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The Elbmarsch Leukemia Cluster: Are There Conceptual Limitations in Controlling Immission from Nuclear Establishments in Germany?

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Abstract. The childhood leukemia cluster in the proximity of the German nuclear establishments of Geesthacht is unique in its spatial and temporal concentration. After a steep increase in cases in 1990, the cluster continues to show a significant increase up to the present. Early investigations of blood samples from a casual sample of local residents showed an increase in dicentric chromosomes in lymphocytes, indicating exposure exceeding dose limits. Analyses of the immission data revealed several unexpected deliveries of fission and activation products in the environment but provided no explanation of the source. Because of the observed overdispersion of dicentric chromosomes in cells, the idea of a contribution by densely ionizing emitters was compelling. The routine programs, however, do not include alpha emitters. These were measured in specific studies that proved contamination by transuranic nuclides. As shown in the present investigation, routine environmental surveillance programs support the occurrence of an accidental event near Geesthacht in September 1986. Until now, neither the cause nor the complete scenario of the activity release could be established. The ongoing discussion highlights limitations in the immission-control concept, which is predominantly based on gamma-radiation monitoring.

The increased incidence of leukemia in young children living in proximity to the Geesthacht nuclear establishments southeast of Hamburg is a continuous phenomenon. It began in 1990 with a steep increase in cases observed in the rural community of the Elbmarsch, then gradually decreased in subsequent years but remained significantly increased (approximately threefold) from 1995 to 2003 (Kaatsch 2003). Figure 1 shows the course of reported cases in the 5-km surroundings. The expected occurrence in this region with approximately 4800 children <15 years old is 0.21 cases/y based on German Childhood Cancer Registry incidence data (Hoffmann *et al.* 1997; Schmitz-Feuerhake *et al.* 1997).

The Elbmarsch is situated opposite the former nuclear research center Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt (GKSS) at the river Elbe (Fig. 2). The GKSS was established in 1958, and its original objective was research and development on the use of nuclear power for commercial ships. In the 1980s, the center was engaged in several research programs on nuclear reactor safety and the development of components for nuclear power plants. It is equipped with two nuclear research reactors, one with 5- and the other 15-MW capacity. A commercial nuclear power plant, Kernkraftwerk Krümmel (KKK), is located west of the GKSS approximately 1.5 km downstream the river Elbe. It has a 1300 MW_{el} boiling-water reactor that began full operation in 1984.

The authorities have carefully studied the living conditions of the leukemia patients and their families. No other common risk factor for leukemia, other than proximity to the potential sources of radioactivity, could be identified. The supervising ministry (German federal state of Schleswig-Holstein, where the facilities are situated) has excluded a radiologic causation of the leukemia. The ministry attested to the regular operation of the nuclear power plant and the GKSS based on emission surveillance of the facilities and referring to the results of routine environmental radiologic surveillance. In addition to depending on their own experts, the federal state government established an independent expert committee, which came to a diverging assessment of the situation (Expert Committee 1998). The experts based their statement on several findings of tritium and other fission and activation products in the environment (Schmitz-Feuerhake *et al.* 1996; Schmidt *et al.* 1998) that were not compatible with the emission data provided by the plants. The committee also considered early results by biological dosimetry in Elbmarsch residents carried out in 1992 and 1993. *In vitro* chromosome studies in peripheral

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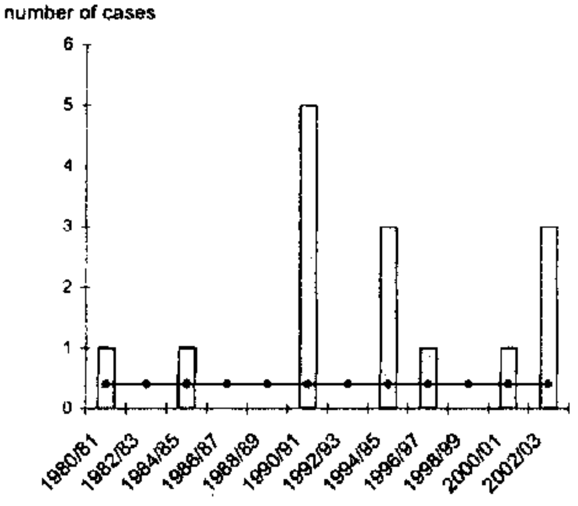

Fig. 1. Number of children with leukemia living in proximity to the KKK and GKSS (from 1990 to 2003 12 cases of acute lymphatic leukemia and 1 case of acute myeloid leukemia). Drawn line – expected value 0.41/2 y.

lymphocytes from 21 adults (7 of them parents of leukemia children) and 5 brothers or sisters of those children showed an approximately fourfold (significant) increase in dicentric chromosomes (Schmitz-Feuerhake *et al.* 1997; Dannheim 1996). A noteworthy result of the cytogenetic investigation was a significant Poisson overdispersion of dicentric chromosomes in the cells, similar to a clustering of aberrations, which indicates an exposure to densely ionising radiation.

These findings motivated further studies about environmental radioactivity because routine surveillance measurements do not measure alpha emitters. In addition to other manmade radionuclides, plutonium isotopes and Am-241 were detected in attic dust of Elbmarsch houses (Schmitz-Feuerhake *et al.* 2003). The composition of the transuranic nuclides showed that neither normal background (fallout from atmospheric atomic tests and Chernobyl) nor the inventory of a normal operating light water reactor such as the Krümmel plant could account for these findings.

In 2001, the German expert group Arbeitsgemeinschaft Physikalische Analytik und Messtechnik (ARGE PhAM), chaired by Arthur Scharmann (Giessen), found contamination from enriched uranium and Th-232 derivates in the environment. ARGE PhAM detected microspheres allegedly consisting of nuclear fuel, which they attributed to experiments with hybrid nuclear systems (fusion plus fission). However, up until now the actual causes of the observed contamination have been unclear.

