IONIZING RADIATION: LEVELS AND EFFECTS

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Annex D

MISCELLANEOUS SOURCES OF IONIZING RADIATION

CONTENTS

Introduction

1. The general population may be exposed to a wide variety of miscellaneous sources of ionizing radiation. These sources can be classified in two categories. The first category includes sources intended for industrial, medical, military or research purposes which, as a result of transportation accident, loss, theft, incorrect use or disposal may escape control and find their way to the public at large, or contaminate the environment. The second category consists of products containing natural or man-made radio-nuclides nominally sealed and which can be acquired by the general public, referred to in this annex as consumer products.

I. Radiation sources not normally available to the general public

2. About 100 transportation incidents involving radio-active material have been reported throughout the world from 1954 to 1968 (58, 60). Fourteen accidents involved aircraft carrying nuclear weapons or components of nuclear weapons (58). Two of those accidents, which resulted in appreciable contamination of the environment, are discussed in annex A (paragraphs 243-244). Other publicized accidents include the disappearance of two nuclear submarines and the burn-up in the upper atmosphere of a ^{238}Pu isotopic generator. More common incidents involve loss or theft of radio-active material during ground transportation. A number of such incidents have been reported in which injuries of varying degrees of severity have resulted for members of the public coming in contact with lost or stolen radio-active sources (3, 19, 33).

3. Among the sources commonly used for industrial, medical, or research purposes, radium deserves special attention as it has been widely utilized since the turn of the century and is one of the most hazardous radio-nuclides. In the United States alone, about 2,000 curies of ^{226}Ra have been processed and imported for use in medical and industrial sources (50). Manufacturer sales data indicate over 1,300 curies of ^{226}Ra (including 550 curies of luminous compounds) has been sold or leased. Estimates based on state licensing and registration programme data can account for about 475 curies of industrial and medical radium at this time. (This estimate does not include Federal use, devices not subject to licensure or registration, and luminous compounds.) Most of the remaining radium not accounted for can be attributed to the disposal of luminous compounds and devices and radium returned to the manufacturer (45). In the medical field, reports of 442 radium incidents occurring since 1905 had been collected by 1 January 1970 in the United States (8). Detailed analysis of 115 radium incidents which occurred during 1966 through 1969 show that 55 per cent of all radium incidents are losses (72 per cent of medical incidents) and that 75 per cent of these losses occur during patient treatment and source removal. However, for 299 incidents involving lost or stolen radium, 66 per cent of the sources were recovered (49).

4. In the case of major transportation accidents, extensive decontamination, when feasible, was carried out and the doses were kept to a minimum (paragraphs 243-246 of annex A). With other incidents, even if the dose to some individuals was high, the number of exposed persons has been very small. The population dose from these sources is certainly negligible when compared to natural background.

II. Products available to the general public

A. Radio-active nuclides added to consumer products

5. Radio-active materials, either natural or man-made, are often incorporated into consumer products. A list of such products, which does not pretend to be comprehensive, is presented in table 1 (13). The use of radio-nuclides to produce luminosity appears at present to be the largest single application of radio-nuclides in products available to the general public. Quantitative data on the doses resulting from the distribution of such products are scarce but it is estimated that the contribution of radio-luminous timepieces, which is relatively well documented, amounts to more than half of the average gonad dose from all consumer products containing radio-active materials (45).

1. *Radio-luminous timepieces*

6. Several studies on doses arising from radio-luminous timepieces were conducted around 1960, when ^{226}Ra predominated as the activating material (12, 25, 31, 34, 51, 52). The alpha activity of such a source is the main means of producing fluorescence, while the beta activity and accompanying gamma rays give rise to the external radiation exposure of the wearer. The radium content of self-luminous timepieces was found to vary considerably, depending upon many factors such as size of hands and dials, and radium concentration in the luminous paint. In a summary of the investigations, Seelentag and Schmier (52) reported that the average radium content of men's wrist watches containing radium as a luminizing material varied from 0.014 to 0.36 microcurie, with a maximum observed value of 4.5 microcurie.

