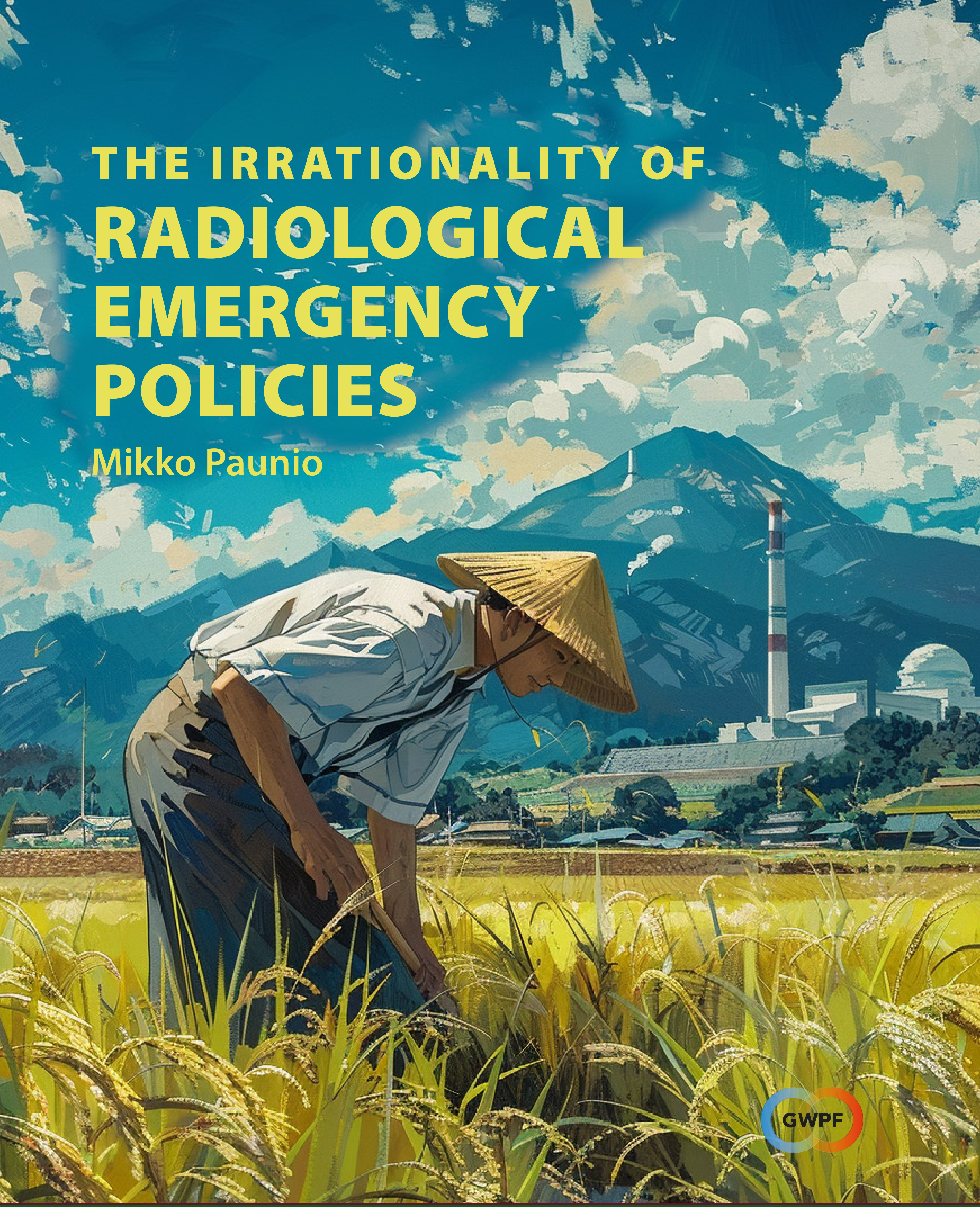
THE IRRATIONALITY OF RADIOLOGICAL EMERGENCY POLICIES

Mikko Paunio



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About the author

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Table 1: Historically most relevant radioactive material releases omitting open air bomb tests and their public health effects

