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September 20, 2001

Mr. Omri Lulav
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20 Lincoln St. Tel Aviv 67134
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Re: Radiation Safety and Legal Aspects of Handling Coals Ash

Dear Mr. Lulav

Please find enclosed my professional opinion in relation with the issue of handling coal ash.
I prepared this document following your inquiry in connection with the possible export of coal ash to Greece where it is to be used in the construction industry.
As indicated in the enclosed document to my understanding of the European Directive 96/29/Euratom, the handling of coal ash as such is exempted from radiation safety requirements (notification, registration, licensing etc.) since such handling does not carry a significant radiological risk.
Please note that there are no restrictions in Israel on the handling of coal ash, although some restrictions are set on the percentage of coal ash that can be used as a constituent of specific building products (such as concrete or bricks)

I will be happy to refer to any further questions, which you may have relating to this issue.

Yours sincerely

Prof Tuvia Schlesinger
Senior Radiation Protection Consultant

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October 2001

Radiation Safety and Legal Aspects of Handling Coal Ash produced in Israel Electric Corporation Power Stations

A statement of opinion by

T. Schlesinger
Senior Radiation Protection Consultant

1. Background

Coal, as many other natural ores, contains several natural radioactive elements e.g. ^{226}Ra, ^{232}Th and their decay products and ^{40}K. The same elements are found in enhanced concentrations in fly ash and bottom ash produced in the process of coal combustion in power stations.

The presence of enhanced quantities of radioactivity in the ash raises some safety and legal questions related to the potential exposure of workers and the public to ionizing radiation when storing and handling the ash in the course of its disposal, conveyance or use (e.g. for landfill or as a constituent of building products, etc).
Actually, the development of modern construction materials containing technologically enhanced concentration of natural radio-nuclides (e.g. phosghogypsum, fly ash, exotic minerals, etc) causes growing health concerns. The results of these concerns are legislation activities and publication of guidance notes by national authorities and international professional organizations related to the radiological implications of these novel technologies.

On the other hand all national and international radiation safety legislation exempt minute quantities of radioactive materials and substances with minimal concentrations of specified radionuclides from radiation safety requirements. These exemptions are based on the general principles and specific conditions discussed below.

This short document discusses the radiation safety aspects of the handling of fly ash and bottom ash produced as a result of the combustion of coal in the process of electricity generation in Israel Electric Corporation Power Stations in Israel and examines the possibility to regard the ash as an exempted *source* and its handling as an exempted *practice.*

2. Radiation Safety Aspects

2.1 Concentrations of certain radionuclides in the ash

Concentrations of the natural radio-nuclides ^{226}Ra, ^{232}Th and ^{40}K in the ash are routinely determined in the framework of a radiation safety program run by the Environmental Unit of the Israel Electric Corporation.

Characteristic values are presented in Appendix 1, tables 1a, 1b, and 1c for the years 1998,1999,and 2000 respectively for coal (upper part of the tables), fly ash (middle) and bottom ash (lower part of the table).

Samples are measured in the laboratories of the Radiation Safety Division of the Soreq Nuclear Research Center in Yavne.

Concentrations of the three above-mentioned radionuclides were found to be in the range 110- 186 Bq/kg for ^{226}Ra, 117-226 Bq/kg for ^{232}Th and 132-447 Bq/kg for ^{40}K. Estimations of levels of exposure to workers and to members of the public in connection with the storing and handling of the ash can be therefore based on maximal concentrations of 200 Bq/kg, 230 Bq/kg and 500 Bq/kg for the 3 radio-nuclides respectively.

2.2 Exposure routes

Workers handling the ash and members of the public can be exposed to ionizing radiation in two major routes:

External radiation: by staying in the proximity of stacks/piles of ash. The extent of the exposure depends on the distance from the stack/pile, the time of stay and the self-absorption by the stack/pile itself. Estimation of the dose caused by this route is presented below.
Internal contamination: ash particles suspended into the air as dust can be inhaled or ingested.

Retention of the radioactive elements in the respiratory system and their transfer through the ingestion tract and uptake of these elements by various body organs will cause internal exposure.

The extent of the internal exposure depends on the dimensions of the dust particles, the solubility of the specific chemical compound containing the radionuclides, the organs of uptake of each specific radionuclide and an effective half-life of the radionuclide in these organs.

Estimation of the dose caused by this route is presented below.