7. The actual dose received by a wearer will depend on a number of factors such as the amount of radium in the watch, the length of time that the watch is worn during the day, and the habits of the wearer. It has been estimated (52) that the annual gonad dose to males wearing a watch only during waking hours (16 hours per day) might be about one fifth of the 24-hour dose, and might be about 15-30 millirads per year, normalized to a watch activity of one microcurie.

8. Radium-dial pocket watches, which are worn in relatively close proximity to the gonads, are potentially a greater genetic hazard than wrist watches with equal amounts of ^{226}Ra (43). However, they are not worn overnight, and measurements on a phantom indicated that the annual dose to the testes is about 60 mrad μCi^{-1}, which is lower than the average annual dose from a wrist watch of the same activity worn 24 hours a day (27). As regards self-luminous alarm clocks, Joyet and Miller (25) estimated the average gonad dose from that source to be only one tenth of the gonad dose from luminous wrist watches.

9. Estimates of the genetically-significant dose from radium in watches around the year 1960 are shown in table 2. On average, the genetically-significant dose was 2 mrad y^{-1} and, in all cases, less than 4 mrad y^{-1}.

10. The fraction of ^{222}Rn leaking out of the watches was reported to vary widely (12). The radon content measured after a build-up of 10 hours in an airtight box was found to vary from around 0.1 to 30 nanocuries per microcurie ^{226}Ra for new, watertight watches and for loosely sealed, old watches, respectively. The dose to the lung after inhalation of ^{222}Rn and its decay products depends on the size and ventilation rate of the room in which the watch is used but can be estimated to be in most cases a small fraction of the contribution of natural background.

11. It was already clear in the early 1960s that, probably because of radiation regulations, the average content of ^{226}Ra in self-luminous wrist watches, as well as the annual production of such watches, was decreasing (52). At the same time, efforts were also made to use beta-active sources of low energy, which emit a small amount of gamma radiation or none at all, such as ^{3}H or ^{147}Pm, to eliminate the external radiation exposure. For a period ^{90}Sr was used but has now been discontinued on account of the beta radiation and Bremsstrahlung escaping from the watch and the hazard for the workers involved. In 1967, the ENEA and the IAEA jointly recommended that only ^{3}H, ^{147}Pm and ^{226}Ra should be used as activating radio-nuclides in luminous paint for dials and hands of timepieces and that ^{3}H or ^{147}Pm should be preferred as far as possible (18). Average and maximum recommended values of the radio-nuclide content to be used per timepiece were also indicated.

12. In recent years, ^{226}Ra in watches has tended to be replaced by ^{3}H and, to a lesser extent, ^{147}Pm. In 1968, the annual United States production and importation of timepieces activated by ^{226}Ra was estimated to be about 3 million whereas 6 to 7 million timepieces contained ^{3}H or ^{147}Pm (45).

13. Although the use of ^{3}H eliminates the risk of external irradiation, experience has shown that tritiated water, or a simple tritiated organic molecule, evolves from the self-luminous compound (26, 63) and leakage of ^{3}H from watches has been found to result in annual doses to wearers of the order of one millirad (65).

14. The Committee is not aware of any recently-published survey on radiation doses resulting from the use of self-luminous timepieces. However, taking into account the increased use of nuclides giving rise to smaller exposure and the development of performance standards, it seems very likely that the genetically-significant dose has considerably decreased since 1960.

2. *Self-luminous devices other than timepieces*

15. Although nowadays radio-luminous phosphors are usually activated by ^{3}H, radium has been extensively used, primarily by the aircraft industry and the military. During World War II, the major United States manufacturer of luminous markers used several hundred curies of radium in production for the armed forces. Some of those products find their way into consumer outlets as government surplus (48).

16. The dose resulting from the normal use of the majority of self-luminous devices is probably very low but the possibility always exists that persons receive greater exposure than expected because of the release of the radio-nuclide during accidents, fire or unconventional use of the product. However, the probability of such circumstances occurring will normally be small (13).