Event	Source term (PBq)	Ground contamination (MBq/m2)	Soil remediation	Evacuation (No. people)	Public health effects
East Urals Radioactive Trace, 1957	740	Immediate vicinity: 3.7–22.2 700 km^2 SPZ: 0.074–0.14 Contaminated area: 15–20,000 km^2	Very limited ploughing with limited success to prevent resuspensions	7–14 days: 1100 330-670 days; 10,000	No acute effects Years 1–2, decrease in group leukocyte/ thrombocyte count By 2006, only 27 out of assumed 1426 cancer cases (2.5%) associated with accidental radiation exposure
Techa River, 1949–56	>100 • (^{90}Sr: 12)	None (contamination in river)	N/A	22 villages evacuated and resettled	No acute effects; By 2007: • 50 of assumed 2303 (2%) solid cancer deaths attributable • ~50% of 72 acute leukemias attributable; 83% of cases received >100 mGy bone marrow dose
Chernobyl, 1986	• ^{137}Cs: 36–120 · ^{90}Sr: 10 • ^{131}I: 5300	Most polluted 1700 km^2: 0.1 Pripyat City: 3.7 Contaminated area: millions of km^2	No soil removal Deep, shallow + skim and burial ploughing Nitrogen, phosphorus and potassium fertilising	117,000 • 49,000 initially • 68,000 more when exclusion zone widened to 30 km	134 received high doses (0.8–16 Gy) • 28 died in first three months • 19 more died in 1987–2004, but not clearly associated with radiation exposure. Thousands of thyroid cancers attributable • but >98.8% non-lethal 15 fatal cancers attributable by 2011
Fukushima NPP accident, 2011	^{137}Cs: 6-20 ^{90}Sr: 0.14 ^{131}I: 520	Most polluted 3100 km^2: 1.5	Removals: • SDZ: 9.1m m^3 • ICAs: 7.9 m m^3 (+ ploughing w/o soil removal)	164,000 either permanently or temporarily	No acute effects. Due to small population exposure on average (0.5 mSv cumulative) observable stochastic health effects are unlikely

Introduction

In this paper, I will evaluate the soundness of policies designed to be applied in the aftermath of nuclear accidents, focusing particularly on soil remediation as was used in Japan after the Fukushima accident.[1] I will do this by looking at measures applied after similar historical events and by comparing the costs of soil remediation to the benefits, namely the number of cancer cases theoretically prevented.

To this end, I will briefly discuss the role of the International Commission on Radiological Protection (ICRP) in formulating the overly cautious risk management policies now adopted in Japan.[2–4]

Soviet-era accidents

There has been little public discussion of two major radiation releases that took place during the early days of the Soviet nuclear bomb programme in the 1950s.[5–9] However, they reveal a great deal about the public health effects of ionising radiation (Table 1).

The incidents are important because the releases of radioactive material were large.

- During the period 1949–1956, radioactive material – notably Strontium 90 – leaked continuously from the Mayak plutonium production facility into the Techa River.[6–9] Over many years people living in villages on its banks received large radiation doses, becoming concentrated particularly in their bone marrow.[6,8] The so-called 'source term' – the amount and type of radioactive material released – was of similar size to that seen at Chernobyl.
- The 1957 East Urals Radioactive Trace (EURT) event took place at the same facility, but this time involved the explosion of a tank containing radioactive waste.[5,8] The source term on that occasion was approximately ten times larger than at Chernobyl.

The effects of both of these releases in the population have been intensively studied by close monitoring of large samples of those affected and reconstructing, at an individual level, the radiation dose received. In both cases, solid cancers resulted at low rates. For the Techa River cohort, by 2007, there had been 50 cancer cases attributable to radiation in a fixed cohort of 29,849 people.[7] In the EURT cohort, meanwhile, by 2006 there had been 27 cancer deaths attributable to radiation in a fixed cohort of 21,427 people.[5] About 1.9–2.5% of solid cancer deaths in these cohorts were attributable to radiation.[*]

The number of radiation-induced acute leukemia cases in the Techa River cohort was around 30, with the radiation-attributable fraction almost 50%.[6,†] Almost all of the leukaemia cases (83%) had received a bone marrow dose of more than 100 milligrays (mGy), mostly through drinking water from the river. Much of the radioactive material released was Strontium 90, which is a beta emitter and has chemistry similar to calcium, which why it finds its way to the bone marrow. Bone marrow doses therefore reached up to 6.7 Sieverts (Sv) in this cohort.[8] The quantity of Strontium 90 released to the Techa River was, at 20×10^{15} Becquerels (Bq), very large – 86 times more than that released in the Fukushima Daiichi NPP accident.