2.3 Estimation of the radiation dose to workers and members of the public that can be caused by handling of coal ash

An estimation of the dose that may be caused by handling of coal ash containing natural radionuclides with concentrations characteristic to ash produced in the Israel Electric Corporation power stations was carried out in 1998 by the author of this document and a co-

worker (1). External exposure and internal contamination anticipated for workers stationed at a distance of 1 m from the edge of a 5x5 m meter stack of ash with a height of 3m, containing ^{226}Ra, ^{232}Th and ^{40}K with concentrations of 200 Bq/kg, 200 Bq/kg and 600 Bq/kg respectively were calculated.

For internal contamination the dose due to radon and the inhalation of dust was estimated assuming work activity in a closed working shed, without wetting the ash. The results of this estimation were as follows:

External Exposure: 0.085 μSv/h. This means an accumulated dose of 170 μSv (17 mrem) for 2000 hours of work in a year.
Increasing the distance from the stack reduce the dose.
Radon: 0.1 μSv/h, i.e. **200** μSv (20 mrem) for 2000 hours of work under these extreme conditions in a year. This dose is equivalent to the annual dose to members of the public due to a residential radon concentration of about 20 Bq/m^3.
Internal contamination: 0.25 μSv/h, i.e. **500** μSv (50 mrem) for 2000 hours of work under these extreme conditions in a year. This dose can be eliminated almost entirely if the ash will be watered and kept wet.

Our estimation is that, if conventional occupational health measures are taken, such as watering the ash and keeping it wet (to avoid suspension of coal-ash dust in the air) and ventilating the working premises, the dose to workers will not exceed 150-200 μSV (15-20 mrem) in a year. The dose to members of the public will, probably, reach only 5% of these values.

3. Legal Aspects

3.1 Legislation addressing exposure to ionizing radiation

The protection of workers and members of the public against the dangers arising from ionizing radiation in the European Community countries is dealt with by specific legislation issued in the form of EC Directives. The European Council published the most recent Directive addressing this issue in 1996 under the title "**Council Directive 96/29/Euratom**" (2).
(The full name of this Directive is "Council Directive 96/29/Euratom of 13 May 1996, laying down basic safety standards for protection of the health of workers and the general public against dangers arising from ionizing radiation).

3.2 Articles in Council Directive 96/29/Euratom apparently relevant to the issue of handling coal ash

Title II of the Directive specifies the scope of **Council Directive 96/29/Euratom**.
It states in **Pa. 1** of **article 2** that: "this Directive shall apply to all *practices* which involve risk from ionizing radiation emanating from an *artificial source* or from *a natural radiation source* in cases where natural radio-nuclides are or have been processed in view of their radioactive, fissile or fertile properties, namely.

(a) the production, proceeding, handling, use, holding, storage, transport to and export from the Community and disposal of radioactive substances.
(b) the operation of any electrical equipment … etc

(c) any other practice specified by the Member State

In **pa. 2** of the same article the Directive add that: ”In accordance with **Title VII** it shall also apply to work activities which are not covered by **pa. 1**, but which involve the presence of *natural radiation sources* and lead to a significant increase in the exposure of workers or members of the public which cannot be disregarded from the radiation protection point of view”.

*Note: **article 1** in **Title 1** of the Directive presents the definitions of specific terms and the meanings assigned to them for the purpose of the Directive.*
***Natural radiation sources** are defined as:”sources of ionizing radiation from natural terrestrial or cosmic origin”*
*A **Practice** is defined as:”a human activity that can increase the exposure of individuals to radiation from an artificial source, or from a natural radiation source where natural radio-nuclides are processed for their radioactive, fissile or fertile properties.”*

Title III of the Directive describes the requirements of reporting and authorization related to radiation *practices* referred to in **article 2 (of Title II)**. **Article 3** in this Title specifies *practices* involving minor quantities of *radioactive substances* and substances containing radioactive elements with concentrations below specified values, which are exempted from the requirements of reporting.

Exemption values for quantities and concentrations of specified radionuclides are presented in table A to Annex I to the Directive. This Annex includes also a description of the general principles of Exemption for practices granted in article 3. The full text of this Annex, including table A is presented in Appendix –2 to this document.

In cases of mixture of more than one radio-nuclide, the requirements for reporting may be waived if the sum of the ratios for each nuclide of the total amount present divided by the value listed in table A is less than or equal to one. This summation rule also applies to activity concentrations where the various nuclides are contained in the same matrix.

