Monitoring Emissions from Nuclear Facilities: Could Relevant Activities Escape Undetected?

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The case in question

Certainty, uncertainty, or probability?

Clusters of childhood leukemia have repeatedly been reported in the vicinity of Nuclear Power Plants (NPP) in the UK and Germany [7, 18]. These observations have started a scientific as well as public discussion about the possible reasons that is still going on. The German Strahlenschutz-Kommission (SSK) has published a statement in 1994, summarizing the results of investigations particularly for the Elbmarsch region around the NPP Krümmel, and concluding that „according to our present knowledge, no scientific confirmation could be found that radioactive releases have caused the accumulation of leukemia cases" [21].

Nevertheless, this is a highly unsatisfactory situation. Even if there is no proof to it, and even if other causes for the leukemia but radiation can equally not be excluded, the population around nuclear facilities may be led to believe that there exists an important, up-to-now unidentified radiation risk.

But if it is true that we cannot say Yes or No, at least we can say something more substantial on the probability, simply by examining in detail the quantitative relation between activity released and dose received. And I think it can convincingly be shown in this way that a causality is highly improbable. This will be undertaken in the following paper.

There are only two possibilities

The key question is: What bone marrow dose causes which increase in childhood leukemia? As we will see, I do not necessarily have to know the answer to make my point. The current understanding is that, for an age of exposure under 10 years, a bone marrow dose of 1 Sv raises the spontaneous rate - 4.5 cases out of 100,000 - by a factor of 40, i.e.180 affections [22]. Applied to the 5 Elbmarsch cases out of 1500, the „conventional" dose estimate therefore would be 1.7 Sv.

As nobody could earnestly allege that as high an exposure could have occured unnoticedly, this leaves only two possibilities. Either radioactivity is *not* the cause, and our case is closed. Or the assumed dose-risk relationship is wrong, and it needs a much lower dose to promote leukemia as observed. For the sake of argument, let us suppose the latter to be true. And as we are now free to speculate, I will state the lowest value that can reasonably be taken into consideration: 10 mSv, or 10 times the average natural bone marrow dose . Because if even lower doses could generate leukemia in the observed extent, there must be several population groups with noticeable increased rates.

Correlating dose and activity

So we have reduced the problem to the - much easier - question what radioactive emissions would give rise to 10 mSv - or any other dose, of course -, and what the probability would be for them to escape undetected.

This procedure requires two steps: establishing the correlation dose received to activity released for all relevant nuclides, and checking the performance of the activity monitoring equipment to see what activities can be detected online at the NPP or, at least, after the event in environmental

samples. The following paper cannot achieve a complete treatment, but it will show the general direction, give examples, and draw some evident conclusions.

How can exposure of the population be caused?

Pathways of transport

Exposure of the population by airborne radioactive emissions from NPPs may occur via the following pathways:

External exposure
- Gamma submersion
- Beta submersion
- Gamma soil radiation from deposited activity

Internal exposure
- Inhalation
- Ingestion

All pathways must be controled by a) measurement of the emitted air or gases, b) by measurement of the dose or doserate at selected spots around the NPP, and c) by activity measurements of environmental samples. In specific cases, incorporation measurements, i.e. direct measurements on persons concerned may be required.
However, if we concentrate on possible causation of leucemia, beta submersion can be excluded from the beginning and does not need to be investigated further.

Calculating exposure via the different pathways

The calculation of exposure via the different pathways caused by presumed activities of various radionuclides is an important part in the licencing process of NPPs, the goal being to prove that no higher exposure than 0.3 mSv per year by either inhalation or ingestion will occur in normal operation. Many individual factors have to be taken into account, starting from the emission rates of activity through meteorological data like dispersion, fallout and washout factors, up to the behaviour of the population. Finally, and essential to all dose assessment, is the knowledge of the so-called dose factors that convert, for each nuclide, either inhaled activity or external exposure by immersion to effective dose equivalent [5]. Accordingly, some kind of standardisation of such calculations is needed and in fact has been layed down by the officials as a set of rules and examples [1]. Once having performed the calculations under standard conditions, it is also possible rather easily to take into account local or temporal deviations. There is, corresponding to the importance of the subject, a wealth of literature available as well as the relevant computer software [8-10]. In particular, I would like to refer to the textbook by H.Bonka: „Strahlenexposition durch radioaktive Emissionen aus kerntechnischen Anlagen im Normalbetrieb“ [2] in which the topic is extensively treated.

