APR/R - 30

BIOLOGICAL HAZARDS OF RADIOACTIVITY AND THE BIOLOGICAL CONSEQUENCES OF RADIONUCLIDE EMISSIONS FROM ROUTINE OPERATION OF NUCLEAR POWER REACTORS

2nd edition

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BIOLOGICAL HAZARDS OF RADIOACTIVITY

The preliminary draft of this review was compiled for the 8th Congress of Israeli Ecological Society, Tel-Aviv, 1977, at the request of the Technion Center of Ecological Engineering Research. It served as a basis for a lecture on the biological consequences of radionuclide emissions during routine operation of nuclear power reactors, delivered on May 30th at the Congress. I was encouraged by the Session Chairman at the Congress, to enlarge the scope of the lecture into a wider review of the issue. As a result, the present work was prepared. Its publication was assisted by the Research Institute for Environmental Health, Tel-Aviv University, Tel-Aviv.

I would like to thank Prof. A. Donagi, Director of the institute and his staff for their assistance.

Tel-Aviv, October 9, 1977

G. Stendig - Lindberg MD LRCPI, research fellow, Karolinska Institute, Stockholm.

BIOLOGICAL HAZARDS OF RADIOACTIVITY

AND

THE BIOLOGICAL CONSEQUENCES OF RADIONUCLIDE EMISSIONS FROM ROUTINE OPERATION OF NUCLEAR POWER REACTORS

A. Biological effects of radiation.

1. Radiation effects at the cellular level

To the best of our knowledge, biological effects will follow radiation, however small its amount[20]. The living cell will be either killed by irradiation, prevented from dividing, or its genetic material will be damaged.

On microscopy, profound changes are seen in the morphology of the cell. The number of chromosomal aberrations of the lymphocyte (a white cell consituent of the blood) e.g., is employed, as one of the indices of the degree of radiation damage.

Considering the exquisite biochemical intricacy of the human organism, it may be well understood that profound multiple metabolic changes will follow irradiation. The precise mechanisms are at present ill understood. This renders measurements of the degree of radiation damage by means of biochemical dosimetry a difficult task[8, 28].

2. Radiosensitivity

The most radiosensitive tissues are the growing, and dividing tissues. The embryo and the infant is highly radiosensitive. Children up to the age of 18 require special provisions to ensure low radiation exposures[9c, 12]. The same applies to pregnant women. These groups which are very sensitive to radiation, constitute examples of the critical groups. Examples of tissues which are extremely radiosensitive, are the reproductive organs (the gonads) and the bone marrow. Consequently, they tolerate much lower radiation doses than e.g., hands and feet, and are called the critical organs.

Certain tissues may be particulary sensitive to a certain radionuclide. For hard β radiation*, the bone marrow is the critical organ, wheras in the case of e.g., the radioactive Iodine, which accumulates in the thyroid, the thyroid gland is the critical organ. Each of the radionuclides differs in its radiotoxicity to man or his environment (cf.D.11.).

3. The units of measurement of radioactivity

These are summarized on Table 1. The quality factors of the radioactive emissions are given on Table 2.

4. Internal radiation

Some normal constituents of human body are radioactive, as well as man's natural background (Table 3). This internal radiation shows steady increases, as we incorporate increasingly higher doses of the radionuclides from the environment (Table 4).

B. The radionuclides

5. Some characteristics of radionuclides (radioisotopes)

The radioactivity of a substance can not be influenced by man. It is cumulative and irreversible. The spontaneous disintegration (decay) of the radioactive substance is measured in half-life; that is the time in which the number of radioactive atoms will decrease to half its value, and when the amount of emitted radiation will also be halved. With each interval of a half-life, it will be further reduced by a half from its previous level.

Uranium - 238 has a half-life of 4.5 billion years, a time comparable to the age of the earth. Its decay daughters are radioactive, as well. The decay chain of Uranium-238 begins with Thorium - 234, Radium - 226, Radon, Polonium; the final member of the decay chain is Lead - 206, which is a stable element. It follows that even in case of a radionuclide of a short half-life, the radioactivity will not necessarily decrease with time but may rise again, due to the radioactive contribution of its decay daughters. Thus, the biological hazards may not diminish with time but actually increase.

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*) mean energies over 0.4 MeV.