Note: the exempted concentrations of ^{226}Ra , ^{232}Th and ^{40}K as presented in table A are: 10 kBq/ kg for ^{226}Ra, 1 kBq/ kg for ^{232}Th and 100 kBq/ kg for ^{40}K (the *values for ^{226}Ra and ^{232}Th in table A were derived assuming that these nuclides are in secular equilibrium with their short and long lived daughters).*

For the ash specified above, with maximal concentrations of 200 Bq/kg, 230 Bq/kg and 500 Bq/kg, for the 3 radio-nuclides respectively, the sum of the ratios of the maximal concentrations for each radionuclide divided by the value listed in table a is 200/10,000+230/1000+500/100,000 = 0.255.

Title VII of the Directive apply to *work activities* not covered by **article 2** (in **Title II** of the Directive, see above) within which the presence of *natural radiation source*s leads to a significant increase in the exposure of workers or of members of the public, which cannot be disregarded from the radiation protection point of view.

In **pa. 2** of **article 40** of this Title the Directive suggest a detailed list of such work activities. Among these it mentions: “work activities involving operations with, and storage of, materials not usually regarded as radioactive, but which contain naturally

occurring radio-nuclides, causing a significant increase in the exposure of workers and, where appropriate, members of the public."

In **article 41** of the same Title the Directive states the Member States should require the setting up of appropriate means for monitoring exposure (of workers engaged in these work activities), and, as necessary, the application of radiation protection measures pursuant to all or part of **Title III.**

3.3 Discussion

3.3.1 Does the Directive apply to handling of coal ash?

Although the handling of coal ash carries some radiation risks emanating from a *natural radiation source,* it seems that it cannot be regarded as a **practice** according to **Pa. 1 in Title 1** because the natural radio-nuclides involved are not processed in view of their radioactive, fissile or fertile properties.

If, however, we regard the ash as an *artificial source,* based on the fact that the concentrations of natural radio-nuclides in the ash are enhanced due to a technological procedure (combustion of the coal) the Directive can be applied to handling of the ash as being a *practice which involve risk from ionizing radiation.*

In addition, if handling of the ash can, apparently, cause significant exposure to workers or members of the public the Directive may apply to it based on **Pa.**2 of **Title 1,** the handling being regarded as "a work activity**,** which involve the presence of *natural radiation sources* and lead to a significant increase in the exposure of workers or members of the public which cannot be disregarded from the radiation protection point of view".

3.3.2 Can the handling of the ash been exempted from the requirements of reporting, licensing and other radiation protection requirements?

If the ash is being regarded as an *artificial radiation source* exemption can be granted to handling of coal-ash from Israel Electric Corporation power stations since this activity complies with the exemption criteria for *practices* because the sum of the ratios, for each of the three radio-nuclides, of the maximal concentrations divided by the values listed in table A is less than one as demonstrated above.

If, however, the ash is regarded as a *natural radioactive source* exemption cannot be granted to handling of the ash because it cannot be defined as a *practice* (see definition of a *practice* in pa. 3.2 above).

In this case it should be considered whether the handling should be regarded as: "a work activity which involve the presence of *natural radiation sources* and lead to a significant increase in the exposure of workers or members of the public which cannot be disregarded from the radiation protection point of view", a working activity to which **article 40** and **article 41**of the Directive can be applied.

3.3.3 What is a significant exposure that cannot be disregarded from radiation protection of view?

No explicit answer to this question can be founding the Directive. Some implicit indication can be derived from **article 42** in Title **VII of** the Directive (the **Title** in the directive addressing the issue of "**Significant Increase in Exposure Due to Natural Radiation**"). The directive imposes in this article on Member States the duty to "make arrangements for undertakings operating aircraft to take account of exposure to cosmic radiation of aircrew who are liable to be subject to exposure to more than 1 mSv per year. The undertakings shall take appropriate measures…, etc". It can be concluded from this article that the lawmakers did consider a dose of 1mSv per year as a significant increase in exposure due to natural radiation. I.e. one mSv/y is the upper limit of an occupational exposure, which can be ignored.

The lower limit can be derived from the general criteria to be considered for the application of **article 3** (basic criteria for exemption of a practice without further consideration as presented in Annex I to the Directive (see Appendix 1 to this document). Pa. 3 in Annex 1 states that one of the basic criteria for the derivation of *exempted* **quantities** and *exempted concentrations* of specific radio-nuclides, involved in a *practice,* is that "the effective dose to be incurred by any member of the public due to the exempted practice is of the order of 10 μSv **(**1 *mrem***)** in a year or less".