A second source of information is seen in identifying the time of a relevant radioactive release. If the majority of the leukemia cases were radiation induced, the sudden onset in 1990 and 1991 would not be compatible with permanent chronic emission but rather would indicate an accidental event or the sudden onset of a process with a higher rate of emissions. A radioactive incidence, other than Chernobyl (April 26, 1986), has in fact been identified.

On September 12, 1986, radioactive contamination of the immediate KKK area occurred. The plant emits by way of a 150-m stack. On that day, a twofold to fourfold increase in short-lived gamma-emitting aerosols was released into the air at 7:30 AM and decreased to normal values at approximately 11:30 AM. No source for the increased release was detected in the plant (KKK GmbH., documentation TKU Wess, March 31, 1993). The shift leader therefore assumed contamination by way of outdoor radioactivity and ordered a check. As a result, the contamination was registered on the grounds of the plant and was thought to be drawn into the building by way of the air inlet. The increase was explained as an increase in natural radioactivity.

The supervising ministry reported that the metereologic instrumentation had shown calm weather on the morning of that day. As a result, the accumulated natural outdoor radioactivity, radon, would have been drawn into the power plant (personal communications from Wolter, Ministry of Finance and Energy of the Federal State of Schleswig-Holstein, to Schmitz-Feuerhake, October 14, 1992 and February 19, 1993). The observed outdoor concentration had increased to a total of "approximately 500 Bq/m^3"(gamma aerosols) according to the ministry, and the following measuring values were given in 1993: Bi-214 (19.7 m; descendant of Rn-222) 73 Bq/m^3; Pb-212 (10.6 h; descendant of Rn-220) 63 Bq/m^3; Pb-214 (26.8 m; descendant of Rn-222) 40 Bq/m^3; Ra-224 (3.64 d; descendant of Th-232) 30 Bq/m^3; and Tl-208 (3.1 m; descendant of Rn-220) 80 Bq/m^3. These values, however, do not represent radon daughters in their natural composition. Ra-224 is the mother of the isotope Rn-220, and normally as a solid substance is not measurable in air. Bi-214 and Pb-214 are solid descendants of Rn-222 and therefore do not exceed the Rn-222 concentration in air (Porstendörfer 1993).

The Geesthacht region belongs to those with the lowest underground concentrations of radon in Germany, and normal outdoor levels are <10 Bq/m^3 (Bundesamt 2003). In cases of very calm weather, a 10-fold increase in Rn-222 and its descendants could be expected; therefore, the given values for Bi-214 and Pb-214 do not contradict the ministry's interpretation. The isotope Rn-220, however, cannot accumulate to a similar level because of its short half-life of 55 seconds, and therefore the reported concentration of its daughters Pb-212 and Tl-208 appears to be much too high, being 1 to 2 orders of magnitude higher than average levels (Porstendörfer 1993). Another point is that the sum of the cited activities is 286 Bq/m^3, and the question arises as to what additional nuclides may have led to a total dispersion of approximately 500 Bq/m^3.

The fact that the inlet fan of the KKK plant is located 44 m above ground (Banz 1984) casts further doubt on the operator's and ministry's scenario. With regard to the relation between decrease in radon concentration and height, Porstendörfer published diffusion lengths between 0.1 and 3 m for isotope 222 (1993). This means that at least 14 diffusion lengths had to be overcome before radon reached the inlet. This could not have led to measurable activity inside the power plant. For radon-220, the descendant of Th-232, this would be even less plausible. Hence, it appears highly unlikely that the accumulation of natural radon generated the increase in radioactivity measured inside the power plant and later released by the

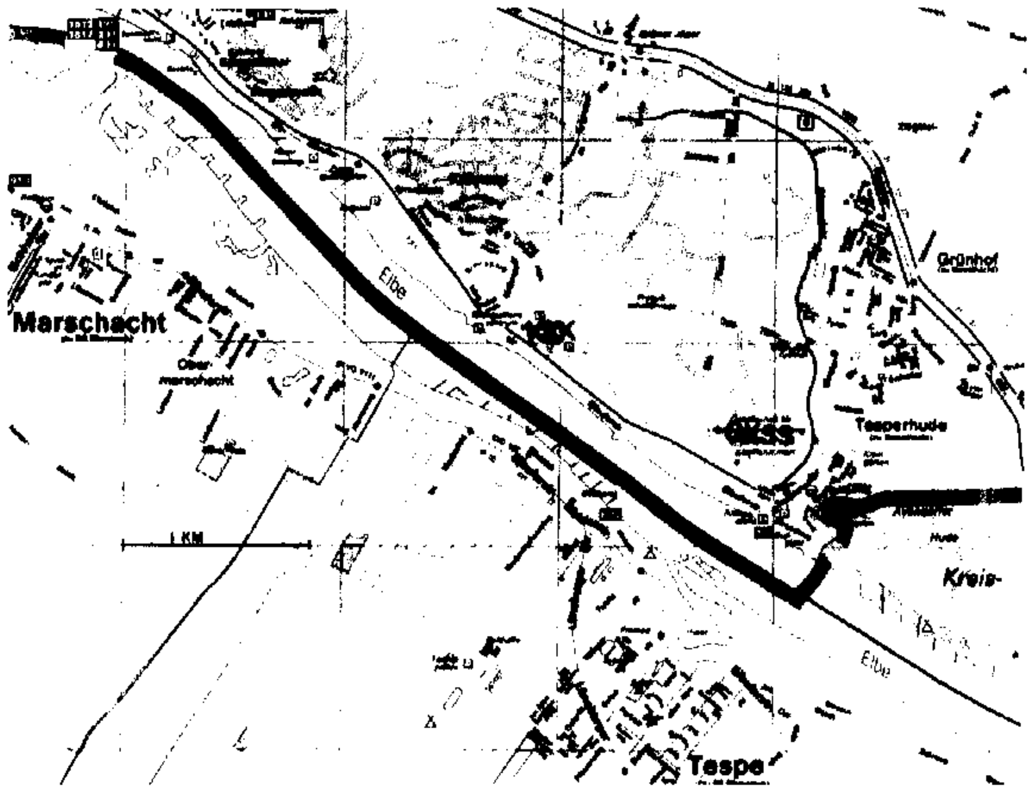

Fig. 2. Location of the nuclear establishments near Geesthacht.

reactor. Because Pb-212, Ra-224, and Tl-208 are descendants of Th-232, the reported results of the ministry support the previously mentioned hypothesis of the ARGE PhAM experts, *i.e.*, a release of nuclear fuel.

