15. Management of the health risks posed by Cryptosporidium in sewage

<u>**Presenter**</u>

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ABSTRACT

We conducted a nationwide monitoring study of Cryptosporidium levels in treated sewage for the quantitative risk evaluation. The risk of infection per capita on an annual basis is in the range 10^{-5} to 10^{-2}. In order to formulate standards for risk management, we drew up potential risk scenarios and considered the standards required for the target risk. The maximum theoretical concentration of Cryptosporidium in raw sewage is 10^{6}/l. We developed two different countermeasure procedures in order to address both of the annual infection risk and the risk of a mass outbreak. When deviation from the probability distribution of Cryptosporidium concentrations in the observation data is used as the standard for developing countermeasures for a mass infection incident, the resulting annual infection risk may be below the target risk 10^{-2}, although the degree of risk reduction depends on the level and type of contact.

Introduction

In Japan, as elsewhere, the health risk posed by pathogenic microorganisms such as mad cow disease and O-157 has become an increasing problem. Following a large-scale outbreak of Cryptosporidium at Ogose in Saitama Prefecture in 1996, water and sewage authorities have been particularly concerned about water-borne pathogenic microorganisms and have instituted a range of countermeasures. Risk management of pathogenic microorganisms during sewage treatment, particularly Cryptosporidium, is increasingly important due to general advances in water risk management and the increasing use of reclaimed wastewater. In Japan, however, there is little continuous monitoring data available on Cryptosporidium levels in sewage and so few attempts have been made to perform quantitative risk evaluation. To this end, we conducted a nationwide monitoring study of Cryptosporidium levels in sewage for the purpose of quantitative risk evaluation. We also drew up a framework of countermeasures for potential risks, designed to provide a platform for developing risk management techniques and standards that can be used to ensure that risk levels do not exceed the threshold value.

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Cryptosporidium levels in sewage at present

Each month for a ten-month period from October 2001 to July 2002, we monitored Cryptosporidium concentrations at eight sewage treatment plants throughout the country. Concentrations were measured in raw sewage, secondary treated water, and reclaimed wastewater at each facility. Table 1 and Table2 give an overview of the size and treatment process of the sewage treatment facilities involved in the study, while Table 3 summarizes the measurement results.

Table 1 Size of sewage treatment facilities

	Treatment area (ha)	Population serviced
Average	5,262	411,000
Maximum	10,543	770,000

Table 2 Sewage treatment process used at sewage treatment facilities

Sewage treatment process	Number of facilities
Biological secondary treatment	8
+ sand filtration	4
+ coagulation and sand filtration	2

Table 3 Cryptosporidium levels measured in sewage

	Raw sewage (per 200 ml)	Secondary treatment (per 20 l)	Sand filtration (per 20 l)	Coagulation and sand filtration (per 20 l)
Total Samples	79	49	20	20
Arithmetic mean	2.7	10.6	1.6	0.35
Variance	40.4	350.6	4.7	0.83
Standard deviation	6.4	18.7	2.2	0.91
Minimum	0 (of 39)	0 (of 11)	0 (of 8)	0 (of 16)
Maximum	35 (of 1)	117 (of 1)	9 (of 1)	3 (of 2)

Note: Measurements are per 15 – 19 l for several of the secondary treatment and sand filtration samples.

Table 4 shows the goodness-of-fit of the measurement data relative to the probability distribution, based on the likelihood ratios.