Emission rates and doses

I cannot give here a complete listing for all relevant radionuclides. However, the few representative results given in Table 1 already show which pathways are important for the groups of radionuclides in question, and what order of magnitude we have to expect. We see from it that, in normal operating conditions, gamma submersion by noble gases is the most important source of exposure, followed by the radiation from long-lived aerosols deposited on the ground. The total dose of 1.3 µSv, however, is less then a factor of 100 lower than the above-mentioned limit for the population of 0.3 mSv per year.

The relevance of exposure calculations to cause-and-effect consideration

Now the point I want to make is the following: If we assume that a certain effective dose equivalent d is required above the natural background exposure to cause a de-

tecable increase in leucemia, and if we allege that d is caused by radioactive effluents from the NPP, we can, by a backward exposure calculation, tell nuclide-by-nuclide what activity must at least have been emitted to produce this dose.
The next step, then, is to compare the so-gained activity values with the detection limits of the monitoring equipment to see if the activity could have been escaped unrecognized.

Monitoring radioactive releases from NPPs

General regulations

Just for the record, I would like to begin with the statement that radioactive releases from NPPs are watched carefully and extensively. The general requirement for monitoring is laid down in the § 46 of the Strahlenschutzverordnung. Details are specified in the „Richtlinie zur Emissions- und Immissionsüberwachung kerntechnischer Anlagen (REI)", revised version 1993 [19]. The REI obliges both parties, the operator and the supervising authorities, to perform independetently exactly determined measurements, stating equally the detection limits.

Emission Monitoring

The hardware and the performance of todays monitoring equipment has equally been described in many publications, not at last by myself [13,14,20]. I therefore will not give here another detailed survey on the techniques of measuring instruments. It seems more worthwile instead to say something about the quality assurance of monitors, and to discuss the measures to avoid possible deficiencies that could bear on undetected releases.
The very first examination of the monitoring equipment is done in the licencing process. There exists a „Atomrechtliche Verfahrensverordnung (AtVfV)" that requests from the NPP operator a very detailed facility description stating all monitoring devices, their location and their performance. Standards from the „Kerntechnischer Ausschuß (KTA)" are setting the requirements [11].The equipment used must be approved to be in accordance with these standards by an independent body, in Germany usually the „Technische Überwachungsverein (TÜV)".
Actual radioactive emissions from all German NPPs, as assessed by the described installations and institutions, are published yearly, as well as „unusual events", in every detail by the Bundesumweltministerium BMU (Ministry of Environment) [4]. Values for Noble Gases, Aerosols and Tritium from 1970 to 1993 of some German NPPs are given in Fig. 1 - 3 just as an example [3].

Environment (Immission) Monitoring

Environmental monitoring around nuclear installations started already in the fifties.
Indeed, my first publication after entering in 1957 my new job at the developing Karlsruhe Nuclear Research Center treated „Die Umgebungsüberwachung kerntechnischer Anlagen mit Zählrohren" [12], giving the base for dose rate and airborne activity concentration measurements around nuclear installations.
Extensive routine measurements are performed today continuously on dose rate and airborne radionuclides, and individually on biological samples of all kinds, in the neighbourhood of NPPs [15,23]. Automatic data transfer to evaluation centers is state of the art [16].
In particular after the Chernobyl event, the existing networks were the backbone of gaining first results. In fact, the accident was detected outside of Russia by monitors of a Swedish NPP. Based on the experience gained in 1986, environmental monitoring installations have been refitted and enlarged tremendously in the past ten years. This is true, above all, for the addition of

iodine and gamma-spectrometric monitors to the networks [17].