We can take as an example Americium-242m (half-life 152 years), an element created by man in the nuclear reactor. Its decay daughters are Americium 242 (half-life 16 hrs.), Curium - 242 (half-life 163 days), Plutonium - 238 (half-life 87 years), Uranium - 234 (half-life 247,000 years), Thorium - 230 (half-life 78,000 years) and Radium - 226 (half-life 1602 years). Furtheremore, the fact that a given isotope has a short half-life does not make it "safer" to man, because the intensity of the emitted radiation is often inversly proportional to its half-life, so that the radionuclides with the "short life time" may be more intensly radioactive, and consequently more radiotoxic, on exposure.

C. Man-made radiation

6. The radionuclides currently released from nuclear power plants/ installations.

The radioactive substances emitted from nuclear power installations are listed on Tables 5 and 6.

7. Estimates of release of radionuclides from nuclear power stations

According to the data presented at the IAEA and AEC Symposium, 1970[30] and Wright[29], the annual total body radiation dose from one Westinghouse nuclear reactor (1000 MW (e)), at the boundary site, is 5 mrem for air releases and 0.2 mrem for water releases, at the design basis (i.e. assuming that the reactor fuel has defects that release 1% of the fission products, and as regards gaseous discharges, in addition, a 45-day hold up of all gaseous activity to eliminate short-lived radioactive isotopes). The radiation exposure from multiple nuclear plant sites, for the zones of overlapping radiation, is not given.

ANS, 1976[2] reports as regards air releases that "small amounts are discharged to the atmosphere in accordance with applicable regulations". The latter "ensure that the exposure of a person sitting on a fence at the site boundary of a nuclear plant 24 hours a day, 365 days a year, will be less than 5 mrem; the average neighbor of the plant will receive less than 1 mrem annually". Concerning water releases, the U.S Nuclear Regulatory Commission safeguards "ensure that the exposure of an individual in an unrestricted area from discharged liquids is no more than 3 mrem per year". Here, reference is made to a table of liquid radioactivity levels: for a typical nuclear power plant 1-10 picocuries/liter. The type of radionuclides contained, their respective quantities and the volume of the effluent, is not specified. Parts of the ANS data[2] are contained in the publication of the Israeli Atomic Energy Commission, 1975[18].

D. Radiation induced health detriment to man

8. The gross clinical effects of sublethal doses

The gross clinical effects of sublethal irradiation doses are shown on Table 7. The clinical effects are divided into immediate and late, somatic and genetic.

9. Late somatic effects

Various forms of cancer are the major known late hazards. One early study which showed dependence of incidence of leukaemia following X-ray exposures (> 250 rem) was that of Court-Brown and Doll (1957)[4].

In 1972, UNSCEAR and BEIR reports[27,1] reviewed the knowledge of the late effects of ionizing radiation. The present estimate of cancer risk is 1:10.000 (0.1 $^{0}/_{00}$) death in radiation induced cancer per 1 rad of exposure[11]. These estimates may change in the future, because cancer has a long latency period.

Other serious hazards are thyroiditis (thyroid storm), loss of immunity and sterility. Furthermore, more knowledge may be gained in the future about less dramatic but incapacitating health effects following irradiation which I call here "ill defined health detriment" (Table 7).

The study of late somatic effects is difficult because of their extreme complexity caused by 1) the multitude of the radionuclides to be studied in relation to one or several target organs,2) the limitations in extrapolating experimental animal data to man and 3) the difficulty of interpreting epidemiological data.

10. Genetic effects

Already in 1958, the UNSCEAR report[20] emphasized that there is no known treshold of radiation exposure below which genetic damage does not occur, and that the mutational effect of a given dose is independent of its rate of delivery. The effect is cumulative, irreversible and proportional to the absorbed dose in the relevant tissue.

Consequently, UNSCEAR (1958)[20], as well as ICRP*,1966, recommended, therefore, "that exposure to radioactive radiation should be reduced wherever possible, and that the medical and industrial precedures

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* International Commission on Radiological Protection.

tending to increase radiation levels to which human population might be exposed should be carefully weighed as to such benefits or hazards as each may have".

