Public health aspects connected to the use of sludge on land

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1 Introduction

Like other urban wastes, sewage sludge may contain different kinds of pathogens that are infectious for different species of animals and plants as well as for humans. The origin and nature of organic wastes such as different types of sludge always causes a hygienic risk in storage, collection, processing, handling and utilisation. These risks exist both when the organic wastes are generated during the treatment of industrial or municipal wastewater, and when the sludge results from industrial processing of organic material. Therefore hygienic principles must be followed in processing, storage, transport and distribution of such materials. Recycling of organic material to agriculture is a desirable aim from the point of view of saving raw materials which are of limited availability such as phosphorous, but this aim may conflict with the necessity to protect humans, animals and plants from undesired infections as well as with general aims of environmental protection. This report covers only the hygienic aspects of the use of sludge on land. However, undesired organic and inorganic pollutants can also cause risks and must be kept in mind.

2 Hygienic risks

Three main types of risks related to human and animal pathogens should be considered under public health aspects in processing and recycling sludge (BÖHM, 1995; BÖHM et al., 1996; STRAUCH, 1998)

- ➪ occupational health risks
- ➪ risks concerning product safety
- ➪ environmental risks

Occupational health considerations in collecting and processing of organic wastes and sludges are not the main subject of this contribution, more details may be found in HICKY and REIST (1975), GRÜNER (1996) and BÖHM (1998). Hygienic risks due to sludge and related products will be discussed here. This includes the direct transmission of pathogens to humans or animals and plants of agricultural importance as well as the introduction of these pathogens into the biozoenosis and environment by the application of such material as organic fertilizers.

2.1 Pathogens in sewage sludge

The basic hygienic risk is the occurrence of pathogens in sewage sludge. This is the starting point for epidemiological reflections and necessary precautions. Tables 1 - 4 show a survey on such pathogens according to STRAUCH (1991).

Table 1. SELECTION OF BACTERIAL PATHOGENS TO BE EXPECTED IN SEWAGE AND SEWAGE SLUDGE, STRAUCH (1991), modified

Primary pathogene	Secondary pathogene
Salmonella spp.	*Escherichia*
Shigella spp.	*Klebsiella*
Escherichia coli	*Enterobacter*
Pseudomonas aeruginosa	*Serratia*
Yersinia enterocolitica	*Citrobacter*
Clostridium perfringens	*Proteus*
Clostridium botulinum	*Providencia*
Bacillus anthracis	Multiresistant bacteria
Listeria monocytogenes	
Vibrio cholerae	
Mycobacterium spp.	
Leptospira spp.	
Campylobacter spp.	
Staphylococcus	
Streptococcus	

From the variety of bacterial pathogens *Salmonella spp.* are the most relevant since they can infect or contaminate nearly all living vectors from insects to mammals.

Multiresistant bacteria are becoming increasingly important since their transmission via the environment as well as the introduction of resistance genes into other bacteria may cause tremendous problems in human and veterinary medicine (TSCHÄPE, 1996). Among viral pathogens, enteroviruses, caliciviruses and rotaviruses are the most relevant from the point of view of environmental risks (METZLER et al. 1996). Special regard must be paid to the parasitic pathogens, not only to eggs of round- and tapeworms but to Giardia lamblia and Cryptosporidium parvum.

Table 2. SELECTION OF VIRUSES EXCRETED BY HUMANS WHICH CAN BE EXPECTED IN SEWAGE AND SEWAGE SLUDGE
(STRAUCH, 1991; HURST, 1989)