Today's measuring systems and their detection limits

I am considering here the main online monitoring systems only - noble gas monitors, iodine monitors, and particulate monitors - without going to far into technical details.

The detection limits for noble gas monitors are based on instruments with a measuring volume of 5 l, and an integrating intervall of 10 min. Assessed is the beta component, meaning a gross activity measurement without identification of individual nuclides. However, the rules afford that weekly - or, in case of unusual events, more frequently - spectrometric average sample measurements are made to control the components of the noble gas mixture.

Iodine monitors feature today mostly Marinelli-type beakers and organic collecting material. Integrating intervals of 1 hour are taken into account.

Three variants of particulate monitors are in use today: Fixed filter systems with simultaneous α and β detection, moving filter systems equally with α and β detection, and moving filter systems with additional γ spectrometry for online nuclide identification.

The last-mentioned type, however, is rather exceptional yet in NPPs, the reason being the still ongoing evaluation process by the certifying bodies. On the other hand, the supervising authorities use them for their own surveys in some NPPs, like Grohnde or Stade.

Table 2 gives the detection limits under realistic operating conditions, calculated according to DIN 25482 Part 1, and the relevant KTA standards with $\alpha = \beta = 0.05$, or a confidence level of 90% respectively.

Please be aware that the limits are given in Bq/m^3 of air *measured*. If we assume that a typical NPP gives off an air stream of 150,000 m^3/h, then 1 Bq/m^3 corresponds to 0.15 MBq/h activity released.

And now: what about the 10 mSv? Which radionuclides could cause such a dose undetected at all?

First of all, I think we could exclude an external exposure from noble gases as a source of a 10 mSv dose. On the one hand, such an exposure value would require a year-long release of about ten thousand times the normal value, or, taking a release duration of one week, fivehundred thousand times. On the other hand, 10 mSv external dose could not remain unnoticed by the environmental doserate monitors or dosemeters. The same would be true for N-16. Besides of its short halflife of 7.13 s, the 6.13 MeV γ ray is also assessed by the monitors with GM- or proportional detectors. The fairy tale of N-16 not being measured has its origin in the indeed reduced detection efficiency of some older types of ionisation chambers for such energies.

We can also exclude the unnoticed presence of long-lived radioactive aerosols. Even if not assessed by stack monitoring, the activities required to produce 10 mSv either by soil radiation or by ingestion remain measurable for quite a time in the biosphere. They must be easily detected there by the routine sample measurements, or could otherwise be identified on suspicion later on.

Tritium is a similar case. The amounts that must be released to cause 10 mSv are about 10^{16} Bq/y or 5×10^{17} Bq/week. Such high activities must be found subsequently in the environment.

Iodine would affect much more the thyroid than the bone marrow, Chernobyl being the typical example. I will allege that where no thyroid cancers develop, iodine could not be the cause for leukemia.

A logical summary

We have seen that radioactive emissions below the detection limit of today's monitoring equipment, be it online monitors at the NPP stack or sample measurements in the environment, simply cannot produce population exposures in the order of 10 mSv.

Then what else is left as a possible „exposure carrier"? Two scenarios have frequently been suggested: Either the monitors failed just at the crucial moment where a short-term high emission occured. Or there exists a particular radionuclide that has been completely overlooked up to now.

In both cases, the villain can only be a rather short-lived nuclide that is inhaled - ingestion of short-lived activity is almost impossible due to the delay in the food-chain - and that leaves no traces in the biosphere or in the persons affected. I do not know of any such nuclide.

If it is, however, alleged that doses well below 10 mSv are triggering leukemia, then such cases should be found around many other nuclear installations, and also in regions with elevated natural background, which has not been observed. So, my personal conclusion is that the probability for undetected radiation emissions from nuclear power plants to cause leukemia in the vicinity is very near zero.

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Anextended version of this paper has been published in Strahlenschutz Praxis 4/96, p.70-77, Verlag TÜV Rheinland Köln 1996.