Table 4 Goodness-of-fit of probability distributions to Cryptosporidium distribution

	Poisson distribution		Negative binomial distribution		Poisson lognormal distribution	
Raw sewage	$-2\ln(\Delta)$	423.9	$-2\ln(\Delta)$	22.2	$-2\ln(\Delta)$	29.0
	$\mu=$	13.4	$\mu=$	39.9	$\eta=$	2.5
			$k=$	1.6	$s=$	1.8
Secondary treated sewage	$-2\ln(\Delta)$	822.0	$-2\ln(\Delta)$	88.3	$-2\ln(\Delta)$	29.6
	$\mu=$	0.5	$\mu=$	1.5	$\eta=$	-0.6
			$k=$	0.5	$s=$	1.6
Sand filtrated sewage	$-2\ln(\Delta)$	22.5	$-2\ln(\Delta)$	8.8	$-2\ln(\Delta)$	8.7
	$\mu=$	0.1	$\mu=$	0.2	$\eta=$	-2.0
			$k=$	0.8	$s=$	1.0

Note:

1. Δ is the likelihood ratio, and –2 ln (Δ) is –2 times the natural logarithm of the likelihood ratio. The smaller this figure, the better the goodness-of-fit.
2. μ and k are the gamma distribution average and shape parameter respectively for the negative binomial distribution, which is a combination of the Poisson and gamma distributions.
3. η and s are the lognormal distribution average (natural logarithm) and standard deviation (natural logarithm) respectively for the Poisson lognormal distribution, which is a combination of the Poisson and lognormal distributions.

For raw sewage, the negative binomial (NB) distribution and the Poisson lognormal (PLN) distribution had almost the same likelihood. For secondary treated water, goodness-of-fit was better for the PLN distribution, while for the sand filtrated sewage, the NB and PLN distributions were roughly the same.

The NB and PLN distributions are the combined distributions of the Poisson distribution (sampling process) and the gamma or lognormal distribution (average concentration), respectively.

Since it is not possible to determine at this stage which of the gamma and lognormal distributions produces a better overall fit to the distribution of Cryptosporidium concentrations, we performed the risk calculations on both distributions.

Evaluation of current risk levels

Table 5 shows the assumed ingestion volume and frequency of exposure for various categories of treated sewage discharge or reuse (Japan Sewage Works Association (2000)). These figures are used in risk evaluation.

Table 5 Ingestion volume and frequency of exposure for treated and reclaimed wastewater

Form of contact/reuse	Persons affected	Form of exposure	Frequency of exposure	Volume ingested per exposure
Bathing	Bath users	Accidentally swallowed while bathing	40 days/year	100 ml/day
Source water for waterworks	Tap water users	Drinking	365 days/year	2 l/day
Recreational water (parks)	Park users	Playing in water	100 days/year	10 ml/day
Landscape water (parks)	Park users	Fishing	2 days/week	1 ml/day
Flush toilet usage (office)	Office workers	Water splashes	5 days/week	0.1 ml/day
Sprinkling water (parks)	Park users	Contact with grass and plants	60 days/year	1 ml/day

The exponential model based on the data obtained by Dupont, et al. (1995) (shown in Expression 1 below) was used as the Cryptosporidium dose-response model.

$$P = 1 - \exp(-D/k) \qquad \text{(Expression 1)}$$

where,

P = probability of infection per exposure incident

D = exposure quantity (i.e. number of Cryptosporidium organisms) per exposure

k = parameter of exponential model (238.6)

Five hundred repetitions of the risk calculation were performed using the Monte Carlo method. The calculations were performed using Crystal Ball 2000™.

Figure 1 illustrates the annual infection risk as determined from the calculations, showing the average value for the risk distribution together with the minimum and maximum values for the 95% confidence interval.

