Hungarian Atomic Energy Authority

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Guideline PP-1

Categorization of nuclear materials, radioactive sources and radioactive wastes

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FOREWORD by the director general

The Hungarian Atomic Energy Authority (hereinafter referred to as HAEA) is a central state administration organ (a so-called government office) having nation-wide competence in the field of peaceful use of atomic energy; it operates under the direction of the Government, it has independent tasks and scope of authority. The HAEA was established in 1990 by the Government of the Republic of Hungary with Govt. decree 104/1990. (XII. 15.) Korm. on the scope of tasks and competence of the Hungarian Atomic Energy Commission and the OAH.

The public service of the HAEA as defined in law is to perform and coordinate, independently of organizations having interest in the application of atomic energy, the regulatory tasks in relation to the peaceful and safe use of atomic energy, including the safety of nuclear facilities and materials, nuclear emergency response and nuclear security, and the corresponding public information activity, and to make proposal to develop and amend, and to offer an opinion on proposed legislations corresponding to the use of atomic energy.

The fundamental nuclear safety objective is to ensure the protection of individuals and groups of the population and of the environment against the hazards of ionising radiation. This is ensured with effective safety measures implemented and adequately maintained in the nuclear facility.

The radiation protection objective is to keep the radiation exposure of the operating personnel and the public all times below the prescribed limits and as low as reasonable achievable. This shall be ensured in the case of radiation exposures occurring during design basis accidents, and as far as reasonably possible during beyond design basis accidents and severe accidents.

The technical safety objective is to prevent or avoid the occurrence of accidents with high confidence, and the potential consequences occurring in the case of every postulated initiating event taken into account in the design of the nuclear facility shall remain within acceptable extent, and the probability of severe accidents shall be adequately low.

The HAEA determines the way how the regulations should be implemented in guidelines containing clear, unambiguous recommendations in agreement with the users of atomic energy. These guidelines are published and accessible to every members of the public. The guidelines regarding the implementation of nuclear safety, security and non-proliferation requirements for the use of atomic energy are published by the director general of the HAEA.

FOREWORD

The internationally accepted bases of physical protection are represented by the Law Order 8 of 1987 on the promulgation of the International Convention on the Physical Protection of Nuclear Materials, the Act LXII of 2008 on the promulgation of the Amendment to the Convention on Physical Protection of Nuclear Materials approved in the frame of the International Atomic Energy Agency and promulgated by Law-decree 8 of 1987 amended by a Diplomatic Conference organized by the IAEA signed on July 8, 2005, and the Act XX of 2007 on the promulgation of the International Convention for the Suppression of Acts of Nuclear Terrorism.

The realization of the stipulations undertaken by Hungary, at the highest level, is represented by the Act CXVI of 1996 (hereinafter referred to as Atomic Act), which includes the fundamental security principles and establishes the frame of the detailed physical protection regulations.

The Govt. decree 190/2011. (IX. 19.) Korm. published based on the authorization of the Act (hereinafter referred to as Government Decree) establishes the legal requirements for the physical protection of the use of atomic energy and for the connecting licensing, reporting and inspection system.

The HAEA is authorized to develop recommendations regarding the implementation of requirements established in laws, which are published in the form of guidelines and made accessible on the website of the HAEA.

For the fast and smooth conduct of licensing and inspection procedures connecting to the regulatory oversight activity, the Authority encourages the licensees to take into account the recommendations of the guidelines to the extent possible.

If methods different from those laid down in the regulatory guidelines are applied, then the Authority shall conduct an in-depth examination to determine if the applied method is correct, adequate and full scope, which may entail a longer regulatory procedure, involvement of external experts and extra costs.

The guidelines are revised regularly as specified by the HAEA or out of turn if initiated by a licensee.

The regulations listed are supplemented by the internal regulations of the licensees and other organizations contributing to the use of atomic energy (designers, manufacturers etc.), which shall be developed and maintained according to their quality management systems.

Before applying a given guideline, always make sure whether the newest, effective version is considered. The valid guidelines can be downloaded from the HAEA's website: http://www.oah.hu.

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1. INTRODUCTION

1.1. Scope and objective of the guideline

The guideline contains recommendations on how to meet the provisions of the Decree on physical protection requirements for various applications of atomic energy and the corresponding system of licensing, reporting and inspection.

It provides detailed guidance and practical examples for the categorization of nuclear materials, radioactive sources and radioactive wastes as required for the determination of the minimum level of physical protection against unauthorized removal and sabotage.

Guideline PP-15 deals with the preparation of the physical protection plan required for the transport of nuclear and other radioactive materials.