Stewart et.al, 1958[24] showed that children of mothers who had received a series of 3-5 pelvic X-rays during pregnancy, were almost twice as likely to develop leukaemia and other cancer before reaching the age of 10, than children of mothers not exposed to X-ray. The study had a bearing on "small" exposures of a critical group of the magnitude of only 0.6 - 1.5 rem. This study was followed by others (15, 23, 25).

The present risk estimate is that a dose of 1 rad per generation (= 30 years) will cause an increase of serious hereditary defects of 0.5% in the first offspring generation and this effect will on average be sustained for perhaps 20 generations and if each generation continues to be exposed, 1% increase in genetic injuries is predicted[11].

The normally occuring rate of severe hereditary defects is 3% per each cohort of offsprings. It is of interest to note that UNSCEAR 1958[20] prediction, based on a broader classification of hereditary defects of 4% in a population, predicted a rise of between > 1% and < 4% hereditary defects, i.e. from 5 - 8%. In a 5 milliard population with an exposure of 1 rad per generation this implies 250.000 to 10.000.000 genetic injuries in each generation resulting from each rad of irradiation from any source, affecting the whole population.

In addition, the genetic control of variation of human characteristics, with effect on life-span, birth weight, stature and intelligence (the biometrical characters) depending on multifactorial genetic causes (the "multifactorial disorders", see Table 7) may be affected detrimentally by radiation. In mice e.g., following fast neutron irradiation, a decrease of life span was observed in the immediate offspring.

The personal suffering, the social burden and the jeopardy to the species implied by the mutational effects outlined, call for the deepest concern and caution.

Whereas it was believed that variation in the natural background radiation in various localities does not necessarily have a bearing on the local genetic mutation rate, Kochupillai, 1976[10] showed, that in Kerala, south India, where the background natural radiation is 0.1 - 2.8 rem per year (mean 1.2 rem[20]) due to the monazite sand, the incidence of severe mental retardation, as well as of chromosome aberrations was higher in children of native mothers. This, particularly in mothers over the age of 30, who would have received a higher dose equivalent of background radiation.

11. Radiotoxicity of plutonium

Plutonium is exceedingly toxic, 5 times as toxic as Radium. It has 16 known isotopes. It can be inhaled, ingested, or translocated from a contaminated open wound. Plutonium is the radionuclide which was most extentively studied (0.3 - 0.5 million curies of Plutonium has been uniformly distributed on earth as a result of weapon tests[3]; 2 picocuries was the avarage dose found in man on autopsies during 1965 - 1966[16]).

Maximum permissible body burden (MPBB) for Plutonium

The annual dose limit, accumulated at a constant rate (for Radium - 226 it is 0.1 /uCi) differs for lung and bone tissue.

Plutonium effects on lung tissue

The "maximum permissible lung burden" (MPLB) of 0.016 /uCi or 0.25 /ug, was arrived at by averaging the dose from inhaled Plutonim over the whole lung mass to give a dose equivalent of 15 rem/year per radiation worker. Radiation workers were recommended to receive radiation doses not exceeding ten times the dose to the general public[9], Table 8. For current recommended annual dose equivalent limits see ICRP (1977) safeguards[9c], Table 8a; p 23a, b.

The issue debated, fairly recently, was, that small particles of insoluble Plutonium ("hot particles") may lodge in the lungs and irradiate their immediate surrounding, proving much more carcinogenic than if the same amount were distributed evenly throughout the lung[26,14]. These findings were repudiated[5,17]. Gofman, 1975[7] claims, nonetheless, that cancer risk from inhaled Plutonium might be much greater than previously believed. Regardless

of the controversies around the cited findings, the review of Bair and Thompson (1974)[3], members of ICRP and NCRP (National Council Radiation Protection), clearly indicates that the mean dose to a tissue may be less important, than the dose to localized regions within the tissue (see also Sanders, 1972[22]), and that Plutonium may be engulfed by the alveolar epithelial cells, transported to pulmonary lymph nodes or incorporated in fibrotic tissue. The distribution of Plutonium in the lung tissue is, thus, nonuniform.

Bair and Thompson[3] predict that Plutonium exposure limits will be changed towards tightened control within the next few years, although the change will probably not be large.