An accidental release in 1986 would be congruent with the known latencies for radiation-induced leukemias in childhood, which show up a maximum of 4 to 6 years after exposure. Compared with other regions in Germany, the local contamination by the fallout from the Chernobyl accident in 1986 was rather low, and its contribution to the leukemia induction, if any, was very small. Therefore, the documents of the immission-monitoring program of the nuclear facilities were examined for further indications of a local event.

Methods and Monitoring Program

Routine Emissions Control

In Germany, an emissions-monitoring program ensures compliance with the dose limits for the population living near nuclear facilities. The operators of the plant are obliged to keep accounts of the quantities of radioactive nuclides released from the plant. If the emitted activity for each specific group of nuclides remains less than the permitted limit, then exposure to the population is assumed to be less than the legal limits. The maximum exposure dose in the vicinity of the facility generating the emissions is predicted by employing the atmospheric transport model and transfer factors provided in the German Radiation Protection Legislative Allgemeine Verwaltungsvorschrift (AVV 1990).

Routine Immissions Control

A program of immission measurements constitutes a second control mechanism. It is specified: "The immission monitoring complements the emission monitoring. It enables an additional control of activity releases and the compliance with environmental exposure limits" (REI 1993). The stipulated annual immission measurements for the KKK and GKSS for 1986 are listed in Table 1. The results are also published in annual reports (KKK 1986; GKSS 1983 to 1991). According to REI, these recordings are to be carried out by the plant operators themselves and additionally by an external independent institute. In the case of the KKK, the GKSS serves as the independent institute; for the GKSS, the Agricultural Institute for Examination and Research in the city of Kiel (LUFA) is the independent institute. The immission-control program for the facilities requires additional measurements according to the "routine monitoring for cases of malfunction"

Table 1. Routine program during regular operation[a]

KKK immission control	GKSS immission control	Status
Air		
Local gamma dose rate Three measuring stations near KKK: S I Grünhof, Schleswig-Holstein, in main wind direction, east; S II pumped storage works, Schleswig-Holstein, west; S III Tespe, Niedersachsen, south Continuous registration (circular recorder) Only owner	Local gamma dose rate Four measuring stations: S I through S III identical to KKK; S IV at the GKSS site Continuous registration Only owner	No
Local gamma dose Seventeen solid-state dosimeters including 10 at the KKK-fence, accumulating dose, annual reading Owner and independent institute	Local gamma dose 21 + 10 solid state dosimeters at the GKSS-fence accumulating dose; annual reading Owner and independent institute	Yes Fig. 3
Aerosols in air **Total long-lived beta activity** Measuring stations S I- through S III, samples taken continuously during 14 d by filters; reading after ≥5 d of storage Only owner	Aerosols in air **Total long-lived beta activity** Measuring station S IV samples taken continuously during 14 d, reading after 6 d of storage Only owner	No
Gamma-emitting single nuclides and Sr 90 Measuring stations S I through S III; continuous sampling by filters, reading after 14 d Owner and independent institute, Sr-90 only by owner	**Gamma-emitting single nuclides** Values of the owner for S I through S III are identical those of independent institute for KKK Quarterly combined sample at S IV Owner and independent institute	No
Total alpha activity Measuring stations S I through S III, continuous sampling by filter, quarterly reading Only owner	**Sr-90 and total alpha activity** only at S IV Measuring methods similar to KKK Only owner	Yes
Gaseous iodine I-131 activity concentration Measuring stations S I through-S III, continuous sampling by charcoal, reading after 14 d Only owner	**Gaseous iodine** I-131 activity concentration S I through S III identical to measurements KKK S IV measuring method similar to KKK Only owner	No
Rain water Gamma-emitting single nuclides Measuring stations S I through S III; quarterly combined samples Only owner		
Soil and vegetation		
Soil in depth 0 to 5 and 5 to 10 cm Gamma-emitting single nuclides and Sr-90 Four measuring stations: S I and S III and reference location Dassendorf 10 km north (owner and independent institute) and reference location Wittorf, 10 km south (independent institute) Two samples/y at S I and S III (1. and 2. hay harvest); sample/y at reference locations, Sr-90 only by owner	Soil in depth 0 to 5 and 5 to 10 cm Gamma-emitting single nuclides and Sr-90 Five measuring stations: S I, S III, S IV, and reference locations Dassendorf and Wittorf Two samples/y at S I, S III, S IV and 1 sample at reference locations by owner, Sr-90 only at S I and S IV Two samples/y at S IV and in Dassendorf by independent institute (only gamma)	No
Grass Gamma emitting single nuclides and Sr-90 Two samples/y at S III and at reference locations Owner and independent institute, Sr-90 only S III	Grass Gamma emitting single nuclides and Sr-90 Owner: locations and time as for soil, Sr-90 only at S III /independent institute: locations and time as for soil (only gamma)	Yes Fig. 4