Guideline PP-8 provides guidance on how to design the physical protection of a nuclear facility (with the exemption of that equipped with a reactor having less than 1 MW thermal power), an interim storage facility and of a final repository of radioactive wastes.

1.2. Corresponding laws and regulations

Legal background of nuclear security requirements are provided by the Atomic Act and the Decree and the following provisions:

a) Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5), IAEA Nuclear Security Series No. 13, IAEA, 2011.

b) Nuclear Security Recommendations on Radioactive Material and Associated Facilities, IAEA Nuclear Security Series No. 14, IAEA, 2011.

2. DEFINITIONS

In addition to the definitions in Section 2 of the Atomic Act and Section 2 of the Decree, this guideline uses the following definitions:

Unacceptable radiological consequence: a consequence of sabotage directed against a nuclear facility, nuclear material, a radioactive source or radioactive waste is unacceptable if it cause or might cause nuclear emergency. Furthermore, if the sabotage causes substantial exceedance of the dose limits for individuals or group of individuals in a short period or it is suitable to cause such extra radiation exposure.

Authority: the Hungarian Atomic Energy Authority and the National Police Headquarters.

3. RECOMMENDATIONS

3.1. General considerations

During the design of the physical protection system, the applicability of the material to build a nuclear or radiological weapon and the potential radiological and safety consequences of an adversary act with such material or sabotage against material, a system or a component should be taken into account.

In order to implement a graded approach, various security levels are specified for the physical protection of materials having different attractiveness and hazard.

In order to determine the minimum required level of physical protection, the nuclear materials, radioactive sources and radioactive wastes under the possession of the obligant should be categorized.

3.2. Categorization of nuclear materials

3.2.1. Conditions, categorization

According to Subsection 4 (1)-(3) of the Decree:

a) Irradiated and unirradiated nuclear materials shall be categorized from the aspect of protection against unauthorized removal, and the unirradiated nuclear materials shall be categorized from the aspect of protection against sabotage based on the fissile material content according to Table 1 of the Annex.

b) Irradiated nuclear materials shall be categorized from the aspect of protection against sabotage based on Cs-137 content according to Table 2 of Annex 1, with the stipulation that irrespective of its quantity the irradiated nuclear fuel shall belong to Category 1 of Table 2 of the Annex.

c) In the course of categorization from the aspect of unauthorized removal of nuclear material the total amount of nuclear material of the same type used, stored within the same physical protection zone or simultaneously transported shall be *taken into account, while the various materials shall be taken into account independently of each other.*

In order to determine the physical protection to be established during the use, storage and transport of nuclear materials, two scenarios should be taken into account in the categorization. According to the first scenario (unauthorized removal of nuclear material) if a group owing appropriate knowledge and technical preparedness removes fissile material, it can produce a nuclear weapon. In this case the categorization rests on the applicability of the material to prepare a nuclear weapon (attractiveness). This case is addressed by Subsection 4 (3) of the Decree, according to which the various types of fissile materials shall be categorized independently of each other.

According to the other scenario, sabotage is committed against the material (sabotage against radioactive material) or a radiological dispersion device is intended to be developed from that (unauthorized removal of radioactive material). In this case the categorization rests on the threat meant by the radioactive material contained in the nuclear material.

3.2.2. Categorization according to applicability to prepare a nuclear weapon

Categorization according to applicability to prepare a nuclear weapon (see Table 1 of the Annex) is based on material properties as follows:

a) material type (plutonium, uranium-235 or uranium-233);

b) isotope composition of the material;

c) radiation level of the material.

During the use of the table, the initial fissile material content of the material should be taken into account. For example for the purpose of categorization 15 kg uranium-235 of 20% initial enrichment is equivalent to 3 kg uranium-235 fissile material content.

The category of such nuclear fuel, which was considered as Category I or II based on its original fissile material content, can be reduced by one category (e.g. from Category II to Category III) if the radiation level from the fuel at 1 m distance exceeds 1 Gy/h without shielding.

Regarding nuclear materials of different type and composition, the categorization is a more complex task. It is important that based on the table the material of the same composition should be summed up only in the rows of the table, so the category of materials of different composition cannot be increased arbitrarily. (For example if 490 g of Plutonium and 950 g of Uranium-235 of 40% enrichment is stored at a site then all of these should be categorized to Category III and it should not be increased to Category II. On the other hand, if in addition, 12 kg Uranium-235 of 19% enrichment is stored at the same site, which belongs then to Category II, the protection of the whole site or the whole building within the site should be designed according to Category II requirements.) It can be considered as an organizing principle that the level of physical protection should be adjusted to the highest categorized nuclear material applied or stored in/at the specific building/site.