To these we can add the observation that the dose constraint to members of the public due to a single practice was set recently by international organizations on 300 μSv (0.3 mSv or 30 mrem) per year.

The practical decision regarding this issue (i.e. the order of magnitude of doses that can be ignored from the point of view of radiation protection) has to be taken by the competent authority of each Member State.

In Israel the Ministry of the environment did adopt in the year 2000 the value of 300 μSv (0.3 mSv or 30 mrem) per year as a dose constraint for *practices* involving *natural radiation sources* which can cause an increase in the exposure of the public to ionizing radiation. The author of this document supports this decision, and suggest that a dose 300 μSv (0.3 mSv or 30 mrem) or to members of the public due to a practice involving natural radiation should be regarded as a significant dose which cannot be ignored from the point of view of radiation protection

4. Summary and Conclusion

Coal ash produced as a result of coal combustion in power stations in Israel contains enhanced concentrations of several natural radionuclides. The handling of the ash may cause some increase in the exposure of workers and members of the public to ionizing radiation.

If the handling is carried out under conventional industrial hygiene measures, the dose to workers due to this activity is anticipated to be limited to less than 0.20 mSv (20 mrem) per year. The dose to members of the public is estimated not to exceed 5 % of this value.

Taking into account the deliberations presented above it may be concluded that the handling of coal ash containing natural radioactive elements with concentrations characteristic to the ash produced in Israel is exempted from radiation safety requirements

(notification, registration, authorization, licensing and other radiation protection measures) since such handling does not carry a significant radiological risk and the concentrations are below the exemption levels specified in **Council Directive 96/29/Euratom(2)**.

Storing and handling of the ash should, however, be carried out under general occupational hygiene and safety measures (e.g. proper ventilation and watering of the ash to avoid suspension of dust in the air).

It should be mentioned that the exposure of the public to natural sources of radiation has been estimated by the United Nations Committee on the Effects of Atomic Radiation (UNSCEAR) to result in an effective dose of 2.4 mSv per year (3).

References

1. T. Schlesinger and Y. Grof, Exposure to ionizing radiation associated with the conveyance and processing of coal ash, Report No, RSP –582-11, Soreq NRC, Sep. 1998.

2. Council Directive 96/29 Euratom, official journal of the European communities No. L 159, 29.6.1996. available in: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31996L0029&from=EN

3. United Nations Scientific Committee on the Effects of Atomic Radiation 1988, Sources Effects and Risks of Ionizing Radiation. Report to the General Assembly (UN, New York 1988)

Appendix 1

Characteristic values of the concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the coal imported to Israel and in the bottom and fly coal ash produced in coal-fired power stations for the production of electricity in Israel as determined in the Soreq NRC laboratories.

Tables 1a, 1b, and 1c present values for the years 1998, 1999 and 2000 respectively, for coal (upper part of the tables), fly ash (middle) and bottom ash (lower part of the table).

Table 1a

חברת החשמל לישראל בע"מ
היחידה למניעת מפגעים ורישוי סביבתי

מעודכן ל 24/06/1999

סיכום בדיקות רדיונוקלידים בפחם ובאפר מתחה"כ של חב. החשמל

הריכוזים ב- Bq/kg

כללי		רוטנברג		אורות רבין ב		אורות רבין א		
ממוצע #	תחום #	7-12/98	1-6/98	7-12/98	1-6/98	7-12/98	1-6/98	תקופה מיוצגת יסוד
פחם								
21	9-32	13	16	19	25	14	9	Ra-226
24	7-40	13	12	21	24	15	7	Th-228
44	13-88	82	66	88	72	72	82	K-40
אפר מרחף								
151	122-186	126	130	150	150	127	127	Ra-226
169	117-226	142	120	177	166	128	117	Th-228
296	132-447	406	290	260	250	362	385	K-40
אפר תחתית								
124	80-169	88	92	140	134	90	141	Ra-226
141	80-190	88	98	165	146	85	169	Th-228
232	79-394	352	304	320	195	252	242	K-40

תוצאות בדיקות של מרכז המחקר הגרעיני נחל שורק
רדיום-226 מייצג את שרשרת האורניום-238, תוריום-228 מייצג את שרשרת התוריום-232
לתקופה 12/98- 7/91

ערך : ישי דביר

Appendix 1 (cont.)