Virus group	Number of types	Diseases or symptoms caused
Enterovirus		
- Poliovirus	3	Poliomyelitis, meningitis, fever
- Coxsackievirus A	24	Herpangina, respiratory disease,meningitis, fever
- Coxsackievirus B	6	Myocarditis, congenital heart anomalies, meningitis, respiratory disease, pleurodynia, rash, fever
- Echovirus	34	Meningitis, respiratory disease, rash, diarrhoea, fever
- New „numbered“ enteroviruses	4	Meningitis, encephalitis, respiratory disease, acute haemorrhagic conjunctivitis, fever
Adenovirus	41	Respiratory disease,eye infections
Reovirus	3	Not clearly established
Hepatitis A-virus	1	Infectious hepatitis
Rotavirus	4	Vomiting and diarrhoea
Astrovirus	5	Gastroenteritis
Calicivirus (Norwalk agent)	2	Vomiting and diarrhoea
Coronavirus	1	Common cold
Adeno-associated virus	4	Not clearly established but associated with respiratory disease in children
Parvovirus	2	One type possibly associated with enteric infection

Table 3. SELECTION OF PATHOGENIC YEASTS AND FUNGI TO BE EXPECTED IN SEWAGE AND SEWAGE SLUDGE (STRAUCH 1991)

Yeasts	Fungi
Candida albicans	*Aspergillus spp.*
Candida krusei	*Aspergillus fumigatus*
Candida tropicalis	*Phialophora richardsii*
Candida guillermondii	*Geotrichum candidum*
Crytococcus neoformans	*Trichophyton spp.*
Trichosporon	*Epidermophyton spp.*

Table 4. SELECTION OF PARASITES TO BE EXPECTED IN SEWAGE AND SEWAGE SLUDGE, STRAUCH (1991), modified

Protozoa	Cestodes	Nematodes
Cryptosporidium parvum *Entamoeba histolytica* *Giardia lamblia* *Toxoplasma gondii* *Sarcocystis spp.*	*Taenia saginata* *Taenia solium* *Diphyllobothrium latum* *Echinococcus granulosus*	*Ascaris lumbricoides* *Ancylostoma duodenale* *Toxocara canis* *Toxocara cati* *Trichuris trichiura*

2.2 Pathogens in sludges of other origin

The spectrum of pathogens found and in which concentrations depends on the origin of sludges. Sludge of animal origin such as from slaughterhouses or meat processing industries will generally contain mostly animal pathogens or zoonotic agents. Table 5 gives an overview of the bacterial counts found in bovine rumen content of selected species, and Table 6 summarizes the pre-valance and resistance of parasitic agents from the gut of cattle and their potential hygienic hazard. Nearly all gut related pathogens can be found in slaughterhouse effluents. If sludges are of plant origin or have been processed by using plant material, they may contain plant-pathogenic viruses, fungi, bacteria, parasites and undesired weeds. This will cause an additional phytohygienic risk if the final product is used in agriculture as fertilizer (BÖHM et al. 1997).

Table 5. BACTERIAL COUNT* INCLUDING SALMONELLA OF RUMEN CONTENT COLLECTED FOR FURTHER PROCESSING

Sample	TBC	EBA	E. coli	FCS	Salmonella	pH-Value	DM
02.03.95	$5.7x10^7$	$4.3x10^5$	$4.3x10^5$	$2.1x10^6$	$7.5x10^2$	6.02	19.90
11.10.95	$4.9x10^8$	$1.5x10^6$	$2.3x10^4$	$2.5x10^5$	$4.3x10^0$ S. Thyphimur	7.48	12.92
08.01.96 (1)	$4.8x10^8$	$2.3x10^7$	$2.3x10^7$	$7.5x10^6$	$7.5x10^2$	6.68	19.92
(2)	$5.4x10^8$	$2.3x10^7$	$9.3x10^6$	$2.3x10^7$	$4.3x10^3$	7.41	19.92
(3)	$5.7x10^8$	$2.3x10^7$	$9.3x10^6$	$3.8x10^7$	$2.3x10^6$	7.07	19.92
(4)	$6.9x10^8$	$2.3x10^7$	$2.3x10^7$	$2.3x10^7$	$4.3x10^3$	7.20	19.92
(5)	$9.9x10^8$	$4.3x10^7$	$9.3x10^6$	$4.3x10^7$	$2.3x10^3$	7.85	19.92
07.03.96 (1)	$4.4x10^8$	$2.9x10^5$	$9.3x10^4$	$9.3x10^5$	$9.3x10^2$	7.25	21.08
(2)	$4.6x10^8$	$2.4x10^6$	$9.3x10^5$	$2.4x10^6$	$4.3x10^3$	7.15	21.08
(3)	$8.4x10^7$	$2.4x10^6$	$2.4x10^6$	$9.3x10^5$	$2.4x10^3$	6.79	21.08
(4)	$3.6x10^8$	$9.3x10^7$	$4.3x10^5$	$9.3x10^5$	$2.4x10^3$	7.24	21.08
(5)	$3.1x10^8$	$9.3x10^5$	$9.3x10^5$	$2.4x10^6$	$4.3x10^3$	7.16	21.08