The Chernobyl accident is the only Soviet-era radiological emergency that has had acute health effects or fatalities, and is also the only one that has had significant stochastic health effects – effects that are statistically detectable in the population rather than being linked by theoretical calculations.[10] It caused, for example, thousands of thyroid cancers, although it is worthy of note that these are readily treatable using a combination of radio-

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[*] For example, in a cohort of 30,000 we might assume that 6000 will eventually die from solid cancers. We might also assume that only 2000 have died so far. Then the 50 radiation-related deaths are 50/2000 = 2.5% of the total.

[†] Although the attributatble fraction is high, the number of attributable cancers is low, due to the rarity of thecondition.

iodine and surgical treatment, and thus have a survival rate of almost 99% in children and young adults.[11]

These stochastic effects were unexpected, but subsequent research has suggested possible causal factors. Firstly, the Soviet public were not told about the accident, and so many people, especially children, will have unwittingly receiving significant[‡] radioiodine doses via cows' milk.[11] The other factor was the prevalence in the affected areas of iodine deficiency, which causes chronic stimulation of the thyroid by the pituitary gland, and might thus have contributed to an increase in thyroid cancer.[12] It seems, therefore, that there were special circumstances at Chernobyl.

Soil remediation

The last section suggests that the public health effects of radiation releases to date have been rather limited. This is interesting to bear in mind as we consider what steps might be necessary to deal with soil that has been contaminated by a release of radiation.

After the Chernobyl accident, the Soviet authorities decided that topsoil removal in agricultural areas was inappropriate, 'because of its high cost, destruction of soil fertility and severe ecological problems related to burial of the contaminated soil'.[10]

However, at Fukushima Daiichi, 25 years later, a major programme of soil decontamination was launched, in an attempt to bring exposures back to below the ICRP's long-term dosimetric maximum of 1 mSv/year.[2]

Remediation measures were applied in two distinct spaces:

- areas temporarily evacuated (the Special Decontamination Zone; SDZ);
- areas of high radiation contamination (Intensive Contamination Areas; ICAs), defined as areas where external radiation levels exceeded 0.23 µSv/h.[1]

This is a very low threshold. In Finland, the background radiation level is 0.1–0.2 µSv/h. There were around 1.9 million people in the ICAs, and 1.5 million were exposed to radiation as a result of the accident. With another 90,000 in the SDZ, a total of nearly 1.6 million people was exposed.

In both areas, the decontamination activities were focused on agricultural and residential land, and several different approaches had been attempted:

- Swapping topsoil and subsoil, while adding zeolite (an absorbent mineral) and potassium.
- Ploughing with zeolite and potassium.
- Cutting weeds, and removing 5 cm of topsoil (sometimes replacing it with fresh uncontaminated topsoil). This technique was only applied in the SDZ.

The effectiveness of the techniques has subsequently been reviewed by the AMORAD project – a Franco Japanese academic consortium (see Table 2):[1]

Table 2: Effectiveness of soil remediation techniques

Technique	Effectiveness
Swapping topsoil and subsoil, adding zeolite and potassium	0.34–0.80
Ploughing with zeolite and potassium	0.21–0.50
Cutting weeds, and removing 5 cm of topsoil	0.34–0.80

A total of 20 million m^3 of topsoil was removed, mostly from agricultural land, and was then transported to long-term storage areas. By 2019, they had cost a total of €23 billion. The final cost may be much higher, because final disposal of the soil will only begin after it has been stored for 30 years.

By applying the ICRP's standard assumptions, we can estimate that this expenditure

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[‡] But rapidly decaying. The half life of ^{131}I is 7 days.

might initially have prevented 13 people[§] per year from developing fatal cancers, with gradually diminishing numbers thereafter (see Appendix).

Have lessons been learned?

With such extraordinary imbalance between the costs and benefits of soil remediation, it might be expected that national planning authorities would adopt a cautious stance towards its future use. However, this appears not to be the case.

Since 1993, the OECD's Nuclear Energy Agency (NEA) has run a series of tabletop exercises – the International Nuclear Emergency Exercises (INEX) – to help its member countries to improve preparedness for nuclear or radiological accidents. INEX-6 ran from January to March 2024, and focused on the best ways for authorities to recover once they had brought the initial crisis under control.[13]

The guidance published ahead of the exercise outlined how countries should prepare for the INEX 6 exercise and how countries should develop their plans.[14] The guidance considers in detail the challenges of dealing with overwhelming amounts of radioactive waste after a nuclear power plant accident.