3. *Other products*

a. *Radio-active gold rings*

17. It has been reported that spent gold-encased radon seeds, originally intended to be implanted into

tumours, have occasionally been used in the manufacture of gold rings (4, 56). In one instance irradiation from long-lived daughter products of radon that became incorporated in the gold caused sufficient damage to adjacent skin to necessitate amputation of the affected finger.

b. *Heart devices*

18. Owing to its high ratio of power output to weight and volume, and to its long half-life, ^{238}Pu is used as a power source for isotopic generators. In the medical field, about 10 ^{238}Pu sources were in use in patients in March 1972 as batteries for heart pacers. This practice has been introduced to avoid the surgical replacement of the conventional electrical batteries in heart pacers each 18 months. ^{238}Pu is also envisaged as a power supply for a mechanical pump which would totally replace the human heart. If all the technological problems can be overcome, there might be as much as 100 megacuries of ^{238}Pu committed to this use by the turn of the century (29).

19. In the present state of technology, the dose equivalent received by someone staying continuously near the patient would be of the order of one rem per year for an artificial heart and of one millirem per year for a heart pacer (15). The dose to the adjacent tissue in a person wearing a pacemaker would be very much higher but is essentially a matter of medical concern only.

c. *Radio-active substances in patients released from hospitals*

20. Members of the families of patients who have been released from hospitals after having been treated with radio-active substances may receive some exposure from radio-active nuclides still retained in the patients. The practices concerning the amount of activity permitted in patients leaving hospitals vary from country to country but often reflect current international recommendations (22) intended to limit the dose received by other persons than the patient to less than 0.5 rad per year.

d. *Radio-active materials used in schools*

21. Pupils in schools sometimes use radio-active materials in science classes. Recommendations for the protection of pupils exposed to radiations used in schools have been given by the ICRP (21).

e. *Radio-active ceramic glazes*

22. The use of uranium compounds to produce certain brightly colored pigmented glazes for ceramic-ware such as platters, pitchers, vases, water mugs and coffee cups was reported as early as 1906. For a set of tableware widely available in the United States, it is estimated that the beta-radiation dose to the hands, assuming a continuous contact with the tableware for 90 minutes per day, ranges from 2 to 10 rads per year (36).

f. *Thoriated electrodes in welding rods*

23. When thoriated tungsten electrodes are used to generate an arc, thorium is released from the arc and becomes airborne as a fume. The activity released is sufficiently diluted by normal convection currents for the concentration in the air breathed by the operator to be very low. Significant concentrations might result only if the equipment is used in a small, totally enclosed, space (5).

B. PRODUCTS THAT ARE NATURALLY RADIO-ACTIVE

1. *Building materials*

24. The relative content of natural radio-nuclides in building materials may lead to a significant difference between the external radiation dose rates received indoors and outdoors. The walls of buildings act as a shield against outside radiation but this effect is often offset by radiation resulting from the radio-activity of the building materials (annex A, paragraphs 132-136).

25. Increases in exposure occur when highly-radio-active construction materials are used. For instance, phosphate rocks often have a high content of radium (37). In the United States, the growth of the phosphate industry, linked to the use of the tailings as building material, has possibly led to a significant increase in the exposure of local populations (32). In a United Kingdom survey, gypsum which is also a waste product from fertilizer from imported phosphate rock was found to be at least twice as active (in terms of gamma-ray emission rate per gramme) as any other building material (14). In Sweden, light-weight concrete from uranium-rich shales has been reported to give indoor dose rates two to three times the normal outdoor dose rate (59).

26. A special situation arose in Grand Junction, Colorado, in the United States, where approximately 200,000 tonnes of uranium-mill tailings were used during the period 1952-1966 as fill material under streets, driveways, swimming pools, water pipes and sewer mains, but also in habitable structures where they resulted in potential exposures from external gamma radiation and inhalation of ^{222}Rn decay products. By August 1971, gamma levels had been assessed in approximately 10,600 structures out of 18,000. About 3,000 of these were actually found to have tailings under, or adjacent to, the building (11, 55). It is estimated that the total number of structures with tailings located under or against them in the Grand Junction area is about 3,600 (55).