Tab.1: Calculated yearly doses related to conventional emission rates [8]

Nuclide Group	Emission MBq/h	γ Subm. µSv/y	Soil Rad. µSv/y	Inhal. µSv/y	Ingestion µSv/y
Noble Gases	5700	0.8	-	-	-
Aerosols	0.057	negl.	0.28	negl.	0.08
I-131	0.12	negl.	0.002	negl.	0.005
H-3	250	-	-	0.012	0.056
C-14	5.7	-	-	negl.	0.06
Total 1.3 µSv/y		0.8 62%	0.28 22%	0.012 1%	0.2 15%

Noble Gases: Kr-85m, Kr-85, Kr-87, Kr-88, Xe-131m, Xe-133, Xe-135, Xe-138
Aerosols: Co-58, Co-60, Sr-90, Cs-134, Cs-137, Ce-144, Pu-239

Tab 2 Detection limits for various types of monitors [6]

Detection limits	Bq/m³		
	α	β	γ
Noble gas monitor		2000 (Kr-85) 5000 (Xe-133)	
Iodine monitor		0.5	
Particulate monitors			
Fixed filter	0.15	0.3	
Moving filter	0.6	1	
Moving filter, γ			0.1 (Co-60)

Fig. 1: Yearly releases (Bq/a) of noble gases from several German NPPs in the years from 1970 to 1992 as given in the Annual Reports of the German Ministry of Environment