* CFU/g TBC = Total Bacterial Count 37 °C FCS = Fecal Streptococci
EBA = Enterobacteriaceae DM = Dry Mater

Table 6. PREVALENCE AND RESISTANCE OF PARASITIC AGENTS FROM THE GUT OF CATTLE AND THEIR POTENTIAL HYGIENIC HAZARD (BÜRGER and STOYE, 1978, modified)

Parasite	Prevalence[a]	Resistance[b]	Priority as a hygienic hazard
Protozoa			
Cryptosporidia	+++	+++	1
Eimeria spp.	+++	+++	2
Helminths			
Trichostrongylus spp.	+++	++	3
Strongyloides papillosus	++	+	
Oesophagostomum spp.	++	++	
Fasciola hepatica	++	+++	4
Dictyocaulus viviparus	+	+	
Trichuris spp.	+	++	
Dicrocoelium dendriticum	+	+++	
Moniezia spp.	+	+	
Toxocara vitulorum	+	+++	

a +++ regular ++ frequent + occasional
b +++ high ++ intermediate + low

3. Epidemiological importance of sludge related pathogens

Pathogens may survive for a remarkable period of time in sludges and the environment. This is a basis for the resulting epidemiological risks. (STRAUCH 1998). Possible means of transmission are summarized in Table 7.

The direct or indirect transmission of zoonotic agents to farm animals is generally regarded as the most relevant risk factor of agricultural utilization of untreated or insufficiently treated sludge. This direct relationship between fertilizing with sewage sludge and infection in cattle fed with forage after spreading was reported by BREER (1981) for Salmonella (Fig. 1). The transmission of parasites was observed much earlier.

Table 7. EPIDEMIOLOGICAL IMPORTANCE OF PROCESSED WASTES AND RESIDUALS AND THEIR RESULTING PRODUCTS

A.	**DIRECT TRANSMISSION TO FARM ANIMALS**
	➪ CONTAMINATION OF MEADOWS
	➪ INTRODUCTION OF PATHOGENS BY STORAGE AND PROCESSING CLOSE TO SUSCEPTIBLE ANIMALS
	➪ AEROGENIC TRANSMISSION BY SPREADING OF MATERIALS INTO FARM LAND
B.	**DIRECT TRANSMISSION TO HUMANS**
	➪ HANDLING OF CONTAMINATED PRODUCTS IN THE HOUSEHOLD
	➪ OCCUPATIONAL EXPOSURE TO CONTAMINATED PRODUCTS
	➪ ACCIDENTAL TRANSMISSION TO IMMUNCOMPROMISED PERSONS
C.	**INDIRECT TRANSMISSION TO FARM ANIMALS**
	➪ VIA FEED FROM CONTAMINATED SITES
	➪ VIA LIVE VECTORS
D.	**INDIRECT TRANSMISSION TO HUMANS**
	➪ VIA INTRODUCTION OF ZOONOTIC AGENTS INTO THE FOOD-CHAIN
	➪ VIA FOOD CONTAMINATED BY LIVING VECTORS
E.	**INTRODUCTION INTO THE ENVIRONMENT**
	➪ GENERATION OF CARRIERS IN THE FAUNA
	➪ INTRODUCTION INTO THE MICROFLORA