The Royal Commission on Environmental Polution, 1976[21] states: "We appreciate that if it were true that "hot particles" represent an additional hazard, this would have profound implications for our study, because it might require a reduction in exposure to Plutonium to levels that would be difficult to detect and control and effectively preclude the use of nuclear power. But, The ICRP (1977)[9c] states: "The Commission believes that the hazard of particulate material in the lung is likely to be less than that of the same material distributed uniformly throughout the lung".

Plutonium effects on bone tissue

It is established in the experimental animal that Plutonium accumulates in the marrow of the bone, as well as on the bone surfaces, with subsequent development of osteosarcoma. Plutonium also translocates into the bone marrow. ICRP, 1972[9a], introduced, therefore, a factor by which the quality factor for α emission is multiplied. Consequently, 1 rad of radiation dose from Plutonium, absorbed by bone tissue, is equivalent to 50 rem. This to compensate for the nonuniform distribution of the radionuclide in bone[3].

The projected number of cumulative health effects attributable to the release of Plutonium, as well as of other actinides*, from the application of the nuclear power industry are given on Table 9 (EPA, 1974[6]).

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*) Elements following Actinium in the periodic table.

12. The projected health detriments of Iodine-129, Tritium (H^3) and Krypton - 85

These are given on Table 9. These emissions are currently not controlled (EPA, 1974[6]). For Krypton - 85, control methods with a decontamination factor of 1000 have been proposed, but are not currently applied in the nuclear power industry. With current praxis, the projected health effects for Krypton - 85, based on the calculation of the global dose commitment, see below, (Lindell, 1976[11,12,13]), but for next 100 years only, will cause 230 apparent health effects (late somatic effects) up to year 2000. It will give another 760 health effects, apparent first after year 2000 but due to irradiation received prior to year 2000. The operations through year 2020 would result in potential world wide impact of 7000 health effects due to this single gaseous radionuclide emission (Table 9; EPA, 1974[6]).

E. Radiation Protection

13. What treatment is there at our disposal to counter radiation?

Medication with Tablets of 0.2g Potassium Iodine used to protect the thyroid gland in cases of known exposures to radioactive Iodine (to load the gland with stable Iodine and prevent uptake of the radio-iodine) is the only routinely used specific treatment. In Plutonium intoxication, diethylenetriaminepentaacetic acid (DTPA) can be administered. It forms a chelate with Plutonium which is then excreted in the urine. The optimal result reported is 50% Plutonium excretion, only. Inhaled, insoluble Plutonium is not effectively mobilized by DTPA[3]. Otherwise, apart from recommendation to excise tissue arround wounds contaminated by radioactive material, the medical treatment of irradiation damage is purely symptomatic. The only route of action left, is to protect ourselves from exposure.

14. Earlier attempts to control releases

In 1971, AEC* published a proposal of guides for objectives and limiting conditions for light water reactors which would seem to make it possible to limit the annual whole-body dose of the most highly

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*) Atomic Energy Commission.

exposed individual or a critical group, to < 5 mrem, provided that efficient equipment was put into operation in the future for retaining radionuclides as long as practicable and that the releases to environment would be avoided.

BEIR[1] set the aim of average doses of exposure of <1 mrem/year per caput of U.S.A. population from nuclear industry. This, providing, that control of sabotage and diversion, avoidance of catastrophies, accidents, adequate control of radioactive wastes and attainment of long term maintenance of anticipated engineering performance, could be achieved.

In 1970, task groups were established in Stockholm to work on a joint Nordic report which was published in 1976 by the Nordic Radiation Protection Institutes of Denmark, Finland, Iceland, Norway and Sweden[11]. Its recommendations state that it should be possible in the future to apply devices for controlling the radioactivity of liquid effluent, which must not exceed 5 mrem/year, but the gaseous discharges are more difficult to control. As regards the operative limits; if the exposure caused by releases from a nuclear power installation (both air and water) should exceed 50 mrem whole body exposure of the critical group in one year (10% of the maximum ICRP annual dose limit), the national authority shall consider whether the operation should be stopped, the ICRP dose limits being unconditional action level for cutting down the operation (§ 19:46;[11]). These limitations are based on the ICRP principle of operative limits "as low as reasonably achievable". However, the future limiting value should be smaller than 50 mrem operative limit, because the current concepts wish to take into consideration long term effects.