27. Analyses of gamma maps of about 1,000 habitable structures, including residences, schools, business and public buildings, were completed by October 1971. Data for 670 residences show that, in 80 per cent of these, the average levels above background (taken as 9 $\mu R\ h^{-1}$) are less than 10 $\mu R\ h^{-1}$; in about 18 per cent they are in the range 10-50 $\mu R\ h^{-1}$, and in only 0.3 per cent above 100 $\mu R\ h^{-1}$ (11). Assuming that the average time spent indoors is 17 hours per day (paragraph 263 of annex A), doses to the gonads corresponding to levels of 10, 50 and 100 $\mu R\ h^{-1}$ are approximately 50, 250 and 500 mrad y^{-1}, respectively.

28. The concentration of ^{222}Rn decay products in structures built with tailings are not readily correlated with the gamma levels. Preliminary measurements indicated levels of radon daughters ranging up to 0.4 WL[1] which is 100 times the background level (11).

[1] A working level (WL) is the term used in uranium mines to describe radon-daughter product activities in air. This term is defined as any combination of short-lived radon-daughter products in one litre of air that will result in the ultimate emission of 1.3 10^5 MeV of potential alpha energy. The numerical value of the working level is derived from the alpha energy released by the total decay through ^{214}Po of the short-lived radon decay products ^{218}Po, ^{214}Pb and ^{214}Bi at radio-active equilibrium with 100 pCi of ^{222}Rn per litre of air.

29. So far the area of Grand Junction is the only one where it has been determined that tailings have been used extensively in construction. However, some tailings have been found under structures in other cities in Colorado and surveys are being carried out in the United States to investigate the extent of use of tailings in all areas surrounding present and former mill operations (11). It is not known if similar situations occur in other countries.

30. By contrast it is clear that an appropriate choice of low radio-activity raw materials would cause a significant reduction in the population dose from external radiation, as several studies have shown that, on a national basis, the radio-activity of a building material varies considerably (30, 64).

2. *Natural gas*

31. Average ^{222}Rn levels in natural gas samples collected from different geological formations of the United States were found to range from 3 to 67 pCi l^{-1}, with a maximum observed value of 160 pCi l^{-1} (6). When natural gas is used, ^{222}Rn is released. Its maximum build-up is expected to occur in a closed area containing unvented gas appliances. In a typical dwelling, its concentration in air would be about 500 times less than its concentration in gas (24). Taking an average ^{222}Rn level in gas of 35 pCi l^{-1}, the concentration in air would be about 0.07 pCi l^{-1}, which, assuming average conditions of radio-active equilibrium between ^{222}Rn and its daughters, corresponds to a dose of about 20 mrad y^{-1} to the basal cell nuclei of the bronchial epithelium (annex A, paragraph 117). However, actual doses are expected to be much lower because most appliances are vented and also because any appreciable transmission time from well to consumer would decrease the ^{222}Rn content by radio-active decay.

C. Electronic products

32. Electronic products may be sources of ionizing radiation when electrons are accelerated at potentials in excess of about 10 kilovolts. Potential emitters of x rays are high-voltage rectifiers, radio-transmitter tubes, klystrons, electron microscopes, etc. A large variety of those devices are used for medical, industrial, or research purposes and are outside the scope of this annex. However, it may be recalled here that the problem of stray x rays around high-voltage tubes was exemplified in 1960 when two technicians exposed to pulsed x rays from an unshielded klystron tube were seriously injured in Lockport, USA (17).

33. Household colour television receivers are the most common electronic products with the potential of exposing the general public to x radiation.