Table 1. Continued

Rural nutritional chain		
Vegetables Gamma emitting single nuclides and Sr-90 at S 1 Two samples/y (1. and 2. hay harvest) by owner Three samples/y by independent institute	Vegetables Gamma emitting single nuclides and Sr-90 at measuring station Tesperhude one sample/y Independent institute only	No
Cow milk Gamma-emitting single nuclides I-131, Sr-90 at four locations, six samples/y each (vegetation period) Independent institute only	Cow milk Gamma-emitting single nuclides and Sr-90 from one dairy producer, one dairy two times/y Iodine monthly during green feeding period Independent institute only	Yes
Surface water		
Surface water (Elbe) Gamma-emitting single nuclides and tritium one sampling location each at inflow and outflow building above and below KKK and near Lauenburg (10 km upstream) and Altengamme (10 km downstream), continuous sampling, monthly analysis Owner	Surface water (Elbe) Gamma emitting single nuclides, tritium, remaining Beta one sampling location each above and below GKSS effluent discharge location Quarterly combined samples from weekly samples Owner	No
Gamma emitting single nuclides, tritium, Sr-90 one sampling location at inflow and outflow building above and below KKK, continuous sampling, monthly analysis (H-3 only quarterly) Independent institute	Gamma-emitting single nuclides and tritium one sampling location each above and below GKSS effluent discharge location Quarterly combined samples from weekly samples Independent institute	
Sediment (Elbe) Gamma emitting single nuclides and Sr-90 Three locations at the Elbe river and inlet of branch canal near Rönne and Drage Quarterly sampling by owner Gamma-emitting single nuclides Two locations at the Elbe river, quarterly sampling by Independent institute	Sediment (Elbe) Gamma-emitting single nuclides one sampling location each above, at, and below GKSS effluent discharge location Quarterly sampling by owner Half-yearly sampling by independent institute	Yes, Fig. 5 and Table 3
Aqueous food chain		
Fish Gamma-emitting single nuclides Samples half-yearly between river km 560 to 588 Only independent institute	Fish Gamma-emitting single nuclides and Sr-90 one sampling location each above, at, and below GKSS discharge, half-yearly Only independent institute	Yes
Ground water Gamma-emitting single nuclides Well west and east (works premises): quarterly combined samples Only owner	Ground water Gamma-emitting single nuclides Reactor draining Quarterly sampling Only owner	No
Drinking water Gamma-emitting single nuclides and Sr-90 Waterworks Geesthacht Quarterly analysis Only independent institute	Drinking water Gamma-emitting single nuclides and Sr-90 Waterworks Geesthacht, identical with KKK measurement Only owner Water-sampling region Curslack (14 km west) Half-yearly analysis Only independent institute	Yes, Fig. 6

[a]Last column is status in September 12, 1986 (yes or no).

(KKK 1986; GKSS 1983 to 1991; see Table 2). These are intended by the REI to serve as quality-control measures in case of malfunction. The last columns in Tables 1 and 2 indicate whether monitoring showed increased radioactivity during September 1986.

Independent Government Monitoring

The supervising ministry, based in the city of Kiel, supplies a system of radiation detectors that is not controlled by the owners of the nuclear plants. It monitors the gamma dose rate

Table 2. Routine test program for cases of malfunction of KKK or GKSS[a]

4.	Air and soil			
4.1	Gamma radiation γ local dose	80 solid-state dosimeters (TL) in the environment, reading yearly	Common program GKSS/KKK (control measurement by LUFA)	No
4.2	Gamma radiation γ local dose rate	Annual short-term measurement at narrow and far locations in surroundings	Periodical measuring drives, monthly changing locations	No
4.3	Aerosols, total beta concentration	Annual sample, reading in the laboratory, locations as for gamma dose rate	Periodical measuring drives, monthly changing locations	No
4.4	Gaseous iodine, J-131 concentration	Annual sample, reading in the laboratory, locations as for gamma dose rate	Periodical measuring drives, monthly changing locations	No
4.5	Soil surface, total beta activity (Bq/m^2)	Annual short-term measurement locations as for gamma dose rate	Periodical measuring drives, monthly changing locations	Yes Fig. 7

[a]Last column is status on September 12, 1986 (yes or no).

at several locations in the vicinity, four on the grounds of the KKK and one on the grounds of the GKSS, and the results are delivered continuously to a laboratory in Kiel.

Data Analysis and Results

Routine Emissions Control

The procedure to calculate maximum exposure of members of the public to emissions of a nuclear facility applies parameters that are given without confidence limits and leads to results without confidence limits. The authorities claim that the results are conservative, which would mean that the majority of the real metereologic constellations are included. The question of conservatism was investigated in a Radiobiologic Evaluatory Report that had been ordered by the supervising ministry because of the leukemia problem (Stevenson 2001). General proof of the reliability of the AVV modelling cannot be derived from the literature (Hinrichsen 2001; Schmitz-Feuerhake 2001). Special orographic situations—as in case of the Geesthacht plants, which lie between a geographic elevation on one side and a river and flat plain on the other—are not considered in the transport model and can lead to underestimation of aerial activity concentrations up to two orders of magnitude greater than predicted (Schumacher 2001).

The concept of emission control for the KKK and GKSS was evaluated by an independent German expert group appointed by the supervising ministry (Öko-Institut 1994, 1996). They attested that there was sufficiently sensitive emission monitoring for the KKK, but for the GKSS they judged that not all technically possible emissions would have been recognized by the emission- and immission-monitoring devices. Therefore, the possibility of relevant unregistered deliveries had existed during the investigated period from 1982 to 1993.

Routine Immission Control

Air monitoring. The gamma dose-rate measurement in air is the only continuous and directly evident measurement required by German law that can detect short-term alterations in environmental radioactivity. The results, including mean and maximum measurements, are documented in the annual reports of the KKK and GKSS in monthly descriptive statistics. For September 1986, these values were unsuspicious at the four locations measured (Table 1). The other aerial measuring parameters showed also no increase during the period of interest. The solid-state detectors, however, yielded interesting information although they registered only an accumulated annual dose.