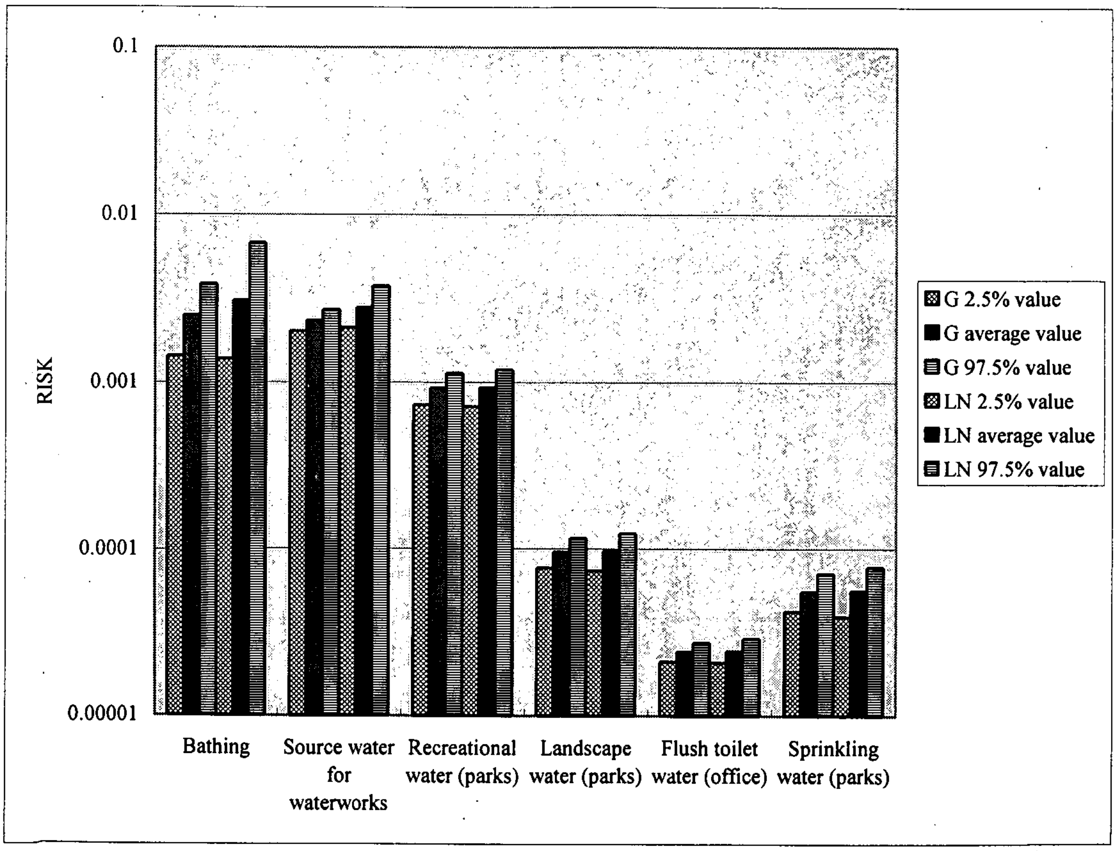

Figure 1 Annual infection risk range based on Monte Carlo simulation

Notes:

1. The G average, G 2.5%, and G 97.5% values are the average, the lower limit of the 95% confidence interval (the 2.5% value), and the upper limit (the 97.5% value), respectively, of the results from 500 repetitions using the gamma distribution to represent the distribution of Cryptosporidium concentrations.
2. The LN average, LN 2.5%, and LN 97.5% values are the average, the lower limit of the 95% confidence interval (the 2.5% value), and the upper limit (the 97.5% value),

respectively, of the results from 500 repetitions using the LN distribution to represent the distribution of Cryptosporidium concentrations.

The results show little major difference between using the LN distribution and the gamma distribution as the predicted distribution, although the LN distribution produces a slightly higher (and therefore slightly safer) forecast. For this reason, we have adopted the lognormal distribution as the predictor for the distribution of Cryptosporidium concentrations for the purpose of the calculations described below.
The annual infection risk values are distributed within the general range 10^{-5} to 10^{-2}. Even for the combination of factors producing the highest risk prediction—bathing in the waters that receiving secondary treated sewage discharge—the risk is less than 10^{-2}.