1. *Colour television receivers*

34. Since the advent of commercial television broadcasting, it has been recognized that cathode-ray tubes of television receivers produce x rays, the output of which depends sharply on tube voltage and is directly proportional to tube current.[2] In monochrome sets, the x rays are produced in small amount and have a poor penetrating power, because of the relatively low accelerating voltage of about 20 kilovolts and the small beam current of some 0.1 milliampere. X-ray production in colour television sets is enhanced because of an increase of the accelerating voltage to 25 kilovolts or more and of the beam current to about one milliampere resulting in a greater production of more penetrating radiation. High-voltage rectifiers and shunt regulator tubes are the other sources of x rays in a television receiver. Certain models are designed to operate without shunt regulator tube and some are fully transistorized. The trend towards solid-state circuitry is likely to continue and implies that the only vacuum device remaining in a television receiver within a few years will be the picture tube (7).

35. The public-health significance of the problem is potentially greatest in the United States, where 25 million colour sets were in use in January 1970 (53) and where it is estimated, from the present rate of increase of colour television sets, that approximately 70 per cent of all homes will have them by 1975 (16). In 1967, approximately 110,000 large-screen colour television receivers were modified by replacing the high-voltage shunt regulators which produced an excessive downward emission of x rays (47). A field survey conducted in the state of Florida in November 1967 on 148 sets showed that the modification programme had been effective but discovered that 43 sets had x-ray emissions from sources other than the shunt regulator tube in excess of the ICRP limit. These x rays originated from component sources that could be associated with the sets of all manufacturers, thus indicating a potential industry-wide problem (38). To obtain additional information, a home survey was conducted in the Washington (D.C.) metropolitan area in December 1967 and January 1968. It was found that 76 per cent of the 1,124 colour television receivers examined did not emit any measurable levels of x rays but that 6 per cent exhibited exposure rates above the ICRP limit, in most cases because of excessively-high voltage (39). X rays were detected regardless of the age of the sets but there was evidence of a downward trend for receivers sold from 1964 to 1967.

36. Table 3 presents the estimates of the average annual doses for both children and adults, based on average viewing habits and on the average front face exposure rate of 43 $\mu R\ h^{-1}$ at five centimetres that were observed in the Washington survey. The average dose to the gonads of male children is estimated at 1.5 mrad y^{-1} but the distribution of x-ray emission would suggest that about 1 per cent of the viewing population might receive doses larger than those presented in table 3 by a factor of about 60 (40). The annual genetically-significant dose to the United States population was estimated to be 0.5 millirad based on the assumptions that, over the country, the distribution of x rays from television sets and the viewing habits of the population are similar to those observed in the Washington metropolitan area (66). However, it was pointed out that the energy dependence of the detectors used in the Florida and Washington surveys led to overestimates of up to a factor of three of the exposure rate of cathode-ray tube and rectifier tube emissions (66).

37. Other home surveys were more recently conducted in the United States in order to check if the x-ray emissions complied with the guidelines. In Pennsylvania and in Puerto Rico, less than 10 per cent of the colour televisions surveyed were found to emit radiation in excess of the ICRP limit and none exceeded

[2] The ICRP recommends that the x-ray exposure rate 5 cm from the surface of any television set should not exceed 0.5 mR h^{-1}, which is equivalent to an air dose rate of 0.435 mrad h^{-1} (20).

3.0 mR h^{-1} (9, 28). In Suffolk County, New York, over 6,000 sets were inspected in 1968-1969; about 16 per cent emitted radiation in excess of 0.5 mR h^{-1}, the maximum observed being 150 mR h^{-1} (1). The outstanding causes of x-ray emissions were improper adjustment of the high-voltage control and faulty shunt-regulator tubes. A follow-up of this survey showed that approximately 11 per cent of the sets that were re-surveyed were emitting x rays above the ICRP limit because of improper servicing (2).

38. The first phase of the United States performance standard for television receivers became effective for sets manufactured after 15 January 1970, and the final and most stringent aspect was effective after June 1971. Television receivers must meet the 0.5 mR h^{-1} limit under conditions of extreme misadjustment and with the component and/or circuit failure that maximizes emission (44). This means that under typical operating conditions, the emission from recently-built colour television receivers is expected to be indistinguishable from background (54).