Table 1b

חברת החשמל לישראל בע"מ
היחידה למניעת מפגעים ורישוי סביבתי

מעודכן ל 06/06/2000

סיכום בדיקות רדיונוקלידים בפחם ובאפר מתחה"כ של חב. החשמל

הריכוזים ב- Bq/kg

כללי		רוטנברג		אורות רבין ב		אורות רבין א		
ממוצע #	תחום #	7-12/99	1-6/99	7-12/99	1-6/99	7-12/99	1-6/99	תקופה מיוצגת יסוד
פחם								
21	9-32	14	10	21	25	14	16	Ra-226
24	7-40	16	13	32	34	17	21	Th-228
44	13-88	46	40	44	47	52	58	K-40
אפר מרחף								
149	110-186	142	110	171	154	118	132	Ra-226
168	117-226	148	137	195	186	132	138	Th-228
296	132-447	395	374	188	213	303	282	K-40
אפר תחתית								
123	80-169	105	81	154	123	124	142	Ra-226
140	80-190	111	93	162	142	139	158	Th-228
228	79-394	257	247	160	163	239	183	K-40

הבדיקות נערכו במרכז המחקר הגרעיני נחל שורק, עד 12/98, ובחברת "רמות" על יד אוניברסיטת ת"א מ- 1/99
רדיום-226 מייצג את שרשרת האורניום-238, תוריום-228 מייצג את שרשרת התוריום-232
לתקופה 12/99- 7/91

ערך : ישי דביר

Appendix 1 (cont.)

Table 1c

חברת החשמל לישראל בע"מ
היחידה למניעת מפגעים ורישוי סביבתי

מעודכן ל 04/06/2001

סיכום בדיקות רדיונוקלידים בפחם ובאפר מתחה"כ של חב. החשמל

הריכוזים ב- Bq/kg

כללי		רוטנברג		אורות רבין ב		אורות רבין א		
ממוצע #	תחום #	7-12/99	1-6/99	7-12/99	1-6/99	7-12/99	1-6/99	תקופה מיוצגת יסוד
פחם								
20	9-32	24	18	---	---	18	17	Ra-226
24	7-40	25	21	---	---	19	22	Th-228
43	13-88	28	36	---	---	35	41	K-40
אפר מרחף								
149	110-186	151	151	150	159	155	138	Ra-226
166	117-226	171	181	166	186	168	166	Th-228
290	132-447	268	247	240	237	283	247	K-40
אפר תחתית								
124	80-169	128	123	127	139	148	126	Ra-226
141	80-190	137	139	133	170	157	145	Th-228
226	79-394	188	206	179	190	222	272	K-40

הבדיקות נערכו בממ"ג נחל שורק מלבד התקופה 6/00 – 1/99 בה הן נערכו בחברת "רמות" שליד אוניברסיטת ת"א
רדיום-226 מייצג את שרשרת האורניום-238, תוריום-228 מייצג את שרשרת התוריום-232
--- לא נדגם

לתקופה 12/00- 7/91

ערך : ישי דביר

Appendix 2

Annex 1 to Council Directive 96/29/Euratom. The annex relates to article 3 of the directive. It presents the general principles of Exemption for practices granted in article 3. Table A in the Annex presents exemption levels for quantities and concentrations of specified radionuclides

ANNEX I

CRITERIA TO BE CONSIDERED FOR THE APPLICATION OF ARTICLE 3

1. A practice may be exempted from the requirement to report without further consideration, in compliance with Article 3 (2) (a) or (b) respectively, if either the quantity or the activity concentration, as appropriate, of the relevant radionuclides does not exceed the values in column 2 or 3 of Table A.

2. The basic criteria for the calculation of the values in Table A, for the application of exemptions for practices, are as follows:

   (a) the radiological risks to individuals caused by the exempted practice are sufficiently low as to be of no regulatory concern; and

   (b) the collective radiological impact of the exempted practice is sufficiently low as to be of no regulatory concern under the prevailing circumstances; and

   (c) the exempted practice is inherently without radiological significance, with no appreciable likelihood of scenarios that could lead to a failure to meet the criteria in (a) and (b).