15. The new concepts in radiation protection

The ultimate goal of radiation protection is the evaluation of the detriment of the collective dose to the world population. This is needed as an element in the consideration of the justification of nuclear power in comparison with other sources. For this purpose,

the global collective dose commitment per unit practice has to be calculated, Lindell[11], (see below).

The other purpose is to estimate the maximum future per caput dose to the world population due to the widespread contamination with long-lived radionuclides, that is; the future maximum per caput annual dose per MW (e)).

The infinite time integral of the average dose rate in a given population due to a specified action, decision, operation or practice is the dose commitment. This may be an infinite time integral of the collective dose rate to a specified population; collective dose commitment, or to the world population; global dose commitment, or to 1 reference man; dose rate integrated over 50 years. It is a measure of the total detriment to health per unit practice and it is measured in manrad, if referring to absorbed dose, or in manrem if referring to dose equivalent.

To assess the future maximum annual per caput dose ($D_{1\infty}$) in a given population (n) under future steady state conditions the collective dose commitment per one year practice (Sc_1) is divided by the population number (n) (provided that n remains constant): $D_{1\infty} = \frac{Sc_1}{n}$ (11).

These new concepts enter into the assessment of exposure of the new Recommendations of the International Commission on Radiological Protection (ICRP, 1977)[9c].

16. The recommended limitations of releases from nuclear installations based on new concepts

Based on above concepts, the future annual global per caput dose from nuclear power operations should never exceed 10 mrem (§19:28[11]), Table 10. This is 10% of the annual dose from natural background radiation. The contribution from nuclear power to the genetic dose would then be 0.3 rem per generation.

According to present assessments, releases from reprocessing plants can be expected to contribute 0.3 - 0.5 manrem per installed MW (e) and year of operation of light water reactors. This does not include contribution from Carbon - 14 and long lived radionuclides. 0.1 manrem is the expected contribution from Uranium mines[11]. It is proposed in

Scandinavia that not more than 0.5 manrem per MW (e)/year be applied to releases from the nuclear power stations[11]. The global collective dose rate (integral over 500 years) from the operation of light water reactors has been assessed to be at present about 2.5 manrem per MW (e)/year (whole-body dose) from Carbon-14 and 0.02 manrem (thyroid dose) per MW(e)/year from Iodine - 129. The global collective dose commitment is thus 5 times higher for Carbon-14 and very much higher for Iodine - 129, than recommended.

17. The costs implied in trying to limit radioactive releases

The 1976 estimate[11,12,13] was, that reduction of releases from nuclear power plants costs $ 1.000 per 1 manrem.

18. Design of environmental survey of radioactive releases

Current recommendations envisage studies of the emissions outside of the boundry of a nuclear installation requiring ingathering of all information on all the relevant factors:

1) The estimate of potential hazard, the activity, physical property and the method and route of release of all emitted radionuclides and the expected contribution of nuclides from external sources. 2) The behaviour of the nuclides in the environment and the natural features of the environment which will affect the behaviour of released nuclides e.g., topography, pedology, geology, hydrology, hydrography, and vegetative cover. 3) Man-made features of the environment have to be surveyed; reservoirs, regulated streams, rivers, harbour installations, the utilization of the area for agriculture, fisheries, water and food supplies, industry and recreation. Finally, the population distribution and habits have to be studied[11].

This will enable to identify the critical nuclides, their pathways and the critical groups (e.g. the fence group, or a group drinking undiluted effluent) in order to evaluate the expected irradiation dose to the critical groups of the population[11].

In this context, in the case of Israel, and the Middle East area, there are at least two factors of particular importance to consider

(apart from such, as war and sabotage risk, lack of area for placing nuclear power installations at a safe distance from densly populated areas). These are 1) The seismological vulnerability of the region 2) The climate. The effect of heat, "hamsins", and desert winds carrying sand particles requires very serious studies, since e.g. the direct effect of ionizing radiation varies with the temperature (lowest at low temperatures)[29], it is also possible that air contamination by any source, and in particular by sand particles may act as a reservoir of radioactivity.

20. Concluding remarks

The recommendations quoted carlier, which try to provide a minimum forseeable safeguard to man against irreversible future health detriment will need political and economical backing, which will only grow from serious attempts to gain full understanding of the gravity of the problem.