It is important to note that if materials of different categories are stored at the same site but in various buildings, then it is not required to protect the whole site according to the highest category, it is enough to protect that specific building by appropriate means, in which the nuclear material of higher category is stored.

Determination of radiation level may take place by measurements in air or water, or by calculation. It is recommended to perform the measurements in water and then to perform the calculation at a distance of 1 meter without shielding. Where it is appropriate, the measurements should be performed for each fuel assemblies separately. In this case the measured element should be separated from the others. If it is feasible, however, the measurement of more than one fuel element can serve reliable result. Following the measures performed under water at a given distance from the axial shaft of the fuel element and at more positions from the center of the fuel element, the level of radiation generated by the fuel assembly at 1 meter distance in air should be recalculated.

3.2.3. Categorization according to applicability to sabotage and preparation of a radiological dispersion device

Categorization of nuclear materials according to applicability to sabotage and preparation of a radiological dispersion device should be performed in line with Table 2 of the Annex based on the contained Cs-137 activity, with the exemption that the irradiated nuclear fuel, from the aspect of protection against sabotage is equivalent to a radioactive source in Category 1 according to Table 2 of the Annex, irrespective of its amount.

Section 3.3 provides guidance on how to apply Table 2 of the Annex.

3.2.4. Examples how to make the categorization according to applicability to prepare a nuclear weapon

Nuclear fuel of the Budapest Research Reactor

The enrichment of a new low enriched nuclear fuel element of the Budapest Research Reactor is 19.7 ±0.3%, its U-235 content is 50±0.5g. Accordingly, 1 fuel element cannot be categorized, since its U-235 content does not reach even the lower limit of Category III.

At the same time, a shipment of more fuel assemblies, which consist of at least 21 elements, belongs to Category III, because its U-235 content definitely exceeds 1 kg (*U-235 content of only 20 assemblies may be under 1 kg in a special case*).

If it comes to 203 pieces or more fuel assemblies, the shipment should fall in Category II, because its total U-235 content exceeds 10 kg.

Similar approach should be applied for the use or storage of fuel assemblies.

Nuclear fuel of Paks NPP

Uranium content of the profiled fuel assemblies having 4.2% enrichment of Paks NPP is 120 ± 1.5 kg, so each of them has the minimum U-235 content of ~4.977 kg. One fresh fuel assembly therefore is not enough to reach Category III, because the lower limit of the category in this case is 10 kg. On the other hand 2 assemblies already exceed this limit, so they, together, shall belong to category III.

Nuclear materials of different type and composition

In the case when nuclear materials of different type and composition are stored at a specific site, the categorization and respective determination of the physical protection of the site or building(s) should always take place according to the highest of the categories of the different nuclear materials. It might take place that 4-4 kg uranium of higher than 20% enrichment is stored at the same site in two separate buildings. These materials should be classified to Category II one by one, but because they are at the same site (with the same protection), and if instead of separately strengthening the physical protection of the buildings, appropriate protection of the site is chosen to be ensured, then the materials together should belong to Category I and, accordingly, the site should be provided with that level of protection.

3.3. Categorization of radioactive sources

3.3.1. Conditions, categorization

According to Subsections 4 (4), (5) and (7) of the Decree:

a) The radioactive sources used, stored or transported individually shall be categorized according to their activity and the isotope-specific normalization factor per Table 2 of the Annex.

b) In the course of categorization of the radioactive sources used or stored within the same physical protection zone or transported together the sum of R values determined by isotopes according to Table 2 of the Annex shall be taken into account.

Categorization of radioactive sources should take place according to the threat they may cause. Based on that the sources should be characterized according to the so-called A/D quotient, where ***A*** is the activity of the radioactive source and ***D*** is a pre-defined normalization factor, the value of which can be found for each isotope in Table 4 of the Annex. The higher is the quotient, the higher is the potential threat meant by the radioactive source to human health. Based on the A/D value the various sources should be grouped into 5 categories. Category 1 sources, if they are out of regulatory control or are inadequately processed from radiation protection or safety points of view, may cause deterministic health effects or fatality, while Category 5 sources do not pose (significant) threat to health even if inadequately processed.

3.3.2. Threat categories

3.3.2.1. Category 1 radioactive sources – extremely dangerous

Such a radioactive source, if being out of regulatory control and not safely managed or securely protected, would likely cause permanent, deterministic injury or fatality due to the radiation exposure to a person who handled it for a period of a few minutes to one hour. This amount of radioactive material may cause permanent damage to life within a few minutes spent in the vicinity of the source. It would probably be fatal to be close to this amount of unshielded radioactive material for a period in the range of a few minutes to an hour.