Risk scenarios

The single largest incident of mass infection in Japan occurred in Ogose, Saitama Prefecture, in 1996, when Cryptosporidium in the tap water supply caused diarrhea and other symptoms in 8,812 (roughly 70%) of the population of approximately 13,800 residents (based on a respondent base of 12,345). Department of Public Health of Saitama Prefecture (1997) reported that some 2,878 residents (33% of those experiencing symptoms) were forced to take time off from school or work due to sickness. 2,856 residents (32% of those with symptoms) sought diagnosis at a medical institution, and 24 were hospitalized. Figure 2 shows changes in the number of sufferers over time, based on actual records, together with the number of Cryptosporidium excretors, based on the assumption that each sufferer was excreting 10^9 Cryptosporidium over a two-week period with a sewage volume of 0.5 m^3 per person per day. Figure 3 shows changes in Cryptosporidium concentration levels in the raw sewage, where the entire area is considered to be a hypothetical town located within a single sewage treatment service area.

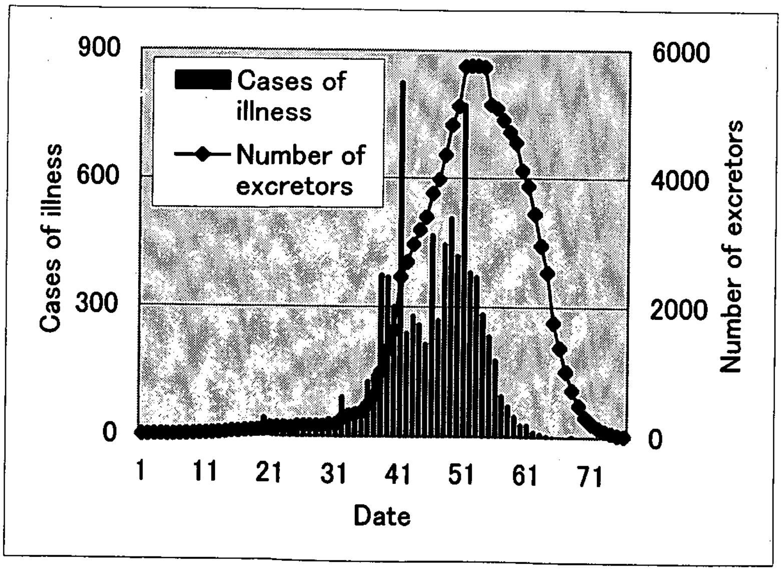

Figure 2 Changes in cases of illness and number of excretors

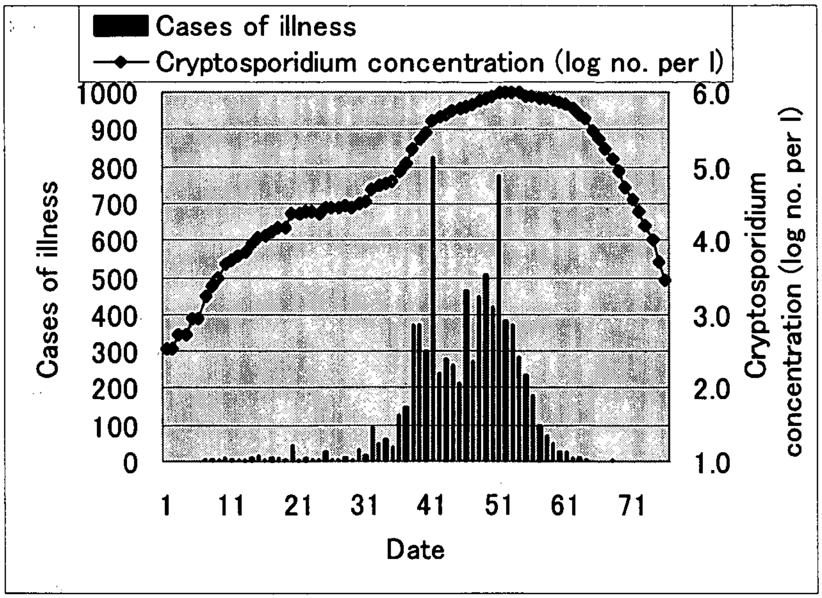

Figure 3 Changes in cases of illness and concentration of Cryptosporidium in raw sewage

According to the calculations, the maximum number of excretors at any one time is 5,760 persons. The excretion rate for 8,294 people (the total 8,812 sufferers less 518 persons for whom the timing of excretion is unknown) is approximately 0.694. Assuming that this figure is fixed for all sufferers, the true maximum number of simultaneous excretors is 6,120 persons (8,812 x 0.694), or 49.6% of the survey respondent base of 12,345 persons.