A review of the justification of nuclear power is the most urgent issue confronting man.

The scientific evidence, already available, however imperfect it may be, presents us with a picture of a prospect of disruption of our external and internal environment.

Consequently, the issue is no longer a scientific but a moral one. The question really confronting us is: are we on moral grounds justified to use nuclear power? Is the already envisaged detriment to health outweighed by any vital need? To find the right answer we have to integrate the index of humanity into our study and seek understanding across the dividing barriers of varied reference frames.

The moral responsibility for the future has to be shouldered by each one of us and each one of us is compelled by the hour to take a stand now.

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TABLE 1

UNITS OF MEASUREMENT OF RADIOACTIVITY

curie, Ci[1] = unit of radioactivity (= 37 billion dps*)

röntgen, R (= 2.58 x 10^4 coulomb/kg) = unit of x and γ - ray (photon) exposure; the exposure = the sum of - or + electrical charges made free in air by secondary electrons produced per unit mass of air by primary photons.

0.87 röntgen = 1 rad.

rad[2] = the unit of absorbed radiation dose = 0.01 joule/kg.

rem[3] (dose equivalent unit) = the unit of effective radiation absorbed by living tissue = the product of rad x Q (Quality factor) x N**).

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*) dps = disintegrations per second.

**) modifying factor[11]; the ICRP at present assigns the value of 1 to N.

It is recommended that in future the above units should be replaced by the following SI units:

1) 1 becquerel (Bq) = s^{-1} (= $\frac{1}{37\,000\,000\,000}$ curie)

2) 1 gray (Gy) = 1 joule/kg (= 100 rad)

3) 1 sievert (Sv) = 100 rem

Table 2

RECOMMENDED VALUES OF QUALITY FACTOR (Q)[9c]

EMISSIONS	QUALITY FACTOR (Q)
X-rays, γ rays and electrons	1
Neutrons*, protons and singly-charged particles of rest mass greater than one atomic mass unit of unknown energy	10
α particles and multiply-charged particles (and particles of unknown charge), of unknown energy	20

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* Q is defined as a function of the collision stopping power (L_∞) in water at the point of interest.

** In the case of thermal neutrons the L_∞ is uniquely defined, and Q may be taken from the tables and diagrams which present Q as a function of neutron energy (ICRP, 1973[9b]), giving Q = 2.3 for thermal neutrons.

TABLE 3

1958: ANNUAL DOSES FROM NATURAL RADIATION SOURCES (IN MREM)[20]

	GONAD DOSE (GENETICALLY SIGNIFICANT DOSE)	MEAN BONE MARROW DOSE
EXTERNAL		
Cosmic rays	28	28
Terrestrial radiation	47	47
Atmospheric radiation	2	2
	77	77
INTERNAL		
K - 40	19	11
C - 14	1.6	1.6
Radon, Thoron	2	2
Radium (taken up from environment)	-	0.5
	22.6	15.1
TOTAL	99.6	92.2

TABLE 4

1976: ANNUAL DOSES OF RADIOACTIVITY (U.K.)
Received by an average member of the public[19].

SOURCE	GENTICALLY SIGNIFICANT DOSE (MREM)	BONE MARROW DOSE (MREM)
Naturally occuring:		
Cosmic rays	33	33
From soil and airborne	44	44
Internal (mainly K_{40})	28	24
	105	101
Man made:		
Medical, diagnostic X-rays	14	32
Medical radiotherapy	5	12
Medical, radioisotope use	0.2	2
	19	46
Fallout from bomb tests	4	6
Occupational doses	0.3	0.4
Nuclear power industry	0.2	0.25
Other activity releases	0.3	0.3
	5	7
TOTAL	129	154

TABLE 5

RELEASES FROM NUCLEAR POWER REACTORS/INSTALLATIONS

GASEOUS WASTE:

"The actual discharges are not published"(21)

- Iodine - 131 H.L.[x] 8 days → Inhalation; → Ingestion via milk → Thyroid gland
- Iodine - 129 — H.L. 16 000 000 years
- Argon - 41 — H.L. 110 minutes
- Tritium (H^3) — H.L. 12.3 years
- Carbon - 14 — H.L. 5730 years
- Krypton - 85 — H.L. ~ 10 years
- Xenon - 133
- Plutonium Oxide (PuO_2)

