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Definition of Nuclear Material in Aspects of Nuclear Nonproliferation and Security

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1. Introduction

In tandem with worldwide growing nuclear energy industry as well as serious accidents and threat at nuclear power plants in recent years, nuclear safety and security have become most important issues ever in nuclear history. After Fukushima accident in 2011, nuclear safety has been one of the priorities among countries with nuclear energy. Nevertheless, nuclear security is easy to be overlooked due to its different target.

This phenomenon results from the different features of nuclear safety and security: Nuclear safety protects human from nuclear material while nuclear security guards the material from human. Therefore, nuclear safety accidents directly affect human health but nuclear security incidents indirectly influence human, which demonstrates the reason why security receives less attention.

However, it is acknowledged that nuclear terrorism is indeed one of the most dreadful threat humanity faces. As part of strengthening nuclear security as well as nonproliferation to response to the threat, we need a better understanding of the nuclear material which needs to be safe under the objective of nuclear security.

In reality, practitioners implement safeguards and physical protection in compliance with the regulation text in domestic legislation. Thus, it is important to specify nuclear material clearly in law for effective implementation.

Therefore, the definition of terminology related to nuclear material is explored herein, within the highest-level legislation on the safeguards and physical protection. First the definition in Korean legislation is analyzed. Then, so as to suggest some improvements, other international efforts are examined and some case studies are conducted on other states which have similar level of nuclear technology and industry to Korea.

Finally, a draft of definition on nuclear material in perspective of nuclear nonproliferation and security is suggested based on the analysis below.

2. The Definitions in Korean Legislation

Table I: The Definitions in Korean legislation

Provided Term	Definition Text of Act	Definition Text of Presidential Decree
Nuclear materials (NSA)	Nuclear fuel materials and nuclear raw materials;	-
Nuclear fuel materials (NSA)	Materials capable of producing nuclear energy, such as uranium and thorium, as prescribed by Presidential Decree;	1. Uranium with same ratio of the isotope 235 to isotope 238 as the ratio occurring in nature and its compounds 2. Uranium with lower ratio of the isotope 235 to isotope 238 than the ratio occurring in nature and its compounds 3. Thorium and its compounds 4. Materials containing at least one material specified in 1~3, which can be used as fuel for reactors 5. Uranium with higher ratio of the isotope 235 to isotope 238 than the ratio occurring in nature and its compounds 6. Plutonium and its compounds 7. Uranium 233 and its compounds 8. Materials containing at least one material specified in paragraph 5~7
Nuclear raw materials (NSA)	Uranium ore, thorium ore, and other materials used as raw materials for nuclear fuel materials, as prescribed by Presidential Decree;	Materials containing uranium and its compounds, and thorium and its compounds excluding the "nuclear fuel materials"
Nuclear materials (APPRE)	Materials capable of producing nuclear energy, such as uranium and thorium and uranium ore, thorium ore, and other materials used as raw materials for nuclear fuel materials, as prescribed by Presidential Decree;	1. Uranium 233 and its compounds 2. Uranium 235 and its compounds 3. Thorium and its compounds 4. Plutonium (except that with isotopic concentration exceeding 80 percent in plutonium-238) and its compounds 5. Materials containing at least one material specified in paragraph 1~4 6. Materials containing uranium and its compounds,

		or thorium and its compounds besides 1~5

In Korea, definition on nuclear material is stated in Nuclear Safety Act (NSA) [1] and Enforcement Decree of the Nuclear Safety Act [2]. Despite of the title of the Act, it stipulates safeguards of nuclear material as well as safety regulation. Physical protection measures are imposed in Act on Physical Protection and Radiological Emergency (APPRE) [3] and nuclear material is somewhat defined differently from the NSA.

In the NSA, classifying nuclear material as nuclear fuel materials and nuclear raw materials seems to reflect the perspective of nuclear safety and radiation. The difference between fuel material and raw material is whether it poses any radiological harm on human health. In this context, the fuel material is of concern in nuclear safety due to its radioactivity, not the raw material.

Still, the definition of 'nuclear fuel material' raises some questions on effectiveness of the definition. It separates uranium depending on the degree of enrichment of uranium. Perhaps, it might want to mention enriched uranium, natural uranium, and depleted uranium. However, this separation seems meaningless in that all are in the same category of nuclear fuel materials.

