibly also hepatitis A virus, adenoviruses, reoviruses including rotavirus, parvoviruses, and coronavirus. The enteroviruses are stable under damp conditions but susceptible to drying, whereas parvoviruses are resistant to drying. It is not yet possible to cultivate hepatitis A virus, rotavirus, or coronavirus.

Viruses can be present in treated wastewater and sludge and have been detected on fruits and vegetables. When they were applied to soil in the wintertime in Denmark, enteroviruses decayed by about 0.5-1 log units per month (29). They are reversibly adsorbed to the upper layer (about 0.1-0.2 m) of soil and, under northern European weather conditions, can be expected to stay there. Extreme downward movements of soft water are required to elute them, but viruses added to the soil through sludge application would normally not reach the groundwater.

The Working Group considered that epidemiological studies would be difficult to evaluate since most enteric virus infections in man are symptomless, the range of symptoms connected with a specific virus infection is very wide, and the same symptom can be caused by many different viruses. The hepatitis A virus infections are those most often clearly associated with the waterborne route, probably because the ratio between infection and clinical disease is lower than for other enteric viruses, a factor perhaps of 10 rather than 100-1000.

Rotavirus in particular and probably also coronaviruses and parvoviruses are normally associated with infantile gastroenteritis, often of a very severe nature. They cause serious disease in the developing countries, but they are not restricted to such areas. Little is known about the stability of these viruses in the environment. Although the faecal-oral route of direct person-to-person transmission is undoubtedly the most important route at present, the Working Group thought that the possibility that these viruses are transmitted in sludge applied to land should be evaluated. It was unable to identify any virological problems associated with the application of sludge to agricultural land other than the application of insufficiently treated sludge to land producing crops eaten uncooked by human beings. However, two participants, Professor Lund and Dr Bertoldi, considered that the spread of hepatitis A virus through the use of sewage and sludge on vegetables (e.g. in southern Italy) and through runoff from fields on which sludge has been incorrectly applied (e.g. in Czechoslovakia) ought to be mentioned. The possibility that newly identified viruses such as the Norwalk agents, rotaviruses, coronaviruses, and possibly parvoviruses can spread and remain in the environment cannot be confirmed for the time being because methods for the cultivation of these viruses have not been developed. In view of the importance of viruses as a cause of gastroenteritis (which is the most significant cause of death among infants in developing countries), this possibility cannot be discounted when considering the application of sludge to land.

Fungi

The following classes of fungi that can be isolated from sludge are able to infect man or induce allergic states: (a) yeasts – *Candida albicans*, *C. krusei*, *C. tropicalis*, *C. guilliermondii*, *Cryptococcus neoformans*, *Trichosporon* species; and (b) filamentous fungi – *Aspergillus* species, *A. fumigatus*, *Phialophora richardsii*, *Geotrichum candidum*, *Trichophyton* species, *Epidermophyton* species.

Trichophyton and *Epidermophyton* are dermatophytes associated with cutaneous infections such as ringworm and athlete's foot. The cryptococci are pathogens infecting mucosae, particularly in vaginitis. *Trichosporon* species infect hair follicles. The problem in assessing the hazard from some of the filamentous fungi is that they are normal soil organisms which, however, are able to multiply in stored sludge cake or during composting to produce copious numbers of spores or toxic metabolites. Thus spores of *Aspergillus* and related species, and particularly of *A. fumigatus*, can, if inhaled, produce severe respiratory symptoms of allergic type in man (e.g. farmer's lung) and set up allergic responses. *Phialophora* is one of several fungi and actinomycetes found in deep-seated infections of the foot (Madura foot). *G. candidum* is a transient inhabitant of the mouth and other mucosae. It is frequently found in activated sludge and can also be found in milk and other foods. Its significance is unclear. Some of the aspergilli are able to produce mycotoxins such as aflatoxin during growth. These fungi and yeasts can be detected in sewage and at all stages of sludge treatment and they should therefore not be disregarded in any consideration of the public health implications of the application of sludge to land.

The Working Group considered that it is not easy to evaluate the significance of these organisms in public health. The mould fungi are among those organisms which are ubiquitous in the environment, and they are present in animal feeds and in harvested grain. Pasteurization of sludge will therefore not solve any problems they might present, since recontamination will occur. The main hazards to man arise from airborne spores and the most likely source of hazard is composting or sludge drying plants. However, a prospective experiment at Beltsville, MD, USA, reported by Dr Farrell, has shown that there is no hazard from composting to the general public living near the works and that the only health measure indicated for workers is careful screening of new employees for a history of asthma.