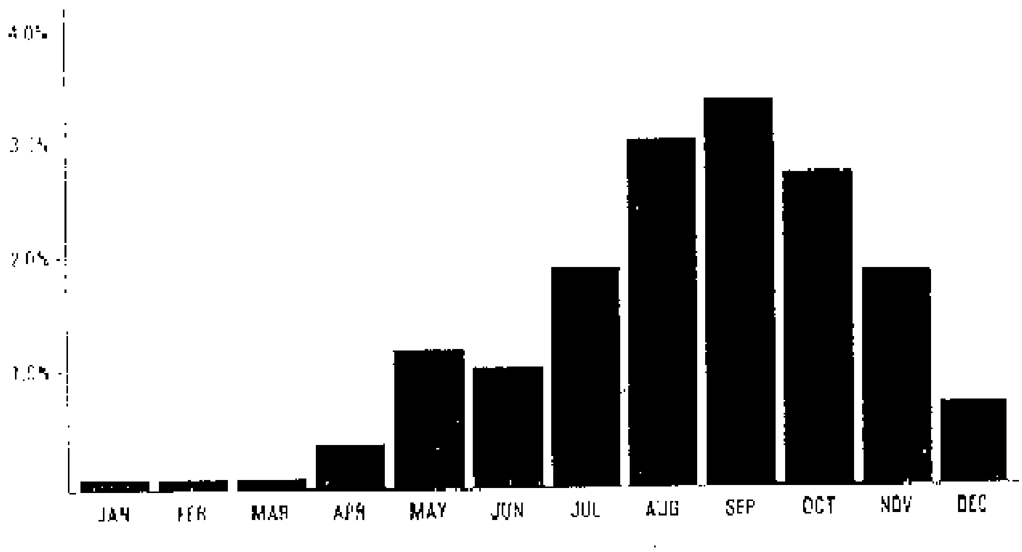

Figure 1. **Seasonal distribution of salmonella isolations from dairy cattle fed with forage after spreading of sewage sludge during the winter and after hay making (BREER, 1981)**

Although transmission to humans via products based on sludge or containing insufficiently treated sludge in households (OTTOLENGHI et HAMPARIAN, 1987) may be a relatively rare event, this must be regarded as a real risk. In addition, accidental contact of imunocompromised persons to contaminated sludge or sludge products may result in infection. The occupational risks in processing and handling of sludge and related products must be taken into account but will not be discussed in detail. Indirect transmission to humans is of special importance, because the introduction of pathogens into the food chain via contaminated fertilizer leading to contaminated animal feed resulting in infection of farm animals and / or excretion of pathogens is of basic epidemiological significance. The risk of transmission of pathogens to human food by living vectors such as insects, rodents and birds from processing, handling and agricultural utilization of slurry should also be taken into account.

Table 8 demonstrates the importance of birds as carriers of salmonella. Sewage treatment plants have been identified as one of the sources of infection in sea-gulls. Additional means of introduction of certain pathogens were demonstrated by KÖHLER (1993). He identified a Salmonella Enteritidis lysotype in waste delivered from West-Berlin to a waste disposal site in the former GDR and followed the introduction of this pathogen via birds into the chicken populations and finally to humans via products containing eggs. This historical example can be followed in table 9.

Table 8. DETECTION OF SALMONELLA IN SEA-GULL DROPPINGS
(Hellmann, 1977)

References	Site	Number of Samples	Salmonella positive	Number of Serovars	Predominant Serovars
PAGON et al. (1974)	Lake Konstanz	996	6,9	8	S. Brandenburg S. Typhimurium S. Manchester S. Newport
HEILMANN et al. (1973)	Steinhuder Meer PURIFICATION POND OF SUGAR PLANT LEHRTE	95 187	9,5 13,9	6 12	S. Typhimurium S. Agona S. Montevideo
WUTHE, H.H (1973)	BREEDING COLONY	196	12,25	12	S. Typhimurium S. Thompson S. Infantis S. Enteritidis
EDEL, W. et al. (1972)	Walcheren (NL)	60	26,7	10	S. Typhimurium S. Montevideo S. Infantis
MÜLLER, G. (1965)	Hamburg, WASTE WATER PURIFICATION PLANT	1037 134	35,6 76,9	13	S. Typhimurium S. Paratypi B S. Manchester S. Infantis