The definition in APPRE seems more reasonable that the target of physical protection is rather clearly specified in the definition. Despite of its clarity, it still needs to be prioritized presented nuclear material: e.g. it is evident that enriched uranium fuel for light water reactor and uranium ore do not require the same level of physical protection measures.

Current definition of nuclear material in Korean legislation seems to be not adequate to elaborate the material in the sense of nuclear security. Not the radiation, how easily the material can be used to develop nuclear weapon is of importance in nuclear nonproliferation and nuclear security. In these context, there are several features of nuclear material needed to be considered; quantity, concentration, physical and chemical form, isotopic composition, irradiation status and quality. Inter alia, material type, which includes element contained and the degree of enrichment according to IAEA Safeguards Glossary [4] might be the one of most important factors to consider.

3. Other Definitions of Nuclear Material

3.1 Definitions in International Regime

Table II: Definitions in International Regime

Regime	Term	Definition Text
•IAEA Statute •CSA •AP	Special fission-able material	1. The term "special fissionable material" means plutonium-239; uranium- 233; uranium enriched in the isotopes 235 or 233; any material containing one or more of the foregoing; and such other fissionable material as the Board of Governors shall from time to time determine; but the term "special fissionable material" does not include source material. 2. The term "uranium enriched in the isotopes 235 or 233" means uranium containing the isotopes 235 or 233 or both in an amount such that the abundance ratio of the sum of these isotopes to the isotope 238 is greater than the ratio of the isotope 235 to the isotope 238 occurring in nature. 3. The term "source material" means uranium containing the mixture of isotopes occurring in nature; uranium depleted in the isotope 235; thorium; any of the foregoing in the form of metal, alloy, chemical compound, or concentrate; any other material containing one or more of the foregoing in such concentration as the Board of Governors shall from time to time determine; and such other material as the Board of Governors shall from time to time determine.
•ICSANT •CPPNM	Nuclear material	"Nuclear material" means plutonium, except that with isotopic concentration exceeding 80 percent in plutonium-238; uranium-233; uranium enriched in the isotope 235 or 233; uranium containing the mixture of isotopes as occurring in nature other than in the form of ore or ore residue; or any material containing one or more of the foregoing; Whereby "uranium enriched in the isotope 235 or 233" means uranium containing the isotope 235 or 233 or both in an amount such that the abundance ratio of the sum of these isotopes to the isotope 238 is greater than the ratio of the isotope 235 to the isotope 238 occurring in nature.
INFCIRC /225 /Rev.5	Nuclear material	1. Unirradiated* plutonium (All plutonium except that with isotopic concentration exceeding 80% in plutonium-238) 2. Unirradiated* uranium-235 3. Unirradiated* uranium-233 4. Irradiated fuel *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. (100rad/h) at 1m unshielded.

The IAEA Statute [5], IAEA INFCIRC/153 (so called Comprehensive Safeguards Agreement, CSA) [6], and INFCIRC/540(so called Additional Protocol, AP) [7] focus on special fissionable material. It does not clarify how much amount of these isotopes should be contained in a certain material.

In the document of the UN's International Convention for the Suppression of Acts of Nuclear Terrorism (ICSANT) [8] and the IAEA's Convention of the Physical Protection of Nuclear Material (CPPNM) [9], nuclear material includes natural uranium and excludes plutonium with isotopic concentration exceeding 80 percent in plutonium-238 but still focusing on the special fissionable material aforementioned.

The difference between the former and the latter definition might be the terminology and the scope of plutonium. The former only mentioned 'plutonium-239' while the latter specified 'plutonium, except that with isotopic concentration exceeding 80 percent in plutonium-238.' There might be a conflict, provided a plutonium compounds with 19% of plutonium-239 and 81% of plutonium-238. The former might (or might not, since there is no specified amount of material to be controlled) control the compound, whereas the latter will not.

Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225) [10], published by the IAEA, is one of the most widely accepted documents among its member states. Many countries, including Korea, have implemented physical protection measures according to the Recommendation. The approach of IAEA Recommendation on Physical Protection for nuclear material is rather unique. The irradiation status is focused without isotopic composition. Furthermore, it classified nuclear material as 3 categories in terms of its quantity to enable graded approach for physical protection measures. However, the type of material is somewhat limited to special fissionable material.

The international regime on nuclear security such as ICSANT, CPPNM, and INFCIRC/225/Rev.5 suggest what nuclear material of concern is in a row. While it might be clear to professionals, newcomers in nuclear security might wonder why these materials are chosen, if without any explanations.

3.2 Case Studies

The case studies were conducted on the act of safeguards and physical protection in other countries. Canada and Japan were selected since they have the most similar environment with Korea being non-nuclear weapon states and nuclear export country. The regulation of France, Russian Federation, United Kingdom, and United States were also probed as advanced nuclear suppliers.

The texts referred are from the highest-level legislation of each country. The below is the founding from the case studies.

Table III: Definitions in Laws of Other Countries

Country	Act	Definition Text
Canada [11]	Nuclear Safety and Control Act	"Nuclear substance" means (*a*) deuterium, thorium, uranium or an element with an atomic number greater than 92; (*b*) a derivative or compound of deuterium, thorium, uranium or of an element with an atomic number greater than 92; (*c*) a radioactive nuclide; (*d*) a substance that is prescribed as being capable of releasing nuclear energy or as being required for the production or use of nuclear energy; (*e*) a radioactive by-product of the development, production or use of nuclear energy; and (*f*) a radioactive substance or radioactive thing that was used for the development or production, or in connection with the use, of nuclear energy.
Japan [12] [13]	• Atomic Energy Basic Act	• The term "Nuclear Fuel Materials" means materials that emit high energy in the process of nuclear fission, such as uranium and thorium which are specified by Cabinet Order; • The term "Nuclear Source Materials" means materials that are used as the raw materials of nuclear fuel materials, such as uranium ore and thorium ore, which are specified by Cabinet Order;
	•Act on the Regula-tion of Nuclear Source Material, Nuclear Fuel Material and Reactors	•The term "specified nuclear fuel material" as used in this Act means plutonium (excluding that having an isotopic concentration of plutonium 238 exceeding 80 percent), uranium 233, uranium with a ratio of uranium 233 and uranium 235 to uranium 238 exceeding the ratio of natural composition and other nuclear fuel material specified by Cabinet Order.
France [14] [15]	•Defense Code Article L1333-1	•The nuclear material fusible, fissile or fertile materials and any material containing one or more fusible, fissile or fertile elements, excluding ores whose list is specified by Order in Council of State
	•Defense Code Article R1333-1	•The list of fusible material, fissile or fertile mentioned in Article L1333-1 of the Code includes plutonium, uranium, thorium,

		deuterium, tritium and lithium 6
Russian Federation [16]	Federal Law No.170 of the Russian Federation on the Use of Atomic Energy	Nuclear materials – materials which contain or are capable of generating fissile(fissionable) nuclear substances;
United Kingdom [17] [18]	•Energy Act 2013 •Anti-terrorism, Crime and Security Act 2001	• "nuclear material" means any fissile material in the form of— (i) uranium metal, alloy or compound; or (ii) plutonium metal, alloy or compound; or any other fissile material prescribed by regulations made by the Secretary of State; • "nuclear material" means— (a) any fissile material in the form of— (i) uranium metal, alloy or chemical compound; or (ii) plutonium metal, alloy or chemical compound;
United States [19]	Atomic Energy Act of 1954	The term "special nuclear material" means (1) plutonium, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51, determines to be special nuclear material, but does not include source material; or (2) any material artificially enriched by any of the foregoing, but does not include source material.

• Canada which invented the heavy water reactor included the deuterium in its control text. The 'element with an atomic number greater than 92' enables to control all the transuranic elements including plutonium, which broadens the scope of control.

• The Japanese control text is the most similar to the Korean.

• The French legislation including fusible material such as deuterium, tritium, and lithium-6 might be explained with the world's largest experimental tokamak nuclear fusion reactor, International Thermonuclear Experimental Reactor or ITER.

• Russia's control text only suggests what nuclear material is without any condition of elements or isotopes.