39. Smaller-scale surveys have been conducted outside the United States. In the United Kingdom, the only source of x rays in currently-produced sets is the picture tube and the maximum dose rate occurs at the front screen. A survey completed by April 1970 concluded that the average male-gonad dose from normal viewing of receivers whose picture tube is set at a typical high voltage is about 0.8 μrad y^{-1} (41). Allowing for high voltage regulation, variability of x-ray output and the effect of line voltage fluctuations, the dose rate in air five centimetres from any receiver leaving a factory is unlikely to exceed 15 μrad h^{-1}, corresponding to an average male-gonad dose of about 0.2 mrad y^{-1}. It was observed that under test conditions of service misadjustment or circuit failure tending to maximize x-ray emission or both conditions combined, some manufacturers' receivers could be made to exceed slightly the ICRP limit (42).

40. In Canada, in contrast to the other surveys, the front face of the sets was not monitored as it was assumed that the glass safety plate of the picture tube provided an effective shielding. About 11 per cent of the receivers tested gave dose rates above the ICRP limit but the proportion was found to decline in successive years since 1966 (10).

41. The foregoing surveys, as well as the results reported from other countries (23), tend to show that, under conditions of normal operation and proper servicing, the x-ray emission from recently-built colour television receivers is negligible.

2. *Electronic products used for educational purposes*

42. Many schools in their science class demonstrations use equipment which produces ionizing radiation. During April 1969, a survey was performed in 181 high schools throughout the United States to determine the magnitude of possible radiation hazards from demonstration devices designed to emit x rays or which may emit x rays as a result of their intended use (61).

43. Survey findings showed that three types of cold cathode gas discharge tubes produced outside the tube significant levels of x rays which were not essential to the effect demonstrated. An estimate of 15,000 to 30,000 of those tubes, which were used to demonstrate the heat effect, the magnetic effect, and the fluorescence effect of cathode rays, had been distributed by the United States producer from about 1910 to 1968. The x-ray exposure rate at a distance of 30 centimetres was greater than 0.1 R h^{-1} for 25 per cent of the 175 tubes tested, and greater than 1 R h^{-1} in the proportion of 6 per cent. The number of students who might have been exposed and the average exposure were not determined. As a consequence of the survey, the company currently manufacturing the tubes in the United States ceased the production of the faulty tubes and redesigned them. The fluorescence-effect and the magnetic-effect tubes were then found to meet the newly-promulgated requirements of 10 mR h^{-1} at 30 centimetres from any surface or enclosure of the tube, and were allowed to be sold. The heat-effect tube failed to meet requirements and its production was terminated (62).

44. In the same survey, 103 x-ray tubes were found, of which 97 were unshielded and many were reported as not in use. Measurements were made on 21 of the unshielded tubes. Eleven emitted at rates of roentgens per hour 60 centimetres from the anode, the maximum calculated value being 108 R h^{-1}. Some of the tubes could emit x rays in all directions at rates many times the recommended maximum. Under the new regulation, the divergence of the x-ray exit beam should not exceed π steradians and the enclosure must be equipped with a beam-blocking device (46).

45. In a preliminary survey conducted in Kansas schools in 1968, measurable exposure rates were recorded in the vicinity of the x-ray tubes and of some cold-cathode gas discharge tubes (57). The maximum exposure which resulted from the use of hand fluoroscopes was to the hands of 10 high school students over a school year and amounted to about 700 millirads. Other exposure rates were lower by at least an order of magnitude. Most of the x-ray-producing devices available in the schools were not in use. Subsequently, discontinuance of hand fluoroscopy was recommended.

3. *Shoe-fitting fluoroscopes*

46. In its 1962 report, the Committee referred to the irradiation of individuals by shoe-fitting fluoroscopes. Information available to the Committee indicates that those devices are much less frequently used than formerly. When in use, they will cause exposure rates to the feet of about 5 rads per minute or more.