Table 9. **TIME TABLE OF TRANSMISSION OF S. ENTERITIDIS (LYSOTYPE 17) FROM WEST BERLIN WASTES TO BIRDS OF THE SCHÖNEICHE WASTE DISPOSAL SITE IN THE FORMER GDR** (KÖHLER, 1993)

ORIGIN	**1989**				**1990**				**1991**				**1992**				Total
	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	
CHILDREN BERLIN-WEST			5	10	8												23
WASTE DISPOSAL SITE SEA GULLS AND CROWS					3							2					5
DOVE ORANIENBURG						1										1	2
CHICKEN						17	12	12	2								43
CHICKEN TRANSPORT CAGES						5	3										8
HUMANS ZOSSEN POTSDAM BRANDENBURG										1	4	3	8		2	2	20
CAKE PUDDING										1		1					2
BLACK GROUSE																1	1
TOTAL			5	10	11	23	15	12	2	2	4	6	8		2	3	104

WILLIAMS et. al (1977) as well as several other authors (COULSEN et. al, 1983; MAYR, 1988) described the importance of vectors in the transmission of Salmonella to farm animals and humans. FOSTER and SPECTOR (1995) described specific molecular mechanisms responsible for the ability of Salmonella to survive environmental stress. This means that the introduction of pathogens in the environment leads to carriers in the natural fauna and to the introduction of transmissible undesired properties of bacteria such as antibiotic resistance plasmids into the microflora and biozoenoses. Figure 2 shows a simplified scheme of the ways in which drugs can be introduced into the environment. When these drugs are antibiotics, this means that selection of resistant pathogens can take place at every stage of distribution. This elevates the risk of spreading resistant bacteria in an uncontrolled manner.