3. Exceptionally, as provided in Article 3, individual Member States may decide that a practice may be exempted where appropriate without further consideration, in accordance with the basic criteria, even if the relevant radionuclides deviate from the values in Table A, provided that the following criteria are met in all feasible circumstances:

   (a) the effective dose expected to be incurred by any member of the public due to the exempted practice is of the order of 10 μSv or less in a year;

   and

   (b) either the collective effective dose committed during one year of performance of the practice is no more than about 1 man × Sv or an assessment of the optimization of protection shows that exemption is the optimum option.

4. For radionuclides not listed in Table A, the competent authority shall assign appropriate values for the quantities and concentrations of activity per unit mass where the need arises. Values thus assigned shall be complementary to those in Table A.

5. The values laid down in Table A apply to the total inventory of radioactive substances held by a person or undertaking as part of a specific practice at any point in time.

6. Nuclides carrying the suffix '+' or 'sec' in Table A represent parent nuclides in equilibrium with their correspondent daughter nuclides as listed in Table B. In this case the values given in Table A refer to the parent nuclide alone, but already take account of the daughter nuclide(s) present.

7. In all other cases of mixtures of more than one nuclide, the requirement for reporting may be waived if the sum of the ratios for each nuclide of the total amount present divided by the value listed in Table A is less than or equal to 1. This summation rule also applies to activity concentrations where the various nuclides concerned are contained in the same matrix.

TABLE A

Nuclide	Quantity (Bq)	Concentration (kBq/kg)	Nuclide	Quantity (Bq)	Concentration (kBq/kg)
H-3	10^9	10^6	Zn-69	10^6	10^4
Be-7	10^7	10^3	Zn-69m	10^6	10^2
C-14	10^7	10^4	Ga-72	10^5	10
O-15	10^9	10^2	Ge-71	10^8	10^4
F-18	10^6	10	As-73	10^7	10^3
Na-22	10^6	10	As-74	10^6	10
Na-24	10^5	10	As-76	10^5	10^2
Si-31	10^6	10^3	As-77	10^6	10^3
P-32	10^5	10^3	Se-75	10^6	10^2
P-33	10^8	10^5	Br-82	10^6	10
S-35	10^8	10^5	Kr-74	10^9	10^2
Cl-36	10^6	10^4	Kr-76	10^9	10^2
Cl-38	10^5	10	Kr-77	10^9	10^2
Ar-37	10^8	10^6	Kr-79	10^5	10^3
Ar-41	10^9	10^2	Kr-81	10^7	10^4
K-40	10^6	10^2	Kr-83m	10^{12}	10^5
K-42	10^6	10^2	Kr-85	10^4	10^5
K-43	10^6	10	Kr-85m	10^{10}	10^3
Ca-45	10^7	10^4	Kr-87	10^9	10^2
Ca-47	10^6	10	Kr-88	10^9	10^2
Sc-46	10^6	10	Rb-86	10^5	10^2
Sc-47	10^6	10^2	Sr-85	10^6	10^2
Sc-48	10^5	10	Sr-85m	10^7	10^2
V-48	10^5	10	Sr-87m	10^6	10^2
Cr-51	10^7	10^3	Sr-89	10^6	10^3
Mn-51	10^5	10	Sr-90+	10^4	10^2
Mn-52	10^5	10	Sr-91	10^5	10
Mn-52m	10^5	10	Sr-92	10^6	10
Mn-53	10^9	10^4	Y-90	10^5	10^3
Mn-54	10^6	10	Y-91	10^6	10^3
Mn-56	10^5	10	Y-91m	10^6	10^2
Fe-52	10^6	10	Y-92	10^5	10^2
Fe-55	10^6	10^4	Y-93	10^5	10^2
Fe-59	10^6	10	Zr-93+	10^7	10^3
Co-55	10^6	10	Zr-95	10^6	10
Co-56	10^5	10	Zr-97+	10^5	10
Co-57	10^6	10^2	Nb-93m	10^7	10^4
Co-58	10^6	10	Nb-94	10^6	10
Co-58m	10^7	10^4	Nb-95	10^6	10
Co-60	10^5	10	Nb-97	10^6	10
Co-60m	10^6	10^3	Nb-98	10^5	10
Co-61	10^6	10^2	Mo-90	10^6	10
Co-62m	10^5	10	Mo-93	10^8	10^3
Ni-59	10^8	10^4	Mo-99	10^6	10^2
Ni-63	10^8	10^5	Mo-101	10^6	10
Ni-65	10^6	10	Tc-96	10^6	10
Cu-64	10^6	10^2	Tc-96m	10^7	10^3
Zn-65	10^6	10	Tc-97	10^8	10^3