This amount of radioactive material, if dispersed by fire or explosion, could possibly – although unlikely – permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a few hundred meters away, but contaminated areas would need to be cleaned in accordance with international standards. The area to be cleaned is a function of several factors (i.e. size of the source, weather conditions and circumstances of dispersion). For large sources the area to be cleaned up could be a square kilometer or even more.

3.3.2.2. Category 2 radioactive sources – very dangerous

This radioactive source, if being out of regulatory control and not safely managed or securely protected, would likely cause permanent, deterministic injury or fatality due to the radiation exposure to a person who handled it for a period of a few hours to a few days. This amount of radioactive material may cause permanent damage to life within a few hours spent in the vicinity of the source. It would probably be fatal to be close to this amount of unshielded radioactive material for a period in the range of a few hours to a few days.

This amount of radioactive material, if dispersed by fire or explosion, could possibly – although it would be very unlikely – permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a hundred meters or so away, but contaminated areas would need to be cleaned in accordance with international standards. The area to be cleaned is a function of several factors (i.e. size of the source, weather conditions and circumstances of dispersion), but would probably not exceed a square kilometer.

3.3.2.3. Category 3 radioactive sources – dangerous

This radioactive source, if removed from regulatory control and not safely managed or securely protected, would likely cause permanent, deterministic injury or fatality due to the radiation exposure to a person who handled it for a period of a few days to a few weeks. This amount of radioactive materials may cause permanent damage within a few days spent in the vicinity of the source. It would probably be fatal to be close to this amount of unshielded radioactive material for a period in the range of a few days to a few weeks.

This amount of radioactive material, if dispersed by fire or explosion, could possibly – although unlikely – permanently injure or be life threatening to persons in the immediate vicinity. There would be little or no risk of immediate health effects to persons beyond a few meters away, but contaminated areas would need to be cleaned up in accordance with international standards. The area to be cleaned up is a function of several factors (i.e. size of the source, weather conditions and circumstances of dispersion), but would probably not exceed a portion of a square kilometer.

3.3.2.4. Category 4 radioactive sources – unlikely to be dangerous

It is very unlikely that anyone would be permanently injured by this source. However, this amount of unshielded radioactive material, if being out of regulatory control and not safely managed or securely protected, could possibly

— although unlikely — temporarily injure someone who handled it for a period of many hours, or who was close to it for a period of many weeks.

This amount of radioactive material, if dispersed by fire or explosion, could not permanently injure persons staying in the immediate vicinity of the explosion or fire.

3.3.2.5. Category 5 radioactive sources – not dangerous

This radioactive source cannot cause permanent injury.

This amount of radioactive material, if dispersed by fire or explosion, could not permanently injure persons staying in the immediate vicinity of the explosion or fire.

3.3.3. Categorization of radioactive source that contains a mixture of radionuclides

In the course of categorization of radioactive sources that contain a mixture of radionuclides, the A/D values of the various radionuclides should be summed and the category should be determined based on the total A/D quotient.

3.3.4. Example for categorization

Radioactive so	**Activity (TBq)**	**D value (for TBq)**	**A/D quotient**	**Category**
Co-60	$6.9*10^{2}$	$3*10^{-2}$	$2.3*10^{4}$	1
Cs-137	$9.3*10^{1}$	$1*10^{-1}$	$9.3*10^{2}$	2
Ir-192	$4.8*10^{-1}$	$8*10^{-2}$	$6.0*10^{0}$	3
Ra-226	$1.8*10^{-3}$	$4*10^{-2}$	$4.5*10^{-2}$	4
Cd-109	$5.6*10^{-3}$	$2*10^{1}$	$2.8*10^{-4}$	5

3.4. Categorization of radioactive wastes

3.4.1. Steps of categorization

According to Subsections 4 (6) and (8) of the Decree:

a) The individually processed, stored or transported radioactive waste shall be categorized based on their activity and the isotope-specific normalization factor related to the specific isotope according to Table 3 of the Annex.

b) In the course of categorization of radioactive wastes processed or stored within the same physical protection zone or transported together, the value individually licensed by considering the calculated sum of R values determined by isotopes according to Table 3 of the Annex and corrected by the factor S shall be taken into account.

The categorization of radioactive wastes takes place based on the radiological threat meant by the specific waste. Categorization of wastes is similar to the categorization of radioactive sources that contain a mixture of radionuclides.

The amount of radioactive waste at a given site/building should be taken into account for the categorization. The total value of A/D summed over each radionuclide contained in the radioactive waste should determine the category:

$$R = \sum_i \frac{A_i}{D_i}$$

Four categories are defined for wastes: 1-4, where the most dangerous materials are in category 1 and category 4 means the least dangerous ones.