The KKK and GKSS use different types of dosimeters, thermoluminescence and phosphate, respectively. Several pairs of both types are positioned on the roof of the KKK turbine hall, which stands 50 m high. One of the locations (no. 12) showed a continuous high increase in dose values during 1986 (Figure 3). The phosphate dosimeters of the GKSS yielded a definitely higher increase, up to a factor of 3. This is only explainable by a strong component of beta irradiation (a higher response is generated by the greater absorption volume of the RPL detector), indicating that the beta emitters must have contaminated the plant from outside. The deposited radionuclides then lead to continuous exposure.

Soil and vegetation. Soil and vegetation were monitored at four sampling stations around the plants. The measurements were carried out only 2 times/y during the vegetation period. At the KKK, they were conducted before September 12 (June 5 and August 15) and hence cannot provide information about the period of interest. The latter sampling showed a significant decrease of Chernobyl-released nuclides in grass compared with the June 5 sampling.

At the fourth location at the GKSS site (site no. 4), sampling was done by the owner on June 5 and September 12, 1986, and the latter sampling showed an increase in Cs-137 and Cs-134 in grass (Figure 4). This contamination indicated a recent deposition because the concentration in soil had also decreased there after Chernobyl. This finding is supported by the fact that the grass concentration at the reference location (Dassendorf) had not increased on September 12, 1986. The increased concentration of Cs in 1987 at the GKSS site (Figure 4) can be interpreted as being left over from the contamination that occurred in September 1986.

Rural nutritional chain. In the KKK immission control, vegetables were measured only 2 times/y before September 1986. The single prescribed measurement of the GKSS

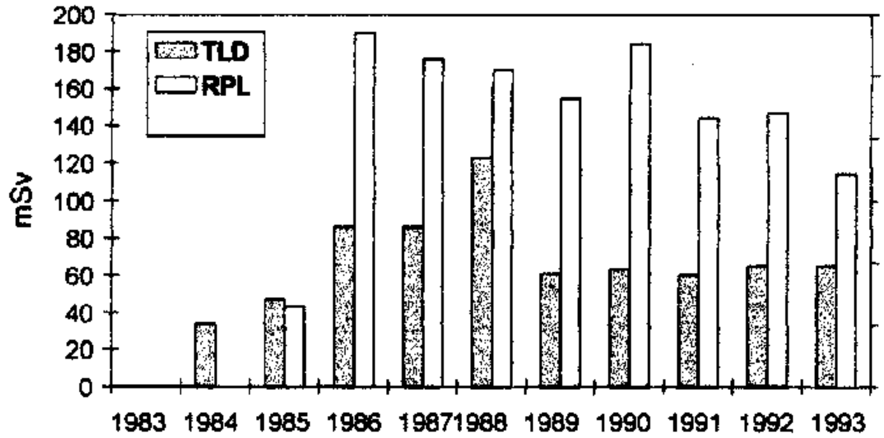

Fig. 3. Dose measurements by solid-state detectors at one position on the roof of the KKK turbine hall. TLD = measurement by thermoluminescence; RPL = measurement by phosphate glass.

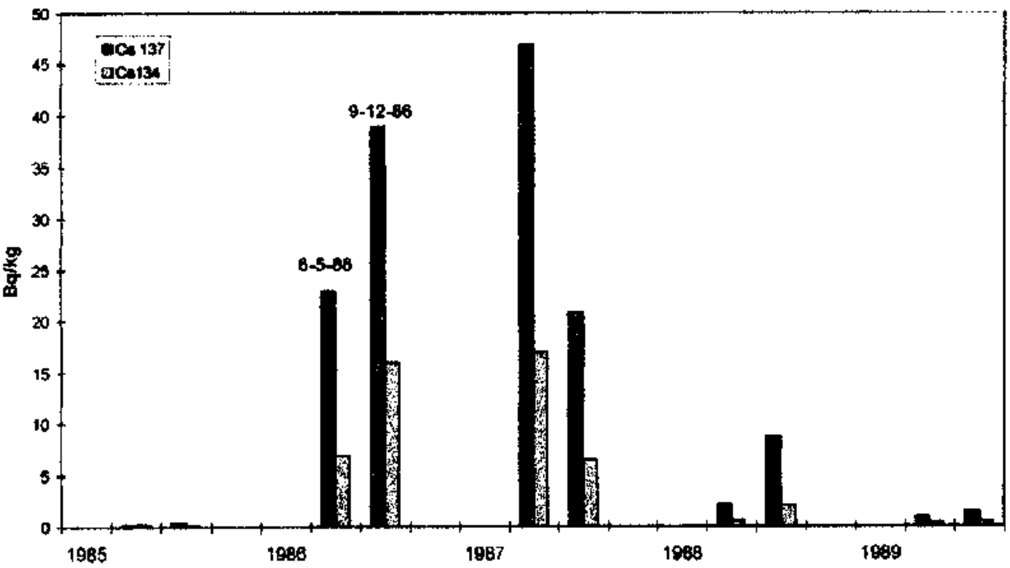

Fig. 4. Cs isotopes in grass at station IV on the GKSS site (2 samples/y).

program was carried out in October and did not allow comparisons with values after the Chernobyl contamination. The cow milk samples taken for gamma and Sr-90 monitoring according to the KKK program were procured before September 1986. I-137 measurements were also done September 6 and October 1 and showed no increase in October. The GKSS program included measurements for gamma emitters (except I-137) and Sr-90 until September. The Cs-137 concentration in milk was increased threefold on September 23 compared with the value measured on August 21.

Inshore waters above ground. Fission products appeared in sediments of the river Elbe outside of the Chernobyl period. Measurements in the GKSS program were carried out at three locations: above, at, and below the GKSS effluent discharges into the river Elbe at km 578.6, 579.1, and 579.6, respectively. Table 3 and Figure 5 show Cs-137 and other fission or activation products in Elbe sediment according to the measurements of the independent institute. In 1986, a measurement was carried out on May 15, shortly after the Chernobyl release in the last days of April, and one more measurement was taken on September 15, *i.e.*, shortly after the period of interest around September 12. The latter sampling showed a multifold increase of manmade gamma emitters, except for Ru-103, compared with the residual activity after the Chernobyl accident.