Nuclide	Quantity (Bq)	Concentration (kBq/kg)
Tc-97m	10^7	10^3
Tc-99	10^7	10^4
Tc-99m	10^7	10^2
Ru-97	10^7	10^2
Ru-103	10^6	10^2
Ru-105	10^6	10
Ru-106+	10^5	10^2
Rh-103m	10^8	10^4
Rh-105	10^7	10^2
Pd-103	10^8	10^3
Pd-109	10^6	10^3
Ag-105	10^6	10^2
Ag-108m+	10^6	10
Ag-110m	10^6	10
Ag-111	10^6	10^3
Cd-109	10^6	10^4
Cd-115	10^6	10^2
Cd-115m	10^6	10^3
In-111	10^6	10^2
In-113m	10^6	10^2
In-114m	10^6	10^2
In-115m	10^6	10^2
Sn-113	10^7	10^3
Sn-125	10^5	10^2
Sb-122	10^4	10^2
Sb-124	10^6	10
Sb-125	10^6	10^2
Te-123m	10^7	10^2
Te-125m	10^7	10^3
Te-127	10^6	10^3
Te-127m	10^7	10^3
Te-129	10^6	10^2
Te-129m	10^6	10^3
Te-131	10^5	10^2
Te-131m	10^6	10
Te-132	10^7	10^2
Te-133	10^5	10
Te-133m	10^5	10
Te-134	10^6	10
I-123	10^7	10^2
I-125	10^6	10^3
I-126	10^6	10^2
I-129	10^5	10^2
I-130	10^6	10
I-131	10^6	10^2
I-132	10^5	10
I-133	10^6	10
I-134	10^5	10
I-135	10^6	10
Xe-131m	10^4	10^4
Xe-133	10^4	10^3
Xe-135	10^{10}	10^3
Cs-129	10^5	10^2
Cs-131	10^6	10^3
Cs-132	10^5	10
Cs-134m	10^5	10^3
Cs-134	10^4	10
Cs-135	10^7	10^4
Cs-136	10^5	10
Cs-137+	10^4	10
Cs-138	10^4	10
Ba-131	10^6	10^2
Ba-140+	10^5	10
La-140	10^5	10
Ce-139	10^6	10^2
Ce-141	10^7	10^2
Ce-143	10^6	10^2
Ce-144+	10^5	10^2
Pr-142	10^5	10^2
Pr-143	10^6	10^4
Nd-147	10^6	10^2
Nd-149	10^6	10^2
Pm-147	10^7	10^4
Pm-149	10^6	10^3
Sm-151	10^8	10^4
Sm-153	10^6	10^2
Eu-152	10^6	10
Eu-152m	10^6	10^2
Eu-154	10^6	10
Eu-155	10^7	10^2
Gd-153	10^7	10^2
Gd-159	10^6	10^3
Tb-160	10^6	10
Dy-165	10^6	10^3
Dy-166	10^6	10^3
Ho-166	10^5	10^3
Er-169	10^7	10^4
Er-171	10^6	10^2
Tm-170	10^6	10^3
Tm-171	10^8	10^4
Yb-175	10^7	10^3
Lu-177	10^7	10^3
Hf-181	10^6	10
Ta-182	10^4	10
W-181	10^7	10^3
W-185	10^7	10^4
W-187	10^6	10^2
Re-186	10^6	10^3
Re-188	10^5	10^2
Os-185	10^6	10
Os-191	10^7	10^2
Os-191m	10^7	10^3