Other pathogens

The Working Group was unable to add any other pathogenic agents to the list considered above.

LONG-TERM UTILIZATION OF SLUDGE AND SEWAGE

The Working Group noted that sewage farming has been practised for over a century, yet there appear to be no published records of adverse health effects on man. Sewage has been applied to land used for raising cattle, grain, vegetables, and citrus fruit and to parkland. On the other hand, it is clear that the main source of human salmonellosis is infected food brought raw into the kitchen and handled there. Any statement to the contrary should not go unchallenged. The Working Group thought that the true rate of cysticercosis in cattle might be underestimated where sewage farming was practised and where cattle were sold to areas outside unless the history of the carcasses could be traced back. Controlled experimental studies in Victoria, Australia, where taeniasis is endemic, showed that cattle reared under *T. saginata*-free conditions became infected with cysticerci when grazed on pasture irrigated with raw sewage and effluents from biological filtration and activated-sludge treatment, but not with lagoon-treated effluent, from which eggs of *Taenia* are removed by sedimentation (30). It is also noteworthy that the rate of human salmonellosis has increased as standards of living have increased, while the practice of sewage farming has fallen. Sewage farming and sludge spreading are usually properly controlled operations and it is probably not surprising to find that they have little effect on human health. This may be contrasted with the well-known problem of schistosomiasis in the eastern Mediterranean and western Pacific regions, where night-soil is still used to fertilize paddy fields and where infection occurs through the skin when workers stand with bare legs in the submerged fields.

The general opinion of the Working Group was that the many medical studies carried out and surveillance had failed to show that sewage farming and sludge spreading, when properly controlled, pose a serious human health problem and that it is possible to use sewage on land with appropriate control. Without such control there are certainly local health effects, since in developing countries, where there is already a high level of parasitic infection in the community, a hazard from the use of night-soil as a fertilizer is clearly identifiable. Some participants expressed reservations about the adequacy of the experimental design and the analytical methods used for enumerating viruses in the examples discussed.

RISKS TO HUMAN HEALTH FROM USE OF SLUDGE ON LAND

The Working Group noted that at a workshop on animal waste in Hanover in November 1980 no strong conclusion had emerged, except to the effect that a hazard to animals from eggs of parasites exists.

No direct effect of sludge spreading on human health can be proved, although sludge spreading is increasing because of the construction of new sewage works and the high cost or unavailability of other means of disposal. There is some evidence for a relation between sludge spreading and the establishment of *Salmonella* carriage in cattle and pigs. This may pose a threat to human health through the contamination of meat, milk and dairy products, and working surfaces in the kitchen. There is no doubt that the use of sludge has been associated for many years with the transmission of cysticercosis to cattle and thereby of *T. saginata* to man. Meat inspection is a very imperfect barrier to such transmission, since it is capable of detecting only a low proportion of infected carcasses. Apart from these two pathogens, no evidence has been found to suggest that sludge is a vehicle for the transmission of disease to man.

The difference between a hazard and an actual risk requires definition. Because sludge regularly contains a variety of pathogens it poses a hazard to health. The existence of a risk to health depends, however, on a number of local factors and particular circumstances and it needs to be defined in each case. As an extreme example, salmonellosis in dairy cattle is a hazard to human health, but the risk from consumption of milk can be overcome by pasteurization. Generally, sewage sludge contains pathogens that represent a hazard to health, but they represent a risk only if circumstances permit them to be ingested in sufficient numbers to cause infection. If food hygiene is good, the risk is small. Two statements made at the Second European Symposium on Characterization, Treatment and Use of Sewage Sludge are relevant to the safeguarding of public health: "economically and practically a no-risk level cannot be obtained, although it may be technologically possible", and "reasonable safety cannot be expressed in absolute terms but would depend upon a number of economic, political and geographical factors".