Thus, approximately 70% of the total population was afflicted with the infection, and 70% of those (around 50% of the total population) were excreting at the same time. If we assume that half the population was excreting 10^9 Cryptosporidium and the sewage volume per capita per day was 0.5 m^3, then:

$$0.5 \times 10^9 / (0.5 \times 10^3) = 10^6/l$$

This figure constitutes the maximum theoretical concentration of Cryptosporidium in raw sewage in Japan experienced to date. As such, this was the figure used as the theoretical maximum in developing strategies to combat Cryptosporidium.

Standards and countermeasures

Countermeasures for dealing with the risk of Cryptosporidium pathogens in treated sewage need to address two different phenomena.

Firstly, countermeasures need to address the stochastic phenomenon that is the annual infection risk. The normal concentration of Cryptosporidium in raw sewage has the potential to cause sporadic incidents of infection at any time. Since this risk essentially varies at random, the appropriate response is an on-going year-round risk minimization strategy based on annual average values.

The second, systematic phenomenon is the risk of a mass outbreak. In the event of a mass outbreak, Cryptosporidium levels will be considerably higher than normal for some time. Risk minimization in this case involves emergency procedures such as use of coagulants to reduce the concentration of Cryptosporidium discharged from sewage.

The flowchart in Figure 4 shows the basic procedure of an on-going infection risk minimization strategy.