3.4.2. Category modification factors

Because each storage or disposal facility and each waste package are different, the following modification factors can be taken into account for the determination of the category. Agreement of the authority is required for each category change (physical protection level decrease), so the licensee should demonstrate that the given modification factor S is adequately applied. Default value of S factor is 1, which can be decreased if the condition listed below is met, but the threat category of the radioactive source should not change by more than 1.

The factors listed below belong to the scope of passive safety and security.

3.4.2.1. Activity concentration

It can be a significant factor regarding planning of unauthorized removal or sabotage. If high level waste is re-conditioned or re-packed and therefore stored as medium level waste, the category of the so processed waste can be lowered (level of physical protection can be decreased).

3.4.2.2. Dispersibility

The dispersibility of the waste is very important, since the risk of contamination of people and environment can be attributable to this property. If the waste is not in a form that is dispersible, its category can be lowered.

3.4.2.3. Robustness of the waste storage container

Storage mode of the waste focuses on retention of the waste in the storage container to avoid environmental contamination. If the storage container meets these requirements, its category can be lowered. For example if the waste is stored in a robust concrete container, it also provides appropriate radiation protection for the environment.

3.4.2.4. Accessibility

It is an important factor that how difficult is to access the container of the waste during its storage. If the waste is disposed in such a way (for example in a geological disposal facility) that prevents easy access, then its category can be lowered.

Annex

Categorization of nuclear and other radioactive materials and other systems and components important to consequences

3.4.3. Table 1 – Categorization of nuclear materials

Material	Form of appearance	Category I	Category II	Category III
Plutonium	Unirradiated	2 kg or more	Less than 2 kg, but more than 500 g	500 g or less, but more than 15 g
Uranium-235	Unirradiated[b]			
	At least 20% enrichment of U-235	5 kg or more	Less than 5 kg, but more than 1 kg	1 kg or less, but more than 15 g
	At least 10 % enrichment of U-235, but not more than 20 %		10 kg or more	Less than 10 kg, but more than 1 kg
	Less than 10 enrichment of U-235, but more than the natural level			10 kg or more
Uranium-233	Unirradiated[b]	2 kg or more	Less than 2 kg, but more than	500 g or less, but more than 15 g

			500 g	
Irradiated fuel			Depleted or natural uranium, thorium or low enriched fuel (with 10% fissile material content)	

[a] All plutonium except that with isotopic concentration exceeding 80% in plutonium;

[b] Material not irradiated in a reactor or material irradiated in a reactor but with a radiation level equal to or less than 1 Gy/h at 1 m unshielded;

[c] Other fuel which by virtue of its original fission material content is classified as Category I or II before irradiation may be increased by one category (its physical protection level can be decreased) while the radiation level form the fuel exceeds 1 Gy/h at 1 m unshielded.

3.4.4. Table 2 – Categorization of radioactive sources

A	B	C
Category	Common practice (example)	R value
1.	Radioactive Thermoelectric Generator	R ≥ 1000
	Irradiator facility	
	Teletherapy unit	
	Gamma knife	
2.	Industrial gamma radiography	1000 > R ≥ 10
	High/medium level dose brachyterapy	
3.	Industrial measurement technique	10 > R ≥ 1
	– level measurement	
	– conveyor measurements	
4.	Low dose brachyterapy	1 > R ≥ 0.01
	Wall thickness measurement	
	Portable measurements (e.g. humidity/density measurements)	
5.	X-ray fluorence instruments	0.01 > R
	Electron catching instrument	
	Mössbauer spectrometry	
	PET diagnosis	

Where $R = \sum_i \frac{A_i}{D_i}$

A_i – activity of isotope i of the radioactive source;

D_i – isotope specific normalizing factor for isotope i as defined in the Annex of Ministerial decree 11 /2010. (III.4.) KHEM issued by the Minister of transport, telecommunication and energy on the rules of accountancy for and control of radioactive materials, and on the corresponding data provisions (hereinafter referred to as KHEM decree).

3.4.5. Table 3 – Categorization of radioactive wastes

Radionuclide inventory (R)	**Category**
R ≥ 1000	1
10 ≤ R < 1000	2
1 ≤ R < 10	3
R < 1	4

Where $R = \sum_i \frac{A_i}{D_i}$, while $R_{real} = R \times S$

A_i – activity of isotope i within the radioactive waste;

D_i – isotope specific normalizing factor for isotope i as defined in the 11 /2010. (III.4.) KHEM decree;
S – factor considering the activity concentration of the radioactive waste, its dispersibility, the robustness of the radioactive waste package and its accessibility