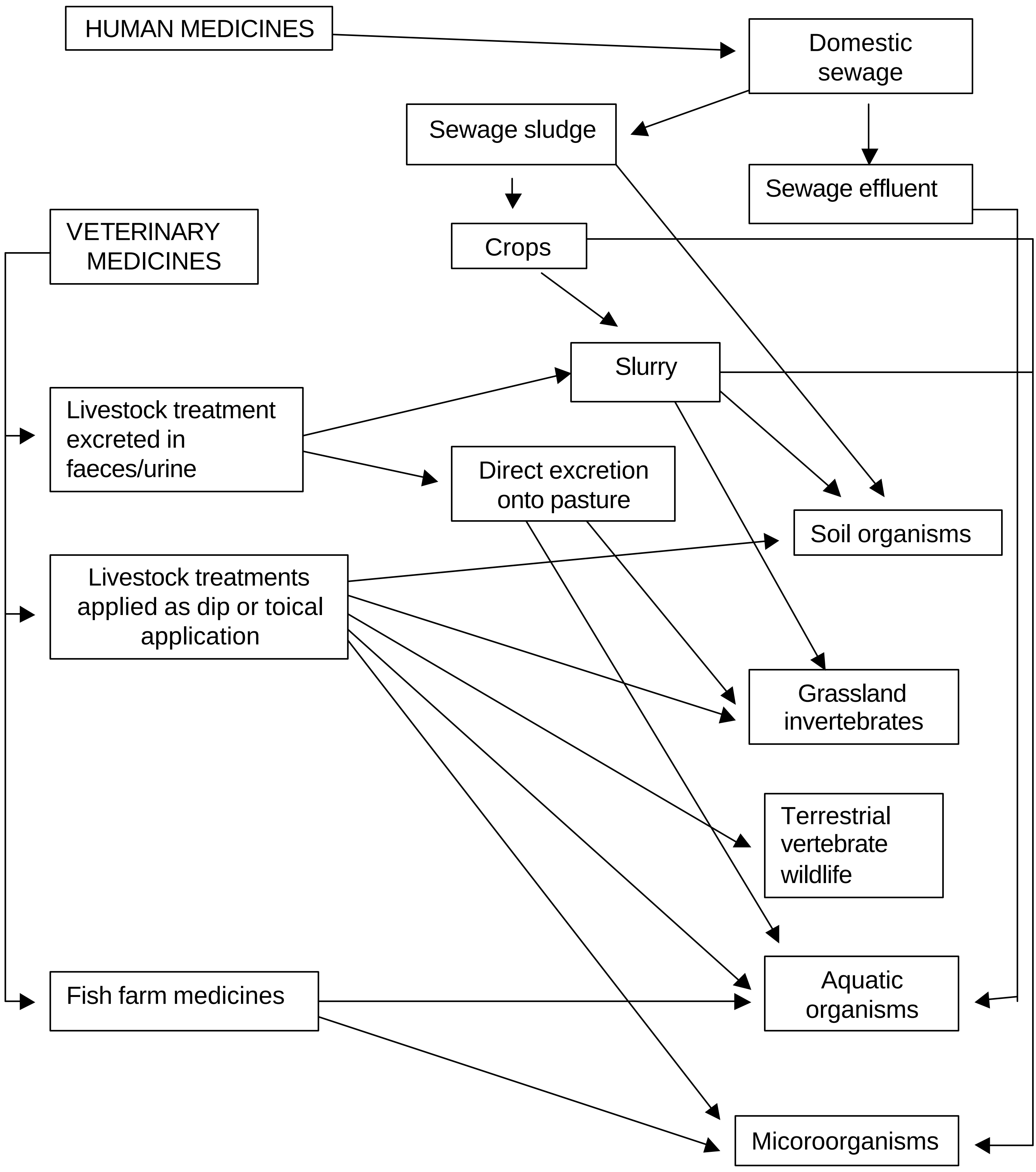

Figure 2. Simplified diagram showing the relationship between medical product uses and environmental risk assessment schemes

4. Strategies to achieve hygienic safety in treatment and use of organic sludge

A compilation of bacterial, fungal, parasitic and viral pathogens for humans and animals which may be present in organic wastes is given above. Plant pathogens can also be significant if sludges other than sewage sludge are used which contain significant amounts of material of plant origin. An extensive list of phytopathogenic viruses, bacteria, fungi and seeds is given by MENKE (1992).
Since it is impossible to test treated sludge for each of the pathogenic agents which can occur, other strategies are necessary in order to assure the hygienic safety of the processed material. The first step in such a strategy is to find a representative indicator organism which can be used to analyse the product for hygienic safety as well as to evaluate the treatment process for its capability to inactivate pathogens which are of epidemiological relevance. The second step which is necessary in this connection is to define hygienic requirements for the treatment itself, since due to the large volume of the product to be controlled as well as to the inhomogenity of distribution of pathogens in the material only products processed in a validated process should be distributed to the consumer or user. This means that the following strategies must be combined with each other in order to assure hygienic safe utilization of the processed sludges

- ➪ Validation of treatment (disinfection by chemical, physical or biological means)
- ➪ Continuous registration of the relevant process parameters (e.g. temperature, pH-value, exposure time)
- ➪ Microbiological supervision of the final product (indicators)
- ➪ Restriction of the utilization of the final product.

The combination of certain restrictions in using sewage sludge as fertilizer and/or soil improver and the type of treatment used with a system of process validation and steady supervision of relevant process data as well as of the final product, as shown in Fig. 3., should provide reasonable protection for farmers, consumers and the environment against hygienic threats. Even if a list of approved treatment processes is available, the methods for the validation of the treatment procedures themselves must be elaborated on EU-level.