LIQUID WASTE:

In oil and water effluents

- Ruthenium - 106
- Strontium - 90 H.L. 29 years
- Cerium - 144

} Reconcentrated in food

- Plutonium 238, 239, 240, 241, 242
- Americium 241, 242, 243
- Other actinides
- Corrosion products*

SOLID WASTE: LOW LEVEL

- Tritium (H^3)
- Carbon - 14

INTERMEDIATE LEVEL

- Strontium - 90
- Caesium - 137 H.L. 30 years

} Reconcentrated in fish

- Cobalt - 60 H.L. 5 years

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* RADIOACTIVE CORROSION PRODUCTS

- Cobalt - 60 H.L. 5 years
- Zinc - 65 H.L. 245 days
- Iron - 59 H.L. 45 days

x) H.L. = half life.

TABLE 6

Some HIGH LEVEL WASTES of nuclear reactors to be forever contained against release to environment.

DECAY DAUGHTERS			HALF - LIFE	
	PLUTONIUM	- 238	87	years
		- 239	24.400	years
Uranium		- 240	6.600	"
Americium		- 241	14.3	"
		- 242	387.000	"
	AMERICIUM	- 241	433	"
		- 242	16	hours
Neptunium		- 242 m	152	years
Curium		- 243	7.370	"
Americium				
	CURIUM	- 242	163	"
		- 243	32	"
Plutonium		- 244	18	"

TABLE 7

ACUTE RADIATION EFFECTS OF SUBLETHAL DOSES ADULT

EARLY EFFECTS, ADULT:

Gastrointestinal tract symptoms
Thyroiditis (thyroid storm) } (caused by I_{131} exposure)
Hypothyroidism } " " " "
Respiratory impairment
Immunological impairment
Sterility
Cataracts (neutron irradiation)
Skin symptoms, loss of hair

INTRAUTERINE IRRADIATION EFFECTS:

Prenatal death
Neonatal death
Congenital malformations } of surviving offspring
Growth retardation }

LATE EFFECTS OF IRRADIATION:

SOMATIC
- Latent cancer fatalities (e.g. Leukaemia, Osteosarcoma, Lung cancer, Thyroid nodules, Thyroid cancer)

GENETIC
- Genetic disorders (caused by increased mutation rate):
  - Single-gene disorders
  - Chromosome- disorders → Spontaneous abortion, Sterile offspring
  - Multifactorial disorders

Ill-defined health detriment

TABLE 8

ICRP RECOMMENDATIONS OF MAXIMUM ALLOWABLE ANNUAL DOSE EQUIVALENTS, PUBLISHED 1966

(1) FOR RADIATION WORKERS TARGET		(2) MEMBERS OF THE PUBLIC DOSE; rem	
Whole body, Bone marrow, Gonads	5	0.5	
Skin and bone[x], Thyroid gland	30[x]	3[x]	(Bone of children: 1.5 for β radiation.)
Thyroid of children	$\leq$16	1.5	
Hands and forearms, Feet and ankles	75	7.5	
Other single organs	15	1.5	

[x] Scandinavian currently recommended dose limit: 15 rem for β radiation (marrow and endostium). For α radiation: calculation of concentration permitted - of source substance - based on comparison with 0.1 μc Radium - 226, with endosteal tissue as critical target (11).

TABLE 8a: RECOMMENDED ANNUAL DOSE-EQUIVALENT LIMITS IN RADIATION WORK (ICRP, 1977[9c])

FOR STOCHASTIC EFFECTS*					FOR NON-STOCHASTIC EFFECTS**
Tissue	Maximum dose limit in rem when only one organ is irradiated***	Mortality risk per 100 rem (1 Sievert; 1 Sv)	Mortality risk/100 rem (1 Sv) expressed in %	W_T***	
Gonads	20	0.004	0.4	0.25	50 rem (0.5 Sv)
Breast	33	0.0025	0.25	0.15	per year, to all tissues,
Red Bone Marrow	42	0.002	0.2	0.12	except the lens of the
Lung	42	0.002	0.2	0.12	eye for which the recommended
Thyroid	167	0.0005	0.05	0.03	limit is 30 rem.
Bone Surface	167	0.0005	0.05	0.03	
Remainder****	17	0.005	0.5	0.30	
Whole body dose equivalent limits remain as on Table 8*****					

* Stochastic effects are those for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose, without treshold, e.g.; hereditary effects and carcinogenesis.