Nuclide	Quantity (Bq)	Concentration (kBq/kg)
Os-193	10^6	10^2
Ir-190	10^6	10
Ir-192	10^4	10
Ir-194	10^5	10^2
Pt-191	10^6	10^2
Pt-193m	10^7	10^3
Pt-197	10^6	10^3
Pt-197m	10^6	10^2
Au-198	10^6	10^2
Au-199	10^6	10^2
Hg-197	10^7	10^2
Hg-197m	10^6	10^2
Hg-203	10^5	10^2
Tl-200	10^6	10
Tl-201	10^6	10^2
Tl-202	10^6	10^2
Tl-204	10^4	10^4
Pb-203	10^6	10^2
Pb-210+	10^4	10
Pb-212+	10^5	10
Bi-206	10^5	10
Bi-207	10^6	10
Bi-210	10^6	10^3
Bi-212+	10^5	10
Po-203	10^6	10
Po-205	10^6	10
Po-207	10^6	10
Po-210	10^4	10
At-211	10^7	10^3
Rn-220+	10^7	10^4
Rn-222+	10^8	10
Ra-223+	10^5	10^2
Ra-224+	10^5	10
Ra-225	10^5	10^2
Ra-226+	10^4	10
Ra-227	10^6	10^2
Ra-228+	10^5	10
Ac-228	10^6	10
Th-226+	10^7	10^3
Th-227	10^4	10
Th-228+	10^4	1
Th-229+	10^3	1
Th-230	10^4	1
Th-231	10^7	10^3
Th-232sec	10^3	1
Th-234+	10^5	10^3
Pa-230	10^6	10
Pa-231	10^3	1
Pa-233	10^7	10^2
U-230+	10^5	10

Nuclide	Quantity (Bq)	Concentration (kBq/kg)
U-231	10^7	10^2
U-232+	10^3	1
U-233	10^4	10
U-234	10^4	10
U-235+	10^4	10
U-236	10^4	10
U-237	10^6	10^2
U-238+	10^4	10
U-238sec	10^3	1
U-239	10^6	10^2
U-240	10^7	10^3
U-240+	10^6	10
Np-237+	10^3	1
Np-239	10^7	10^2
Np-240	10^6	10
Pu-234	10^7	10^2
Pu-235	10^7	10^2
Pu-236	10^4	10
Pu-237	10^7	10^3
Pu-238	10^4	1
Pu-239	10^4	1
Pu-240	10^3	1
Pu-241	10^5	10^2
Pu-242	10^4	1
Pu-243	10^7	10^3
Pu-244	10^4	1
Am-241	10^4	1
Am-242	10^6	10^3
Am-242m+	10^4	1
Am-243+	10^3	1
Cm-242	10^5	10^2
Cm-243	10^4	1
Cm-244	10^4	10
Cm-245	10^3	1
Cm-246	10^3	1
Cm-247	10^4	1
Cm-248	10^3	1
Bk-249	10^6	10^3
Cf-246	10^6	10^3
Cf-248	10^4	10
Cf-249	10^3	1
Cf-250	10^4	10
Cf-251	10^3	1
Cf-252	10^4	10
Cf-253	10^5	10^2
Cf-254	10^3	1
Es-253	10^5	10^2
Es-254	10^4	10
Es-254m	10^6	10^2
Fm-254	10^7	10^4
Fm-255	10^6	10^3

TABLE B

List of nuclides in secular equilibrium as referred to in point 6 of this Annex

Parent nuclide	Daughter nuclides
Sr-80+	Rb-80
Sr-90+	Y-90
Zr-93+	Nb-93m
Zr-97+	Nb-97
Ru-106+	Rh-106
Ag-108m+	Ag-108
Cs-137+	Ba-137
Ba-140+	La-140
Ce-134+	La-134
Ce-144+	Pr-144
Pb-210+	Bi-210, Po-210
Pb-212+	Bi-212, Tl-208, Po-212
Bi-212+	Tl-208, Po-212
Rn-220+	Po-216
Rn-222+	Po-218, Pb-214, Bi-214, Po-214
Ra-223+	Rn-219, Po-215, Pb-211, Bi-211, Tl-207
Ra-224+	Rn-220, Po-216, Pb-212, Bi-212, Tl-208, Po-212
Ra-226+	Rn-222, Po-218, Pb-214, Bi-214, Pb-210, Bi-210, Po-210, Po-214
Ra-228+	Ac-228
Th-226+	Ra-222, Rn-218, Po-214
Th-228+	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208, Po-212
Th-229+	Ra-225, Ac-225, Fr-221, At-217, Bi-213, Po-213, Pb-209
Th-232sec	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208, Po-212
Th-234+	Pa-234m
U-230+	Th-226, Ra-222, Rn-218, Po-214
U-232+	Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208, Po-212
U-235+	Th-231
U-238+	Th-234, Pa-234m
U-238sec	Th-234, Pa-234m, U-234, Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Pb-210, Bi-210, Po-210, Po-214
U-240+	Np-240
Np-237+	Pa-233
Am-242m+	Am-242
Am-243+	Np-239