III. Conclusion

47. The widespread use of self-luminous wrist watches activated by ^{226}Ra led to a genetically-significant dose of about 2 mrad y^{-1} around 1960. As a consequence of international recommendations and national regulations in some countries, the use of ^{226}Ra is being gradually discontinued and is being replaced by ^{3}H and, to a lesser extent, ^{147}Pm, which give rise to much lower doses to the users. There is no recent estimate of the present contribution of self-luminous wrist watches to the genetically-significant dose but it is expected to be considerably reduced from the 1960 value. However, significant individual doses are likely to be received in case of accidental ingestion of the radio-luminous paint.

48. The radiation exposure from colour television receivers seems to follow the same trend. In the United

States, the genetically-significant dose from that source was estimated to be 0.5 mrad y^{-1} in 1967. Since then, federal performance standards for television receivers have gone into effect so that the genetically-significant dose should now be very small. In the other countries, because the proportion of colour television sets is much lower than in the United States, the genetically-significant dose is also certainly very small.

49. The external radiation is influenced to a large extent by the radio-active content of the building materials. Analysis of table 18 of annex A indicates that the average external dose rate indoors may be lower or higher than the outside dose rate depending upon local circumstances such as geology, choice and origin of building material, etc. It is evident that the influence of the building material on the external dose rate is very high, and that the choice of material therefore should be given proper attention. Building materials with unusually high radio-active contents should be avoided.

TABLE 1. PRODUCTS CURRENTLY AVAILABLE CONTAINING RADIO-NUCLIDES (13)

Products	*Nuclide*	*Activity or mass per product (range of approximate values)*
A. Radio-luminous products		
(a) *Paints and plastics*		
1. Timepieces	^{3}H	5 to 25 mCi
	^{147}Pm	65 to 200 μCi
	^{226}Ra	0.1 to 3 μCi
2. Aircraft instruments	^{3}H	up to 10 Ci
	^{147}Pm	up to 0.3 Ci
	^{226}Ra	up to 20 μCi
3. Compasses	^{3}H	5 to 50 mCi
	^{147}Pm	10 μCi
4. Instrument dials and markers	^{3}H	25 mCi
5. Instruments, signs and indicators	^{147}Pm	0.75 Ci
6. Thermostat dials and pointers	^{3}H	25 mCi
7. Automobile lock illuminators	^{3}H	2 to 15 mCi
	^{147}Pm	2 mCi
8. Automobile shift quadrants	^{3}H	25 mCi
9. Bell pushes	^{3}H	0.3 mCi
10. Speedometers	^{147}Pm	0.1 mCi
11. Rims for underwater watches	^{3}H	0.3 mCi
12. Fishing lights	^{14}C	3 to 4 mCi
13. Spirit levels	^{3}H	5 to 25 mCi
(b) *Sealed tubes*		
1. Marine compasses	^{3}H	0.2 to 2 Ci
2. Marine navigational instruments	^{3}H	0.25 Ci
3. Markers	^{3}H	4 Ci
	^{85}Kr	0.3 Ci
4. Instruments, signs and indicators	^{3}H	2 Ci
	^{85}Kr	0.25 Ci
5. Exit signs for commercial buildings	^{3}H	15 Ci
6. Large signs	^{3}H	30 Ci
7. Small exit signs	^{3}H	2 Ci
8. Step markers	^{3}H	2 Ci
9. Mooring buoys and lights	^{3}H	2 Ci
10. Public telephone dials	^{3}H	0.5 Ci
11. Light switch markers	^{3}H	0.2 Ci
12. Bell pushes	^{3}H	10 mCi
13. Miniature light sources	^{3}H	20 mCi
B. Electronic and electrical devices		
1. Electronic tubes	^{3}H	1 to 10^{4} μCi
	^{63}Ni	1 to 5 μCi
	^{147}Pm	1 μCi
	^{85}Kr	1 to 5 μCi
	^{60}Co	0.15 to 5 μCi
	^{226}Ra	0.1 μCi
	^{137}Cs	5 μCi

TABLE 1. PRODUCTS CURRENTLY AVAILABLE CONTAINING RADIO-NUCLIDES (13) (*continued*)