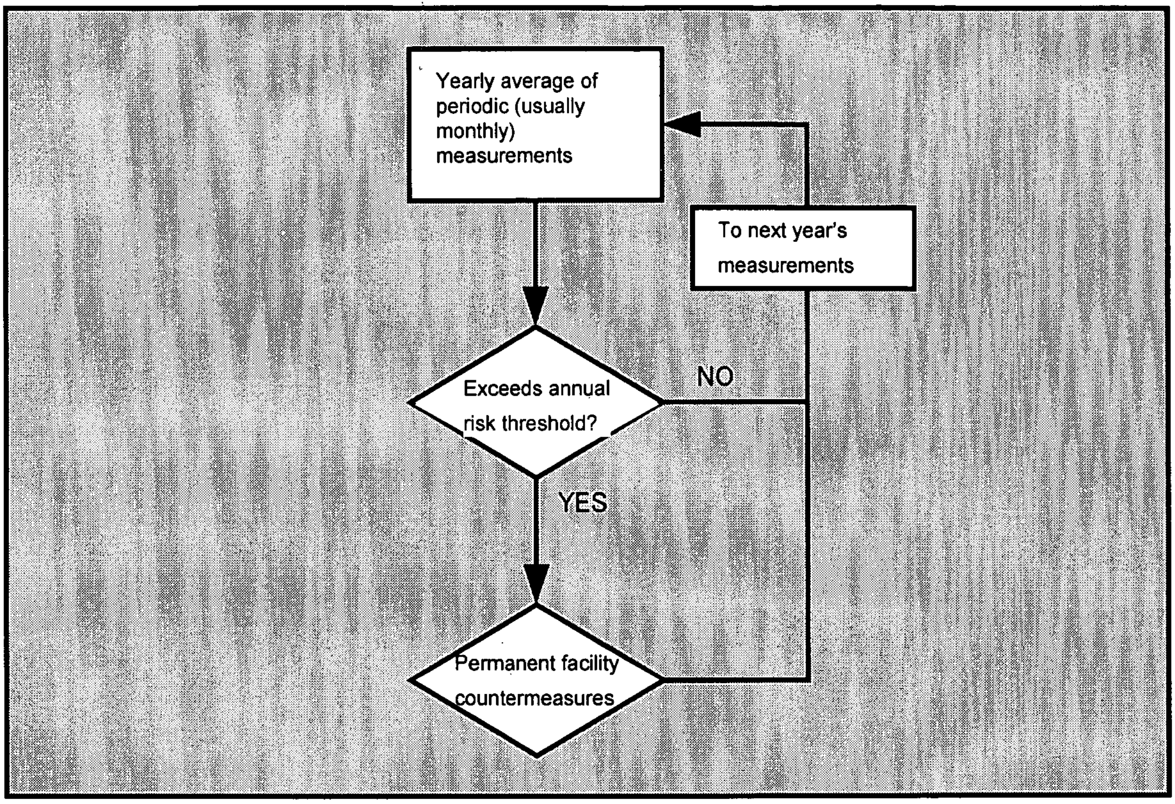

Figure 4 Ongoing year-round risk minimization strategy

It is assumed here that if the arithmetic mean of measurements taken over the year (i.e., the average of the 12 measurements) exceeds the risk threshold, then stronger disinfection procedures such as ultraviolet irradiation or ozone treatment will be necessary. We have proposed defining the annual risk threshold as the value needed to ensure that the annual risk of infection to any one individual is no greater than 10^{-2}. In the United States, the Environment Protection Agency suggests the maximum acceptable risk level as 10^{-4}. The Cryptosporidium risk level in Japan is currently in the range 10^{-5} to 10^{-2}. In the absence of a quantitative benefit-cost analysis on reducing the risk to 10^{-4}, let alone any public consensus on the cost of investment required, we have adopted 10^{-2} as the provisional threshold value, which can be agreed widely as the minimum countermeasure level.

The maximum daily tolerable exposure level (calculated on the assumption that exposure is uniform throughout the year) may be used as the threshold values.

The flowchart in Figure 5 shows the general procedure for countermeasures in the event of a mass outbreak.