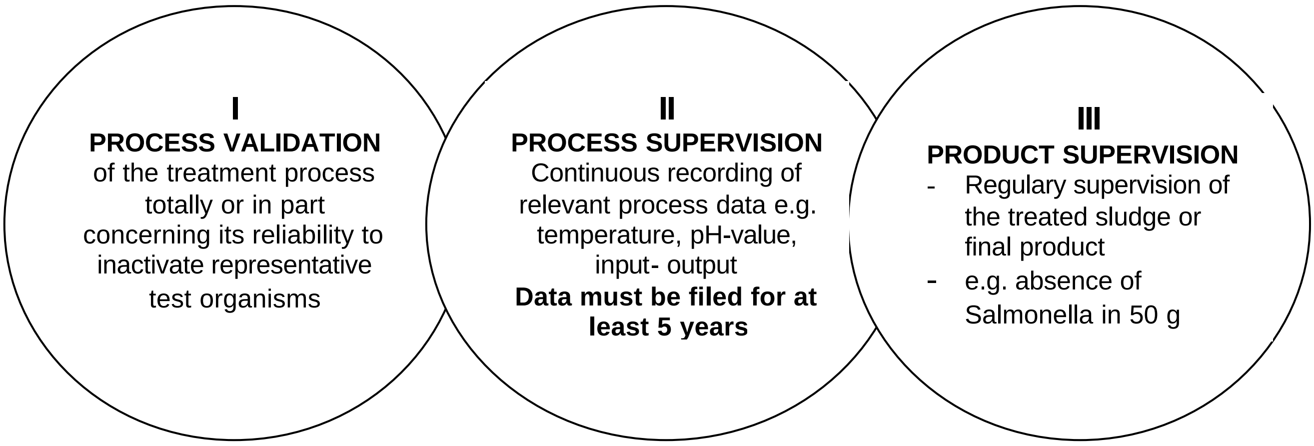

Fig. 3 Process validation and supervision combined with product supervision in order to assure hygienic safety of sewage sludge and related products for use as fertilizer or soil improver

5 References

1. BÖHM, R., FINK; A., MARTENS, W., PHILIPP, W., WEBER, A., WINTER, D. (1997), Abschlußbericht zum Forschungsvorhaben 02-WA 9257/5 "Veterinär- und seuchenhygienische Untersuchungen zur Überprüfung von Gülleaufbereitungsverfahren und der erzeugten Gülleaufbereitungsprodukte", Insitut für Umwelt- und Tierhygiene, Universität Hohenheim, D-70593 Stuttgart

2. BÖHM, R., MARTENS, W., BITTIGHOFER, P.M. (1998): Aktuelle Bewertung der Luftkeimbelastung in Abfallbehandlungsanlagen. M.C. Baeza-Verlag, Witzenhausen

3. BREER, C. (1981): Freilandbiologie und Infektzyklen der Salmonellen. Schweiz. Arch. Tierheilk., 123, 89-96

4. BÜRGER, H.-J., STOYE, M. (1978): Parasitological problems associated with recycling of animal excretions, pp 24-34. In: W.R. KELLY (ed.): Animal and human health hazards associated with the utilization of animal effluents. ECE-EUR 6009, Office for the official publications of the European Communities, Luxembourg

5. COULSON, J.C., BUTTERFIELD, J. and THOMAS, C. (1983): The herring gull Loras argentatos as a likely transmitting agent of Salmonella montevideo to sheep and cattle. J. Hyg. Camb. 91, 437-443

6. EDEL, W., GUINNEE, P.A.M., VAN SCHOTHORST, M. and KAMPELMACHER, E.H. (1972): The roll of effluents in the spread of salmonellae. Zbl. Bakt. Abt. Orig. A 221, 547-549

7. FOSTER, J.W., and SPECTOR, M.P. (1995): How Salmonella survive against the odds. Annu. Rev. Microbio., 49, 145-174

8. GRÜNER, C. (1996): Gesundheitszustand und Belastung von Beschäftigten im Abfallbereich. Erste Ergebnisse und Schlussfolgerungen für die Praxis, pp 315-334. In: Biologische Abfallbehandlung III (Wiemer, K., Kern, M., Eds.), Baetza-Verlag, Witzenhausen