3.4.6. Table 4 – Activities of radionuclides in terms of D activity

Radionuclide	**D activity (TBq)**
H-3	2×10^{3}
Be-7	1×10^{0}
Be-10	3×10^{1}
C-11	6×10^{-2}
C-14	5×10^{1}
N-13	6×10^{-2}
F-18	6×10^{-2}
Na-22	3×10^{-2}
Na-24	2×10^{-2}
Mg-28	2×10^{-2}
Al-26	3×10^{-2}
Si-31	1×10^{1}
Si-32	7×10^{0}
P-32	1×10^{1}
P-33	2×10^{2}
S-35	6×10^{1}
Cl-36	2×10^{1}
Cl-38	5×10^{-2}
Ar-37	∞
Ar-39	3×10^{2}
Ar-41	5×10^{-2}

Radionuclide	D activity (TBq)
K-40	∞
K-42	2×10^{-1}
K-43	7×10^{-2}
Ca-41	∞
Ca-45	1×10^{2}
Ca-47	6×10^{-2}
Sc-44	3×10^{-2}
Sc-46	3×10^{-2}
Sc-47	7×10^{-1}
Sc-48	2×10^{-2}
Ti-44	3×10^{-2}
V-48	2×10^{-2}
V-49	2×10^{3}
Cr-51	2×10^{0}
Mn-52	2×10^{-2}
Mn-53	∞
Mn-54	8×10^{-2}
Mn-56	4×10^{-2}
Fe-52	2×10^{-2}
Fe-55	8×10^{2}
Fe-59	6×10^{-2}
Fe-60	6×10^{-2}
Co-55	3×10^{-2}

Radionuclide	**D activity (TBq)**
Co-56	2×10^{-2}
Co-57	7×10^{-1}
Co-58	7×10^{-2}
Co-58m	7×10^{-2}
Co-60	3×10^{-2}
Ni-59	1×10^{3}
Ni-63	6×10^{1}
Ni-65	1×10^{-1}
Cu-64	3×10^{-1}
Cu-67	7×10^{-1}
Zn-65	1×10^{-1}
Zn-69	3×10^{1}
Zn-69m	2×10^{-1}
Ga-67	5×10^{-1}
Ga-68	7×10^{-2}
Ga-72	3×10^{-2}
Ge-68	7×10^{-2}
Ge-71	1×10^{3}
Ge-77	6×10^{-2}
As-72	4×10^{-2}
As-73	4×10^{1}
As-74	9×10^{-2}
As-76	2×10^{-1}

Radionuclide	D activity (TBq)
As-77	8×10^{0}
Se-75	2×10^{-1}
Se-79	2×10^{2}
Br-76	3×10^{-2}
Br-77	2×10^{-1}
Br-82	3×10^{-2}
Kr-81	3×10^{1}
Kr-85	3×10^{1}
Kr-85m	5×10^{-1}
Kr-87	9×10^{-2}
Rb-81	1×10^{-1}
Rb-83	1×10^{-1}
Rb-84	7×10^{-2}
Rb-86	7×10^{-1}
Rb-87	∞
Sr-82	6×10^{-2}
Sr-85	1×10^{-1}
Sr-85m	1×10^{-1}
Sr-87m	2×10^{-1}
Sr-89	2×10^{1}
Sr-90	1×10^{0}
Sr-91	6×10^{-2}
Sr-92	4×10^{-2}

Radionuclide	D activity (TBq)
Y-87	9×10^{-2}
Y-88	3×10^{-2}
Y-90	5×10^{0}
Y-91	8×10^{0}
Y-91m	1×10^{-1}
Y-92	2×10^{-1}
Y-93	6×10^{-1}
Zr-88	2×10^{-2}
Zr-93	∞
Zr-95	4×10^{-2}
Zr-97	4×10^{-2}
Nb-93m	3×10^{2}
Nb-94	4×10^{-2}
Nb-95	9×10^{-2}
Nb-97	1×10^{-1}
Mo-93	3×10^{2}
Mo-99	3×10^{-1}
Tc-95m	2×10^{-1}
Tc-96	3×10^{-2}
Tc-96m	3×10^{-2}
Tc-97	∞
Tc-97m	4×10^{1}
Tc-98	5×10^{-2}

Radionuclide	D activity (TBq)
Tc-99	3×10^{1}
Tc-99m	7×10^{-1}
Ru-97	3×10^{-1}
Ru-103	1×10^{-1}
Ru-105	8×10^{-2}
Ru-106	3×10^{-1}
Rh-99	1×10^{-1}
Rh-101	3×10^{-1}
Rh-102	3×10^{-2}
Rh-102m	1×10^{-1}
Rh-103m	9×10^{2}
Rh-105	9×10^{-1}
Pd-103	9×10^{1}
Pd-107	∞
Pd-109	2×10^{1}
Ag-105	1×10^{-1}
Ag-108m	4×10^{-2}
Ag-110m	2×10^{-2}
Ag-111	2×10^{0}
Cd-109	2×10^{1}
Cd-113m	4×10^{1}
Cd-115	2×10^{-1}
Cd-115m	3×10^{0}