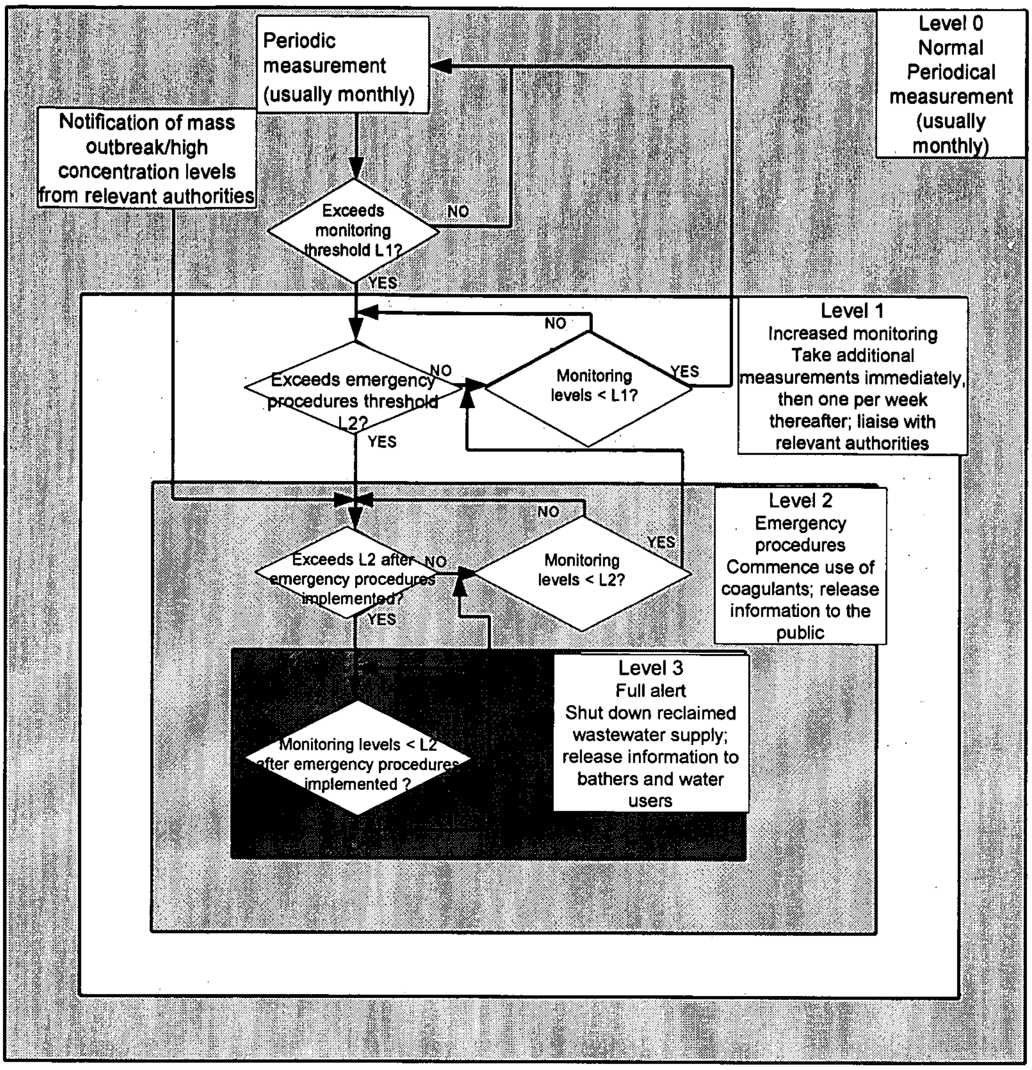

Figure 5 General procedure for countermeasures in the event of a mass outbreak

Where observed values deviate significantly from the lognormal distribution based on measurement data taken after secondary treatment and after sand filtration, this indicates an abnormal situation with the potential to cause a mass outbreak and emergency procedures should be instituted. L1, the threshold for increased monitoring, may be defined as the upper limit of the 95% confidence range for the distribution obtained from the geometric mean of certain number of samples (i.e., several consecutive separate measurements). L2, the threshold for emergency procedures, may also be defined in the same way. When the threshold value is exceeded, the relevant countermeasures are instituted. Ideally, the geometric mean of the measurements would be used for comparison with the threshold values; however, in cases where the latter of the consecutive measurements is higher and the concentration level appears to be on the increase, this situation may satisfy the prerequisites for the geometric mean. For this reason, in order to allow for a margin of safety, all of the consecutive measurement values are required to be below the geometric mean.

In some situations, the threshold for mass outbreak countermeasures may be lower than the threshold for annual infection risk countermeasures. If the former value is used and the mass outbreak countermeasures are properly instituted, then the annual infection risk will be well under the target value of 10^{-2}. The degree of risk reduction will depend on the level and type of contact.

Conclusions

In this paper we have described studies of countermeasures against the risk posed by the Cryptosporidium pathogen in sewage. The risk of infection by Cryptosporidium in sewage per capita on an annual basis is in the range 10^{-5} to 10^{-2} in Japan. The maximum theoretical concentration of Cryptosporidium in raw sewage is 10^{6} /l. When deviation from the probability distribution of Cryptosporidium concentrations in the observation data is used as the standard for developing countermeasures for a mass outbreak, the resulting annual infection risk may be below 10^{-2}, although the degree of risk reduction depends on the level and type of contact.

The threshold values of the standards are currently under the review process among the members of our research project and thus not shown here. We will continue to pursue research in this area by generating more observation data and developing and refining detection methods and quantitative risk evaluation techniques. We also plan to develop superior pathogen risk management targets and risk management techniques based on quantitative risk-benefit analysis and risk communication.

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