The guidance urged countries to adopt proportionate policies, and advised them not to overwhelm waste management capacities, stressing the need to consider the financial consequences of radioactive management policies and choices, and to draw lessons from mistakes made after Fukushima Daiichi.

Despite this, and remarkably, given extraordinary costs involved at Fukushima, the INEX-6 guidance still includes agricultural soil removal as a remediation option.[14]

The ICRP and the precautionary principle

So we have moved from soil remediation being seen as pointless at the time of Chernobyl to it becoming a central feature of the recovery from radiation leakages, despite the costs apparently far outweighing the benefits. Why should this be? The answer appears to lie in the ICRP's adherence to the Linear No-Threshold theory, which suggests that there is no safe level of radiation beneath which no harm to humans takes place.[2]

Remarkably, despite having stuck with the LNT theory over many decades, the ICRP suggests that it is impossible to calculate the harm caused by low doses of ionising radiation:[2]

> (66) Because of this uncertainty on health effects at low doses, the Commission judges that it is not appropriate, for the purposes of public health planning, to calculate the hypothetical number of cases of cancer or heritable disease that might be associated with very small radiation doses received by large numbers of people over very long periods of time…
>
> (161) Collective effective dose is not intended as a tool for epidemiological studies, and it is inappropriate to use it in risk projections. This is because the assumptions implicit in the calculation of collective effective dose (e.g., when applying the LNT model) conceal large biological and statistical uncertainties. Specifically, the computation of cancer deaths based on collective effective doses involving trivial exposures to large populations is not reasonable and should be avoided.

Despite these admissions, the ICRP ends its subsection on 'The induction of stochastic effects' by suggesting that society should continue to act as if harms had been established:[2]

> (99) The Commission considers that the continued application of the LNT model combined with a judged value of dose and dose-rate effectiveness factor (DDREF) provides a prudent basis for practical purposes of radiological protection, i.e., the management of risks from low-dose radiation exposure in prospective situations.[11]

[§] ^{137}Cs – the most important nuclide causing exposure – has a 30-year half-life

The ICRP can only justify the apparent contradiction by invoking precaution. Its 1954 recommendations advised 'that every effort [should] be made to reduce exposures to all types of ionising radiation to the lowest possible level', and this deeply precautionary tone has been retained to the present day:[2]

> (217) Optimisation is a frame of mind, always questioning whether the best has been done in the prevailing circumstances, and whether all that is reasonable has been done to reduce doses.
>
> (218) Therefore it is not relevant to determine, a priori, a dose level below which the optimization process should stop.
>
> (287) Reference levels for existing exposure situations should be set typically in the 1 mSv to 20 mSv band of projected dose… The individuals concerned should receive general information on the exposure situation and the means of reducing their doses. In situations where individual lifestyles are key drivers of the exposures, individual monitoring or assessment as well as education and training may be important requirements. Living on contaminated land after a nuclear accident or a radiological event is a typical situation of that sort.

Why has the ICRP adopted this irrational precautionary approach to radiological emergencies and existing exposure situations? It suggests that its motivation for imposing ever more stringent reference levels was the so-called Life Span Study (LSS), a 1990s' review of the health histories of survivors of the atomic bomb detonations in Hiroshima and Nagasaki:[2]

> (8) The annual dose limit of 50 mSv for workers set in 1956, was retained until 1990, when it was further reduced to 20 mSv per year on average based on the revision of the risk for stochastic effects estimated from the life-span study of the Hiroshima–Nagasaki atomic bomb survivors (ICRP, 1991b). The annual dose limit of 5 mSv for members of the public was reduced to 1 mSv per year on average in the Commission's 'Paris statement' (ICRP, 1985b) and in Publication 60 (ICRP, 1991b) the dose limit was given as 1 mSv in a year with the possibility of averaging over 5 years 'in special circumstances'.