The Working Group noted that the difference in terms of disease between using sterilized sludge and using unsterilized sludge would, in practice, prove to be small, since there are many alternative sources of environmental contamination. Because of animal-to-animal transmission and the existence of carriers in herds of food animals, the elimination of contamination from sludge would have no immediate identifiable effect on public health even in areas where a causal relationship exists between disease and the application of sludge to land, and it might well take many years to reduce infection in animals significantly. Where contamination from other sources is substantial, the removal of sludge as a vector would, at best, have only a minimal effect on the risk. The use of sludge on land presents the risk that food animals may become carriers of salmonellosis or become infected with *Cysticercus bovis*, but the risk can be minimized by adopting suitable agricultural practices. If the risk is high, it may not be possible to apply sludge to land. Contamination of the environment can be reduced by heat treatment of sludge (for example, by pasteurization at 65-70°C for 30 minutes or an equivalent

treatment), by addition of lime (to destroy salmonellae), or by imposing periods of storage or delay before reintroducing animals on the land.

The Working Group did not favour universal recommendations since, depending on local circumstances, different measures are needed in different localities and situations to reduce the problem to an acceptable size. The formulation and application of suitable control measures must be a local decision.

CONCLUSIONS AND RECOMMENDATIONS

Sewage sludge contains a variety of pathogens, including bacteria, viruses, parasites, and fungi, reflecting the presence of these agents in the human and animal population contributing to the sewage. Utilization of such sludge on agricultural land used for raising crops and for grazing animals is frequently a low-cost means of sewage disposal; it provides plant nutrients and may improve the properties of the soil, although it also results in the distribution of pathogens in the environment. However, a number of other sources and routes of transmission of pathogens contribute to the total risk to human and animal health. The additional risk of a given sludge disposal practice must therefore be considered against this background. It is, however, extremely difficult and expensive to measure the risk by microbiological and epidemiological methods. The public health risk from the disposal of sewage sludge on land may nevertheless be reduced by appropriate treatment and use of the land. It would be unrealistic to expect a significant or early reduction in the incidence of disease if other important sources of pathogens remain unaffected.

Acceptable levels of risk in given communities depend on a number of different factors. These include: the health status of the local population; the nature of the soil; the temperature, humidity, precipitation, and groundwater table; the nature of the agriculture and animal husbandry; and the way in which the sludge can be safely transported and spread on the land. Such acceptable levels cannot be expressed in absolute terms, but the public health risk may be controlled by the use of appropriate guidelines, which would vary from place to place according to local circumstances.

Salmonellae responsible for food poisoning represent one of the risks to human health that may be increased by the spreading on land of sewage sludge containing these organisms. Although there is no epidemiological evidence available for this yet, it has been shown that cattle exposed to such sludge may become carriers of salmonellae to a greater extent than controls. *T. saginata* is a specific parasite of man, and where infection occurs the eggs are excreted in human faeces. They may be disseminated by sewage

sludge and thus infect cattle, the subsequent development of cysticerci presenting an infection risk for man. Salmonellae and eggs of *T. saginata* in sewage sludge can be eliminated or reduced by various forms of heat treatment, by ionizing radiation, or by long-term storage. In contrast to the salmonellae, the eggs of *T. saginata* are resistant to chemical disinfectants.

The risk to public health from other pathogenic agents appears to be less than those from salmonellae and *Taenia* in most areas studied. However, the possible risk from viruses and from parasites such as *Sarcocystis* has not been adequately evaluated. For example, the presence of hepatitis A virus in sewage sludge may represent an additional risk in areas where the incidence of this infection is high.

On the basis of its discussions the Working Group decided on the following recommendations.

1. Measures should be taken to effect a substantial reduction in the concentration of pathogens in sewage sludge before it is allowed to come into contact with crops such as fresh vegetables and fruit that are brought into the kitchen raw.

2. Sludge containing pathogens that may multiply in or contaminate meat, poultry, and dairy products should not be spread on land where food animals are raised unless an adequate interval of time elapses between spreading the sludge on the land and allowing the animals to graze.

3. The following measures should be taken for the disinfection of sewage sludge so that its use can be relatively unrestricted:

- (a) heat treatment, such as 70°C for 30 minutes, thermophilic composting, or heat drying;
- (b) ionizing radiation with at least 5 kGy;
- (c) extended batch storage for a time that is inversely related to the temperature;
- (d) treatment with chemical agents that destroy the organisms in the sludge environment.

4. For restricted use, where direct contact with fresh food that may be brought into the kitchen raw is not involved, anaerobic digestion and other stabilization processes should be utilized if they are carried out in such a way as to minimize recontamination.

5. Uniform regulations should not be imposed over large regions without due regard to local conditions.

6. Carefully planned epidemiological investigations into the relationship between sludge spreading and the public health should be encouraged.

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