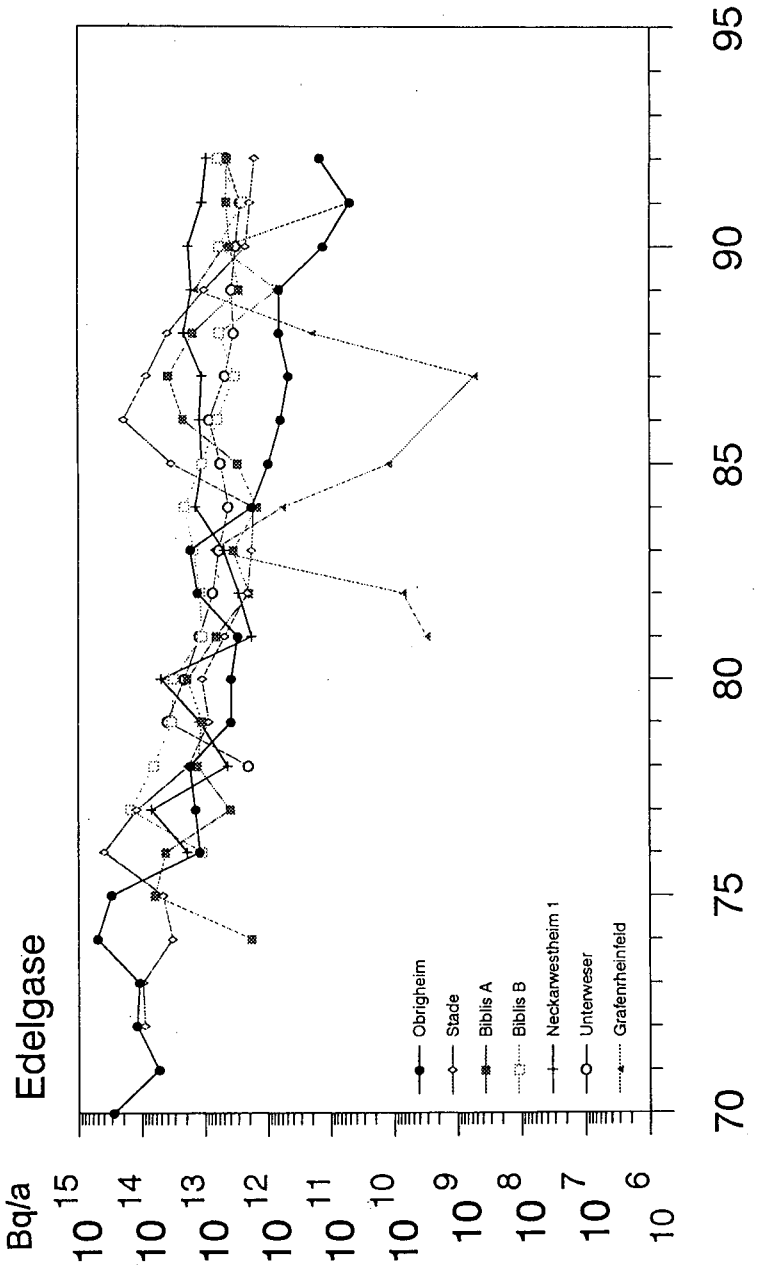

Fig. 2: Yearly releases (Bq/a) of aerosols from several German NPPs in the years from 1970 to 1992 as given in the Annual Reports of the German Ministry of Environment

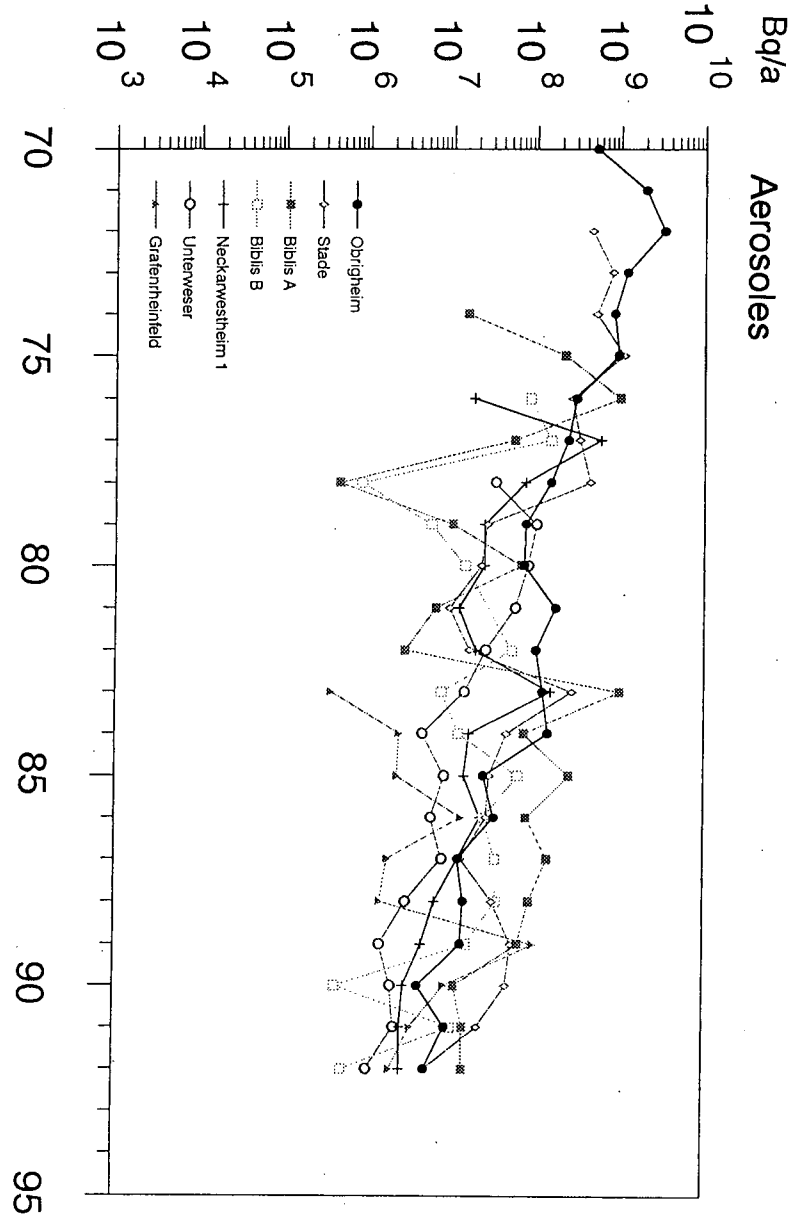

Fig. 3: Yearly releases (Bq/a) of tritium from several German NPPs in the years from 1970 to 1992 as given in the Annual Reports of the German Ministry of Environment