Table 4 lists sediment measurements from the GKSS taken at the same location but on different dates. In 1986, there was one measurement also on May 15 and then another on August 8, which showed only a marginal increase during the post-Chernobyl period. A further measurement on November 13 indicated a severe increase in fission products. Relevant with respect to the possible cause were the values upstream the

Table 3. Fission and activation products in sediment: Results of the GKSS immission monitoring (GKSS 1986)

Location	Date	Cs-137	Cs-134[b]	Sb-125	Ru-106	Ru-103	Nb-95	Ce-144
Elbe above GKSS effluent discharge	1983							
(at river km 578.6)	5-1	5.7						
	11-1	10.3						
	1984							
	5-9	6.6						
	11-15	3.8						
	1985							
	6-20	2.9						
	10-31	6.3						
	1986							
	5-15	23.4	10.1	<2.9	7.4	25.9	<2.2	<6.4
	9-15	**111.6**	**50.1**	**3.6**	**48.9**	**23.1**	**4.2**	**7.6**
	1987							
	4-8	8.6	3.2					
	8-20	8.4	2.8					
	1988							
	4-11	5.7	1.5					
	10-21	62.8	13.5					
	1989							
	3-16	13.3	2.2					
	9-7	14.5	2.2					
	1990							
	3-23	31.1	3.4					
	10-25	39.4	4.7					
	1991							
	3-14	39.2	4.3					
	8-15	0.7	0.3					
	1992							
	4-9	0.8	(0.2					
	11-5	2.4	0.3					

Measurement by independent institute. Two samples per year (expressed as Bq/kg). Empty fields in the nuclide columns indicate results lower than detection limit. Bold numbers mean conclusive data.

GKSS outlet because the sediments at the level of the outlet and below may have been contaminated by the permitted discharges to the river Elbe from the GKSS; therefore, only the upstream values are shown in the tables. The observed activity increase on September 15 upstream the GKSS outlet was too high to be explained by usual fluctuations in radionuclide activity values. It is also unlikely to be explained by different storage capacities of the sediment because the annual report of the GKSS (1986) showed that it was repeated systematically at the lower (downstream) locations (Figure 5). These measurements are therefore compatible with the fresh deposition of airborne fission products between August 21 and September 15 (see Table 4).

Aqueous nutritional chain. The concentration of Cs-137 and -134 in fish from the Elbe river was much higher after September 12, 1986, than in May after the Chernobyl accident. This parameter, however, is not useful in this context because the habitat of the fish is not known. A sample taken on September 30, 1986, from the reservoir of the waterworks at Geesthacht showed increased Cs-137 contamination (Figure 6). An earlier sampling on June 30 revealed levels below the detection limit. The contamination can therefore not be explained in terms of the effects of Chernobyl. Drinking water was sampled from several wells located 0.5 to approximately 5 km from the KKK (personal communication from Wolter, Ministry of Finance and Energy of the Federal State of Schleswig-Holstein, to Schmitz-Feuerhake, October 14, 1992). At that time, it was enriched with oxygen by flowing through outside air. Mixtures with surface waters are unfavorable for both hygienic and water quality reasons and are regarded as unlikely to have occurred. Therefore, a likely cause for the observed contamination was again airborne radioactivity deposited between June 30 and September 30. The measuring samples are taken 4 times/y. None of the samples showed contamination from September 1986 since 1983, the beginning of the measurement. As shown in Figure 6, another unexplained contamination occurred in 1989.

Malfunction program. The malfunction program (Table 2) includes annual measurements at approximately 50 locations for beta surface activity on soil. They are performed as a short time-direct registration using a surface monitor. On September 12, 1986, five such measurements were carried out (GKSS 1986): (1) location Obermarschacht 3 km west of the GKSS at 9:00 AM; result = **3000** Bq/m^2; (2) location Eichholz 5.5 km southwest of the GKSS at 9:30 AM; result = 600 Bq/m^2; (3) location Oldershausen 7.5 km southwest of the GKSS at 9:45 AM; result = 300 Bq/m^2; (4) location Handorf 8.5

Table 4. Fission and activation products in sediment: Results of the GKSS immission monitoring (GKSS 1986)

Location	Date	Cs-137	Cs-134	Sb-125	Ru-106	Ru-103	Nb-95	Ce-144
Elbe above GKSS effluent discharge (at river km 578.6)	1984							
	1st quarter	4.2						
	2nd quarter	8.6						
	3rd quarter	4.3						
	4th quarter	10						
	1985							
	3-28	3.5						
	6-20	1.0						
	8-29	7.2						
	10-31	1.8						
	1986							
	3-26	<0.3	<0.2	<0.7	<2	<0.3	<0.3	<2
	5-15	30	15	<1	15	54	0.48	<3
	8-21	58	27	<2	29	19	10	8.4
	11-13	**410**	**180**	**13**	**170**	**33**	**13**	**20**
	1987							
	4-2	3.1	1.1	<2	<5	<0.6	<0.6	<3
	6-11	2.7	0.93					
	8-20	9.5	2.9					
	11-12	11	3.4					
	1988							
	3-24	2.2	0.55					
	6-15	98	2.3					
	10-28	35	8.2					
	1989							
	2-9	8.6	1.7					

Measurement by GKSS. Four samples per year (expressed as Bq/kg). Empty fields in the nuclide columns indicate results lower than detection limit. Bold numbers mean conclusive data.