In practice, the ICRP reference level of 20 mSv per year has become the threshold for population evacuations in the guidelines or even legislation in many countries. However, this is irrational. In Finland, where I live, between 100,000 and 200,000 people receive higher doses every year. Hundreds if not thousands of people receive doses of *hundreds* of millisieverts from radon exposure every year. Many people evacuated from Fukushima remain unable to return home due to government-mandated restrictions imposed as a result of conservative radiation exposure criteria. The evacuations themselves caused 2313 premature deaths, with 90% of them in people aged 66 and older.

However, the LSS study appears to be fatally flawed. In 2017, *The Journal of Radiation Research* published an English-language translation of an astonishing epidemiological study that had appeared in 1957 in Japanese, but which had subsequently been forgotten.[15] The study revealed the non-lethal but acute health effects of the 'Black Rain', the intense precipitation – darkened by the presence of radioactive soot and other particulates – that hit both Hiroshima and Nagasaki soon after the bombings. The Black Rain delivered high doses of radiation to the survivors, but critically, this was never taken into account in the study. The abstract of the study set out the implications:

> This means that (i) some of those who entered Hiroshima in the early days after the blast could be regarded as indirect hibakusha [the term referring to those affected by the bomb]; (ii) 'in-the-city-control' people in the…LSS must have been irradiated more or less from residual radiation and could not function properly as the negative control; (iii) exposure doses of hibakusha were largely underestimated; and (iv) cancer risk in the LSS was largely overestimated.

In summary then, the ICRP adopted an unsupported scientific theory (LNT) and an irrational philosophy (the precautionary principle), with the result that deeply damaging measures, such as soil remediation, are deemed necessary.

Conclusions

In the current guidelines, the ICRP makes the following admission:[2]

> (224) ... while this report should be seen as providing decision-aiding recommendations mainly based on scientific considerations on radiological protection, the Commission's advice will be expected to serve as an input to a final (usually wider) decision-making process, which may include other societal concerns and ethical aspects, as well as considerations of transparency.

In other words, planning for recovery from radiological accidents will now encompass 'societal concerns and ethical aspects' – euphemisms for radiation phobia – as well as (or perhaps instead of) science and rationality.

The ICRP – an institution without any democratic oversight – has enormous power; almost all its recommendations are simply copied into national legislation or, in the EU, into directives. But it has used its power, not to counter radiation phobia, but to foster irrationality, through its extreme precautionary approach. The resulting burden of compliance has led to high energy costs, has stalled nuclear energy construction, hindered scientific development and the use of radiation in healthcare, and is now leading to foolish and costly interventions in radiological emergencies.

Appendix

According to a recent extensive review of the remedial actions taken after Fukushima, the collective dose avoided in the Intensive Contamination Areas (ICAs) was around 1000 manSv* and in the Special Decontamination Zones (SDZs) 1666 manSv.[1]

According to the LNT model, if a person receives 1 Sv (effective dose), their fatal cancer risk is increased by 5%. As the cumulative baseline risk for a fatal cancer in Japan is 25%,[16] someone who receives a 1-Sv radiation dose sees their cancer risk rise to 30% on average.

In the ICAs

If a 1.5 million population avoids a 1000 manSv collective dose, the individual dose avoided is on average 0.00067 Sv, or 0.067 mSv. Using the LNT model, the number of fatal excess-cancer cases in an irradiated population is:[17]

> …the number of persons exposed multiplied by the effective dose (mSv or rem) per person multiplied by the excess relative risk (/mSv). A widely cited excess relative risk…value is that recommended by [the US National Council on Radiation Protection and Measurements] report, 5×10^{-5} per person per mSv.

Thus the initial annual number of fatal cancers prevented by soil remediation in the ICAs can be calculated as:

$$1{,}500{,}000 \times 0.067\,\text{mSv} \times 0.00005 = 5$$

The number gradually reduces over time.† Soil remediation costs so far have been €11 billion euros in the ICAs.

In the SDZ

If a 90,000 population avoids a 1666 manSv collective dose, the individual dose avoided is on average is 0.018 Sv, or 1.8 mSv. Thus the annual number of fatal cancers prevented by soil remediation in the SDZ is:

$$90{,}000 \times 1.8\,\text{mSv} \times 0.00005 = 8$$

As in the previous subsection, this is the initial figure; it declines gradually after the first year. Soil remediation costs in the SDZ so far have been €12 billion.

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* The SI unit for collective dose is the man-Sievert (manSV).

† ^{137}Cs, the most important nuclide causing exposure, has a 30-year half-life.

Notes

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