** Non-stochastic effects are those for which the severity of the effect varies with the dose, and for which a treshold may therefore occur, e.g.; a cataract of the lens, non-malignant damage to the skin, cell depletion in the bone marrow, gonadal cell damage leading to impairment of fertility, damage to blood vessels or connective tissue.

For explanation of*** **** and***** see continuation on p. 23b.

Footnote to Table 8a Continued

*** For stochastic effects the Commision's recommended dose limitation is based on the principle that the risk should be equal whether the whole body is irradiated uniformly or whether there is non-uniform irradiation. This condition will be met if $\sum_T W_T H_T \leq H_{wb,L}$ (W_T is a weighting factor, representing the proportion of the stochastic risk resulting from tissue (T) to the total risk, when the whole body is irradiated uniformly, H_T is the annual dose-equivalent in tissue (T), $H_{wb,L}$, is the recommended annual dose-equivalent limit for uniform irradiation of the whole body, namely 5 rem (50 mSv)).

**** The Commission recommends that a value of W_T 0.06 is applicable to each one of five organs or tissues of the remainder (e.g., stomach, small intestine, upper large intestine, lower large intestine, salivary glands, liver, etc.) receiving the highest dose equivalents, and that the exposure of all other remaining tissues can be neglected (W_T 0.30 = W_T 0.06 x 5_T).

***** This is an upper limit and the doses should be kept as low as practically achievable. At the maximum allowable dose limit, the mortality risk factor is $\sim$ 0.014 - 0.02 / Sv (1.4 - 2% / 1 Sv). This is an avarage for both sexes and all ages compounded from a) the total risk of mortality from radiation induced cancer as a result of uniform whole body irradiation and b) the risk for serious hereditary effects in the next two generations. This means 140 - 200 fatalities per 1.000.000 humans / 1 rem of whole body irradiation and correspondingly, 700 - 1000 per 1.000.000 humans / 5 rem of annual whole body irradiation. In comparison, an average occupational death rate carries the risk of 0.01 %, i.e.100 annual death per 1.000.000 workers. This is equivalent to the risk caused by an average annual whole body irradiation dose of 0.5 - 0.7 rem.

TABLE 9

PROJECTED NUMBER OF CUMULATIVE HEALTH EFFECTS ATTRIBUTABLE TO RELEASE OF 4 RADIONUCLIDES BY NORMAL OPERATION OF THE NUCLEAR POWER INDUSTRY(6)

Year	Iodine - 129		Tritium (H^3)		Krypton - 85		Actinides*	
	Past	Future	Past	Future	Past	Future	Past	Future
1970	0	0	0	0	0	0	0	0
1975	0	0	2	0.5	0.3	5	2	26
1980	0	1	11	3	3	26	12	140
1985	1	4	35	8	14	79	38	440
1990	3	9	88	21	42	190	96	1190
1995	6	17	190	43	110	410	210	2200
2000	11	32	360	81	230	760	400	3900
2005	21	53	630	140	460	1300	[illegible]	6500
2010	34	82	1000	230	830	2100	1200	10,000
2015	53	120	1600	340	1400	3200	1900	15,000
2020	78	170	2300	500	2300	4600	2800	21,000
	1/4 fatal		2/3 fatal		2/3 fatal		All fatal	

Based on assumption that controls will be used to reduce Kr-85 by a factor of 1000 & Tritium by a factor of 100

*Their eventual impact over many centuries may be many times that of next 100 years.

TABLE 10

SCANDINAVIAN RECOMMENDATIONS
OF MAXIMUM PERMISSIBLE ANNUAL RADIATION CONTRIBUTIONS*

Source of contribution	Annual genetically significant dose
Occupational exposure	10 mrem
Consumer products, outstanding benefit	10 mrem
Consumer products, low benefit	2 mrem
Environmental contamination:	
1. Nuclear power plant releases	10 mrem
2. Other activity releases	5 mrem
T O T A L	< 40 mrem

* § 4:57; Lindell, 1976[11]

The actual doses should be considerably lower[9,9c].