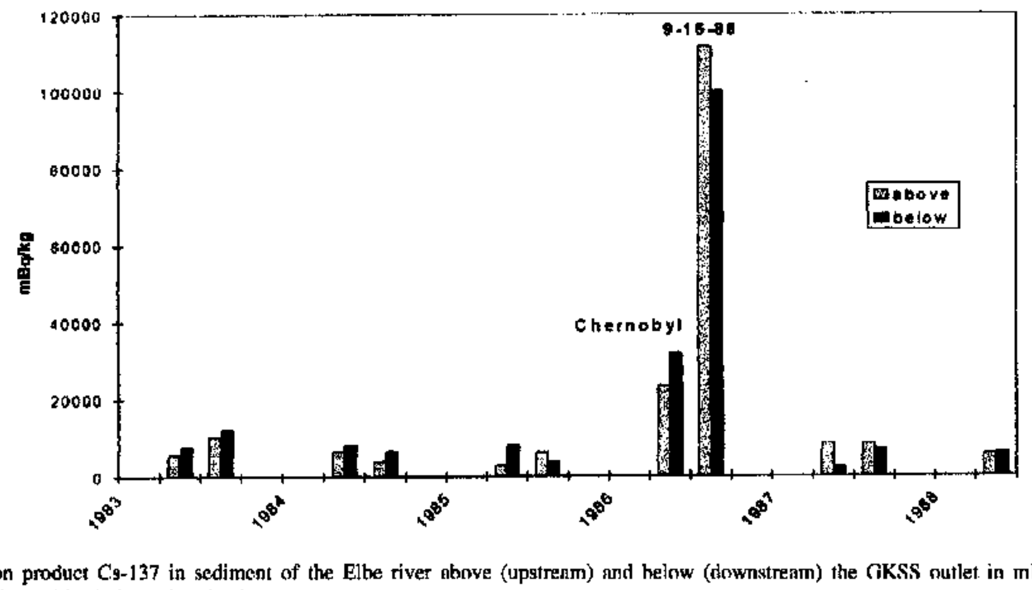

Fig. 5. Fission product Cs-137 in sediment of the Elbe river above (upstream) and below (downstream) the GKSS outlet in mBq/kg. Measurement performed by independent institute.

km southwest of the GKSS at 10.15 AM; result = 300 Bq/m^2; and (5) location Rottorf 11 km southwest of GKSS at 10.45 AM; result = 600 Bq/m^2.

The result at Obermarschacht, which is the nearest location to the KKK and GKSS (Figure 2), was a singular peak not registered anywhere else in bare soil during the considered period of 1983 to 1991. Generally, the values at the selected locations are approximately 600 Bq/m^2.

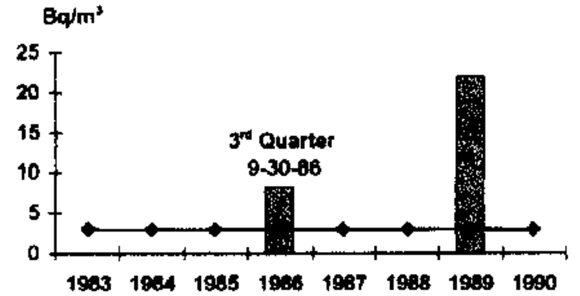

Fig. 6. Fission product Cs-137 measured in the waterworks Geesthacht. Two values were above the detection limit (line).

Therefore, in Obermarschacht an approximate fivefold increase in beta surface activity was documented on September 12, 1986 (Figure 7). Figure 7 shows the course of the measurement values for the five locations previously listed during 1985 to 1991 (there is no documentation for 1988 in the GKSS annual report). According to the quality-control program (4.1 through 4.4 in Table 2), the other measurements showed no increases at the five locations on September 12, 1986.

Independent Government Monitoring

September 12, 1986, was the Friday of the 37th week of the year. Members of the expert committee investigated the weekly registrations of the data. The GKSS measuring station showed a loss of registrations between the 37th and the 50th week of 1986, which was explained by a fire, which in turn resulted in the measuring station being reinstalled at another location.

Discussion

Environmental radioactivity being the cause of increased cases of leukemia in individuals living near nuclear facilities is often excluded because exposure to the population appears much too low to explain the effect (Shleien *et al.* 1991; Laurier *et al.* 2002). If, however, as in the present case, the information about the real contamination is as incomplete as shown, the question arises if the present concept for environmental surveillance is sufficient to evaluate any unusual contamination. This concept is based on the assumption that any unusual event of radiologic relevance would cause a measurable increase in monitored beta and gamma radiation. This was in fact the case in the discussed example, but the increases were evidently too subtle to cause a reaction by the operators of the facilities or the supervising authorities. Unfortunately, the Chernobyl accident had occurred in the same year, and its radioactive fallout added even more complexity to the interpretation of the plant's monitoring data.

Non-Chernobyl-induced radioactive deposition was recorded on September 12, 1986, from measurements of beta surface activity at Obermarschacht. The beta contamination was increased approximately fivefold compared with the normal background. This information, however, was obtained from a single measuring campaign in September. The only other four locations at which this kind of investigation was carried out at that date refer to distances up to 11 km away from the potential source of activity.

According to the AVV model (1990), the observed beta surface activity at such a distance, approximately 3.3 km from the GKSS and 2 km from the KKK, is not compatible with the permitted emissions by way of the provided pathways. It follows that the dose limit to the surrounding population was not guaranteed. Assuming that the activity at Obermarschacht of approximately 2400 Bq/m^2 was generated by dry deposition of aerosols in 1.5 hours (from the beginning of the aerosol elevation in KKK at 7.30 AM until the measurement at 9.00 AM), and using the sinking velocity for aerosols ($v_g = 1.5 \times 10^{-3}$ m/s) given by the AVV, a concentration of beta aerosols of approximately 300 Bq/m^3 in air is derived (normal background about 1 m Bq/m^3). This would have been approximately 400 times higher than the maximum concentration in that region after the Chernobyl event (GKSS 1986; Bundesminister 1986). According to nuclide-specific analyses, routine monitoring showed also emission of fission products at that time or shortly thereafter at some locations.