Radionuclide	D activity (TBq)
In-111	2×10^{-1}
In-113m	3×10^{-1}
In-114m	8×10^{-1}
In-115m	4×10^{-1}
Sn-113	3×10^{-1}
Sn-117m	5×10^{-1}
Sn-119m	7×10^{1}
Sn-121m	7×10^{1}
Sn-123	7×10^{0}
Sn-125	1×10^{-1}
Sn-126	3×10^{-2}
Sb-122	1×10^{-1}
Sb-124	4×10^{-2}
Sb-125	2×10^{-1}
Sb-126	2×10^{-2}
Te-121	1×10^{-1}
Te-121m	1×10^{-1}
Te-123m	6×10^{-1}
Te-125m	1×10^{1}
Te-127	1×10^{1}
Te-127m	3×10^{0}
Te-129	1×10^{0}
Te-129m	1×10^{0}

Radionuclide	D activity (TBq)
Te-131m	4×10^{-2}
Te-132	3×10^{-2}
I-123	5×10^{-1}
I-124	6×10^{-2}
I-125	2×10^{-1}
I-126	1×10^{-1}
I-129	∞
I-131	2×10^{-1}
I-132	3×10^{-2}
I-133	1×10^{-1}
I-134	3×10^{-2}
I-135	4×10^{-2}
Xe-122	6×10^{-2}
Xe-123	9×10^{-2}
Xe-127	3×10^{-1}
Xe-131m	1×10^{1}
Xe-133	3×10^{0}
Xe-135	3×10^{-1}
Cs-129	3×10^{-1}
Cs-131	2×10^{1}
Cs-132	1×10^{-1}
Cs-134	4×10^{-2}
Cs-134m	4×10^{-2}

Radionuclide	D activity (TBq)
Cs-135	∞
Cs-136	3×10^{-2}
Cs-137	1×10^{-1}
Ba-131	2×10^{-1}
Ba-133	2×10^{-1}
Ba-133m	3×10^{-1}
Ba-140	3×10^{-2}
La-137	2×10^{1}
La-140	3×10^{-2}
Ce-139	6×10^{-1}
Ce-141	1×10^{0}
Ce-143	3×10^{-1}
Ce-144	9×10^{-1}
Pr-142	1×10^{0}
Pr-143	3×10^{1}
Nd-147	6×10^{-1}
Nd-149	2×10^{-1}
Pm-143	2×10^{-1}
Pm-144	4×10^{-2}
Pm-145	1×10^{1}
Pm-147	4×10^{1}
Pm-148m	3×10^{-2}
Pm-149	6×10^{0}

Radionuclide	D activity (TBq)
Pm-151	2×10^{-1}
Sm-145	4×10^{0}
Sm-147	∞
Sm-151	5×10^{2}
Sm-153	2×10^{0}
Eu-147	2×10^{-1}
Eu-148	3×10^{-2}
Eu-149	2×10^{0}
Eu-150b	2×10^{0}
Eu-150a	5×10^{-2}
Eu-152	6×10^{-2}
Eu-152m	2×10^{-1}
Eu-154	6×10^{-2}
Eu-155	2×10^{0}
Eu-156	5×10^{-2}
Gd-146	3×10^{-2}
Gd-148	4×10^{-1}
Gd-153	1×10^{0}
Gd-159	2×10^{0}
Tb-157	1×10^{2}
Tb-158	9×10^{-2}
Tb-160	6×10^{-2}
Dy-159	6×10^{0}

Radionuclide	D activity (TBq)
Dy-165	3×10^{0}
Dy-166	1×10^{0}
Ho-166	2×10^{0}
Ho-166m	4×10^{-2}
Er-169	2×10^{2}
Er-171	2×10^{-1}
Tm-167	6×10^{-1}
Tm-170	2×10^{1}
Tm-171	3×10^{2}
Yb-169	3×10^{-1}
Yb-175	2×10^{0}
Lu-172	4×10^{-2}
Lu-173	9×10^{-1}
Lu-174	8×10^{-1}
Lu-174m	6×10^{-1}
Lu-177	2×10^{0}
Hf-172	4×10^{-2}
Hf-175	2×10^{-1}
Hf-181	1×10^{-1}
Hf-182	5×10^{-2}
Ta-178a	7×10^{-2}
Ta-179	6×10^{0}
Ta-182	6×10^{-2}