9. HEILMANN, G., HÖPKEN, W. und MÜHLENBERG, W. (1973): Salmonellen bei Lachmöwen - ein neues Problem für die Landwirtschaft. Gesh.Wes. Desinfektion 65, 145-147

10. HELLMANN, E. (1977): Latente Salmonellen-Infektionen der Tiere und ihre Ursachen. Wiener Tierärztl. Mschr., 64, 173-180

11. HICKEY, J.K.S. and REIST, P.L. (1975): Health Significans of Airborne Microorganisms from Wastewater Treatment Processes. Journal WPCF 47, 12, 2741-2773

12. HURST, C.J. (1989): Fate of viruses during wastewater sludge treatment processes. CRC Crit. Rev. Envir. Control, 18, 317-343

13. KÖHLER, B. (1993): Beispiele für die Anreicherung von Salmonellen in der Umwelt. Dtsch. tierärztl. Wschr., 100, 264-274

14. MAYR, A. (1983): Verbreitung von Infektionserregern über Abfälle durch Haus-, Gemeinde und Freilandungeziefer unter besonderer Berücksichtigung der Gesundheit des Menschen. Zbl. Bakt.Hyg., I. Abt. Orig. 1B, 178, 53-60

15. MENKE, G. (1992): Hygienische Aspekte der Bioabfallkompostierung. Teil 1: Phytohygiene, pp 68-73. In: Proc. Symposium des Umweltministeriums Baden-Württemberg und der LG-Stiftung "Natur und Umwelt", 26. März 1991 in Stuttgart, "Bioabfallkompostierung - Chance der Abfallverwertung oder Risiko der Bodenbelastung?". Stuttgart: LG-Stiftung "Natur und Umwelt", Königstr. 3-5, D-70173 Stuttgart

16. METZLER, A., REGLI, W., LEISINGER, M., Heider, H., SCHWEIZER, K. und TABISCH, A. (1996): Viren und Parasiten im Trinkwasser: Risiken und Prävention. Mitt. Gebiete Lebensm.Hyg. 87, 55-72

17. MÜLLER, G. (1965): Die Salmonellen im Lebensraum einer Großstadt (Untersuchungen über Vorkommen und Lebensdauer in der Außenwelt). Beitr.Hyg. Epidemiol. 19, J. Ambrosius Barth Verlag, Leipzig

18. OTTOLENGHI, A.C. and HAMPARIAN, V.V. (1987): Multiyear study of sludge application to farmland: Prevalence of bacterial enteric pathogens and antibody status of farm families, Appl. Environ. Microbiol. 53, 5, 1118-1124

19. PAGON, S., SONNABEND, W. und KRECH, U. (1974): Epidemiologische Zusammenhänge zwischen menschlichen und tierischen Salmonella-Ausscheidern und deren Umwelt im schweizerischen Bodenseeraum. Zbl. Bakt. Abt. I Orig. B 158, 395-411

20. STRAUCH, D. (1991): Survival of pathogenic micro-organisms and parasites in excreta, manure and sewage sludge, Rev. Sci. Techn. Off. Int. Epiz. 10. 813-846

21. STRAUCH, D. (1998): Pathogenic micro-organisms in sludge. Anaerobic digestion and disinfection methods to make sludge usable as fertiliser. European Water Management 2, No. 2, 12-26

22. TSCHÄPE, H. (1996): Die Verbreitung antibiotikaresistenter Keime in der Umwelt mit besonderer Beachtung der Salmonellen. Dtsch. tierärztl. Wschr. 103, 273-277

23.

24. WILLIAMS, B.M., RICHARDS, D.W., STEPHENS, D.P., and GRIFFITHS, T. (1977): The transmission of S. livingslone to cattle by the herring gull (Larus argentatus). Vet. Rec. 100, 450-451

25. WUTHE, H.H. (1973): Salmonellen in einer Brutkolonie von Lachmöven. Berl. Münch. Tierärztl. Wschr. 86, 255-256