Measurements of activity from sediment are not suitable for dose estimations according to the AVV because it must be assumed in the case of an accident that the exposure of the population is dominated by inhalation of the radioactivity. The concentration in air cannot be reconstructed by the contamination of this medium. An air concentration can be derived from the Cs-137 contamination of drinking water in September 1986 (8.3 Bq/m^3) because it had been oxygenated by 30 L air in 1000 L water (communication from Wolter, Ministry of Finance and Energy of the Federal State of Schleswig-Holstein, to Schmitz-Feuerhake, October 14, 1992). This yields 277 Bq/m^3 of Cs-137 in air, which is approximately 300-fold the maximum Cs-137 concentration measured in that region after Chernobyl accident (Bundesminister 1986).

A further rough estimate of the radioactivity concentration in air can be obtained based on nuclides deposited on the roof of the KKK turbine hall (Figure 3). For protection purposes in the case of a nuclear accident, the German Commission on Radiological Protection has suggested an approximate dependency between surface beta activity and dose rate: 40,000 Bq/m^2 delivered at 1 Sv/d above the surface (Bundesminister 1989). If one assumes that the dose on the roof (180 mSv) was generated in 1986 by dry deposition of nuclides that were released in 4 hours on September 12 (see above), a concentration of beta emitters in the radioactive cloud of 9.000 Bq/m^3 must have existed.

The derived values for the air concentration are indices for a rather high contamination. However, neither the GKSS immission-control program nor that of the nearby nuclear power plant provided information about the spatial extension and the temporal course of the release and the complete composition of the involved radioactive nuclides. Therefore, no further details of the underlying scenario can be reconstructed from the immission investigations. Nuclide-specific air monitoring is performed at only four stations near the plants (Table 1). Aerosols are collected in filters continuously

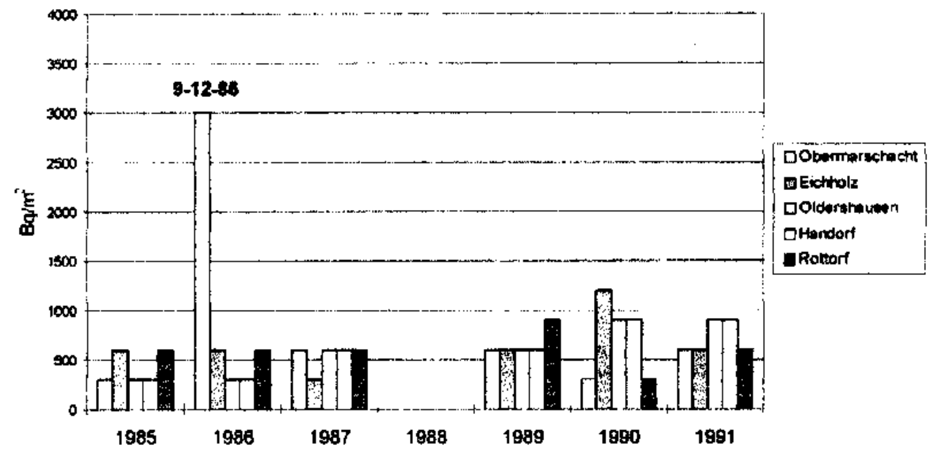

Fig. 7. Beta surface activity measured by the GKSS at different locations.

during 14 days and then measured four times a year in quarterly combined samples (*i.e.*, each collected during 3 months) by gamma spectroscopy after at least 5 days of storage. This technique is not optimized for the registration of sudden alterations and the detection of short-lived radioactivity. Cs-137 and Cs-134 aerosols appeared during the period of interest in 1986 but were not distinguishable from Chernobyl contaminations.

A considerable information gap concerning immission control is that the measurements do not discriminate between different alpha emitters. The only estimation of alpha radiation is a cumulative one in air (Table 1). It measures high fluctuations possibly caused by natural radiation and is therefore rather meaningless (this measurement was therefore eliminated in the revised regulation of 1993, but it was not replaced by a more specific alpha registration). Finally, it cannot be derived from the immission-control programs whether any of the establishments caused the contamination and, if so, which one.

Regarding the Geesthacht leukemia cluster, the best information until now about the kind and degree of exposure that could lead to such an increase in leukemia cases has been obtained from biological and medical parameters. The occurrence in childhood and the gender distribution of the leukemia cases support a radiation origin. In 1990, leukemia was pre-
3,3:1 dominantly increased in boys (male-to-female ratio 3.3:1), whereas the normal gender distribution in children is 1.3:1 (Kaletsch *et al.* 1996). This corresponds to the findings in the Japanese A-bomb survivors who showed a 2:1 ratio for leukemia (Finch and Finch 1988).

The observed increase in dicentric chromosomes indicates an exposure above the permitted limit (Schmitz-Feuerhake *et al.* 1997; Dannheim 1996). In case of an accidental release of transuranic nuclides, uranium, and fission products, the main exposure would likely have originated from inhalation. Some of the ill children, including all children diagnosed in 1995, were born after September 1986. Therefore, the continuity of the epidemiologic cluster effect (Figure 1) cannot be explained in terms of different latency times after a single exposure. Rather, we would have to hypothesize an ongoing exposure, *e.g.*, by remaining contamination and/or preconceptional exposure, of the parents at time of the assumed contamination.

Our investigations have revealed a variety of radioactivity increases in the environment of the KKK and GKSS that do not coincide with an event occurring in September 1986 (Schmitz-Feuerhake *et al.* 1996, 1997; Schmidt *et al.* 1998). The second contamination, observed in the waterworks of Geesthacht in 1989 (Figure 6), may have been a consequence of extensive dyke-building measures that took place in the Geesthacht region in 1988 and 1989. These may have led to renewed inhalation exposure of the population.

To clarify the cause, nature, and magnitude of the exposure in the affected region, further environmental studies are necessary. One key question would be whether the recently observed contamination with nuclear fuel coincides with the documented appearance of fission products in the environment in September 1986. In the face of the lasting leukemia risk in that region, especially in young children, these efforts must be demanded not only for scientific reasons but also to prevent further harm to the population.

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