Radionuclide	D activity (TBq)
W-178	9×10^{-1}
W-181	5×10^{0}
W-185	1×10^{2}
W-187	1×10^{-1}
W-188	1×10^{0}
Re-184	8×10^{-2}
Re-184m	7×10^{-2}
Re-186	4×10^{0}
Re-187	∞
Re-188	1×10^{0}
Re-189	1×10^{0}
Os-185	1×10^{-1}
Os-191	2×10^{0}
Os-191m	1×10^{0}
Os-193	1×10^{0}
Os-194	7×10^{-1}
Ir-189	1×10^{0}
Ir-190	5×10^{-2}
Ir-192	8×10^{-2}
Ir-194	7×10^{-1}
Pt-188	4×10^{-2}
Pt-191	3×10^{-1}
Pt-193	3×10^{3}

Radionuclide	D activity (TBq)
Pt-193m	1×10^{1}
Pt-195m	2×10^{0}
Pt-197	4×10^{0}
Pt-197m	9×10^{-1}
Au-193	6×10^{-1}
Au-194	7×10^{-2}
Au-195	2×10^{0}
Au-198	2×10^{-1}
Au-199	9×10^{-1}
Hg-194	7×10^{-2}
Hg-195m	2×10^{-1}
Hg-197	2×10^{0}
Hg-197m	7×10^{-1}
Hg-203	3×10^{-1}
Tl-200	5×10^{-2}
Tl-201	1×10^{0}
Tl-202	2×10^{-1}
Tl-204	2×10^{1}
Pb-201	9×10^{-2}
Pb-202	2×10^{-1}
Pb-203	2×10^{-1}
Pb-205	∞
Pb-210	3×10^{-1}

Radionuclide	D activity (TBq)
Pb-212	5×10^{-2}
Bi-205	4×10^{-2}
Bi-206	2×10^{-2}
Bi-207	5×10^{-2}
Bi-210	8×10^{0}
Bi-210m	3×10^{-1}
Bi-212	5×10^{-2}
Po-210	6×10^{-2}
At-211	5×10^{-1}
Rn-222	4×10^{-2}
Ra-223	1×10^{-1}
Ra-224	5×10^{-2}
Ra-225	1×10^{-1}
Ra-226	4×10^{-2}
Ra-228	3×10^{-2}
Ac-225	9×10^{-2}
Ac-227	4×10^{-2}
Ac-228	3×10^{-2}
Th-227	8×10^{-2}
Th-228	4×10^{-2}
Th-229	1×10^{-2}
Th-230	7×10^{-2}
Th-231	1×10^{1}

Radionuclide	D activity (TBq)
Th-232	∞
Th-234	2×10^{0}
Pa-230	1×10^{-1}
Pa-231	6×10^{-2}
Pa-233	4×10^{-1}
U-230	4×10^{-2}
U-232	6×10^{-2}
U-233	7×10^{-2}
U-234	1×10^{-1}
U-235	1×10^{-4}
U-236	2×10^{-1}
U-238	∞
U natural	∞
U depleted	∞
U enriched to 10-20%	8×10^{-4}
U enriched >20%	1×10^{-4}
Np-235	1×10^{2}
Np-236b	7×10^{-3}
Np-236a	8×10^{-1}
Np-237	7×10^{-2}
Np-239	5×10^{-1}
Pu-236	1×10^{-1}
Pu-237	2×10^{0}

Radionuclide	D activity (TBq)
Pu-238	6×10^{-2}
Pu-239	6×10^{-2}
Pu-240	6×10^{-2}
Pu-241	3×10^{0}
Pu-242	7×10^{-2}
Pu-244	3×10^{-4}
Am-241	6×10^{-2}
Am-242m	3×10^{-1}
Am-243	2×10^{-1}
Am-244	9×10^{-2}
Cm-240	3×10^{-1}
Cm-241	1×10^{-1}
Cm-242	4×10^{-2}
Cm-243	2×10^{-1}
Cm-244	5×10^{-2}
Cm-245	9×10^{-2}
Cm-246	2×10^{-1}
Cm-247	1×10^{-3}
Cm-248	5×10^{-3}
Bk-247	8×10^{-2}
Bk-249	1×10^{1}
Cf-248	1×10^{-1}
Cf-249	1×10^{-1}

Radionuclide	D activity (TBq)
Cf-250	1×10^{-1}
Cf-251	1×10^{-1}
Cf-252	2×10^{-2}
Cf-253	4×10^{-1}
Cf-254	3×10^{-4}
Pu-239/Be-9	6×10^{-2}
Am-241/Be-9	6×10^{-2}