Products	*Nuclide*	*Activity or mass per product (range of approximate values)*
2. Glow discharge tubes	^{85}Kr	0.01 to 10 μCi
3. Voltage discharge tubes	^{147}Pm	3 μCi
4. Cold cathode tubes	^{3}H	90 μCi
5. Fluorescent lamp starters	^{226}Ra	1 μCi
6. Gas discharge lamps (high pressure mercury-vapour lamps)	Natural thorium	$6\ 10^{-3}$ μCi
7. Vacuum tubes	Natural thorium	0.8 to 1.2 per cent by weight
8. Electric lamps	Natural thorium	50 mg
9. Germicidal lamps, sun lamps, lamps for outdoor and industrial lighting	Natural thorium	2 g
10. Glow lamps	^{3}H	0.01 mCi
11. Spark gap tubes	^{147}Pm	30 μCi
	^{60}Co	5 μCi
	^{63}Ni	5 μCi
	^{137}Cs	5 μCi
12. High voltage protection devices	^{147}Pm	3 μCi
13. Low voltage fuses	^{147}Pm	3 μCi
C. Antistatic devices		
1. Lightning rods	^{226}Ra	0.2 to 1 mCi
	^{241}Am	0.06 to 0.7 mCi
2. Antistatic devices contained in instruments	^{226}Ra	10 μCi
3. Antistatic brushes	^{210}Po	0.05 to 0.5 mCi
	^{241}Am	2 to 25 μCi
4. Antistatic devices contained in precision balances	^{3}H	1 mCi
D. Gas and aerosol (smoke) detectors		
1. Smoke and fire detectors	^{241}Am	0.06 to 0.1 mCi
	^{226}Ra	0.01 to 15 μCi
	^{85}Kr	7 mCi
	Natural or depleted uranium	7.5 mg
E. Ceramic, glassware, alloys, etc. containing uranium or thorium		
1. Chinaware	Natural uranium	10^{-2} μCi cm^{-2} surface
2. Ceramic tableware glaze	Natural thorium	20 per cent by weight (glaze)
	Natural or depleted uranium	20 per cent by weight (glaze)
3. Glassware, glass enamel, glass enamel frit	Natural thorium	10 per cent by weight
	Natural or depleted uranium	10 per cent by weight
4. Optical lenses	Natural thorium	Up to 30 per cent by weight
5. Incandescent gas mantles	Natural thorium	Up to 0.5 g
6. Magnesium-thorium alloys	Natural thorium	Up to 4 per cent by weight
7. Products containing rare earths i.e.: arc carbons, lighter flints, metallurgical additives, precision lenses, television tubes, electronic ceramics, microwave devices, etc.	Natural thorium	0.25 per cent by weight
	Natural or depleted uranium	0.25 per cent by weight
8. Welding rods	Natural thorium	1 to 2 per cent by weight
F. Other devices, including scientific instruments		
1. Gas chromatographs	^{3}H	250 mCi
	^{63}Ni	12 mCi
2. Static meters	^{241}Am	0.5 to 50 μCi
3. Vending machine coins	^{14}C	2 μCi
4. Bank cheques	^{14}C	0.01 μCi

TABLE 2. ESTIMATED ANNUAL GENETICALLY-SIGNIFICANT DOSES (GSD) FROM RADIUM IN SELF-LUMINOUS WATCHES

Country	*Year*	*Estimated annual GSD (mrad)*	*Reference*
Denmark	1961	1.2	34
Switzerland	1960	3.3	25
Federal Republic of Germany	1959	2.6	51
Federal Republic of Germany	1961	1.5	52
United Kingdom	1960	0.5–1.0	35
Sweden	1960	1–3	31

TABLE 3. ESTIMATED AVERAGE ANNUAL DOSE FROM COLOUR TELEVISION SETS, BASED UPON THE WASHINGTON, D.C., SURVEY (40)

Organ	*Children less than 15 years of age (mrad)*	*People 15 years of age and older (mrad)*
Skin	3.6	1.6
Thyroid	2.6	0.9
Male gonads	1.5	0.7
Female gonads	0.4	0.2
Lens of eye	3.0	1.3

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