• United Kingdom's definition is rather broad and simple, which mentions only uranium and plutonium. A notable thing is the definition of nuclear material in Energy Act is consistent with the one in legislation in nuclear security.

• The definition of United States is similar to IAEA's.

The scope of special fissionable material generally follows the IAEA's definition as shown in legislation of Japan and U.S. although the words are not exactly same.

3.3 International efforts to define nuclear material

Table IV: Definitions in Other International Documents

International Panel on Fissile Materials	Fissile material	i) Plutonium of any isotopic composition except plutonium that contains 80 percent or more plutonium-238 ii) Uranium containing uranium-235 and/or uranium-233 in a weighted concentration equivalent to or greater than 20 percent uranium-235 iii) Any other fissile material suitable for the manufacture of nuclear weapons as agreed to in a protocol to this treaty iv) Material containing any combination of the foregoing
IAEA Safeguards Glossary	•Special fissionable material •Fissionable material (Fissile material) •Fertile material •Direct use material	• Plutonium-239; uranium-233; uranium enriched in the isotopes 235 or 233; any material containing one or more of the foregoing •In general, an isotope or a mixture of isotopes capable of nuclear fission. Some fissionable materials are capable of fission only by sufficiently fast neutrons (e.g. neutrons of a kinetic energy above 1 MeV). Isotopes that undergo fission by neutrons of all energies, including slow (thermal) neutrons, are usually referred to as fissile materials or fissile isotopes. For example, isotopes 233U, 235U, 239Pu and 241Pu are referred to as both fissionable and fissile, while 238U and 240Pu are fissionable but not fissile. •A nuclear material which can be converted into a special fissionable material through capture of one neutron per nucleus. There are two naturally occurring fertile materials: 238U and 232Th. Through the capture of neutrons followed by two beta decays, these fertile materials are converted to fissionable 239Pu and 233U, respectively. •Nuclear material that can be used for the manufacture of nuclear explosive devices without

		transmutation or further enrichment. It includes plutonium containing less than 80% 238Pu, high enriched uranium and 233U. Chemical compounds, mixtures of direct use materials (e.g. mixed oxide (MOX)), and plutonium in spent reactor fuel fall into this category. Unirradiated direct use material is direct use material which does not contain substantial amounts of fission products; it would require less time and effort to be converted to components of nuclear explosive devices than irradiated direct use material (e.g. plutonium in spent reactor fuel) that contains substantial amounts of fission products.
	•Indirect use material	•All nuclear material except direct use material. It includes: depleted, natural and low enriched uranium, and thorium, all of which must be further processed in order to produce direct use material.

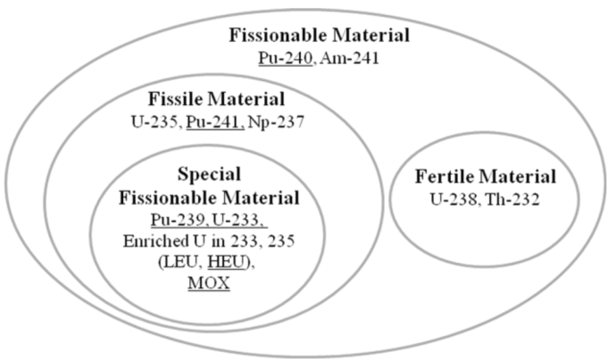

Fig. 1. Categorization of Nuclear Material based on IAEA Safeguards Glossary (underlined materials are 'direct use material')

Besides international regime which reached global consensus, there are efforts to define nuclear material among states.

The International Panel on Fissile Materials (IPFM) tries to present draft of Fissile Material Cut-off Treaty (FMCT) [20] with brief explanations. It is explicit in composition of isotopes in its 1st and 2nd paragraph.

IAEA Safeguards Glossary provides definition of terminology aforementioned such as special fissionable material, fissionable material, fissile material, and fertile material. In addition, it suggests another category for classifying nuclear material such as 'direct use material' and 'indirect use material.'

In terms of IAEA's definition, fissionable material should be of concern. Among fissile material, special fissionable material should be stressed in connection with its convenience of diversion to nuclear weapon.

Direct use material and indirect use material might provide most desirable definition in the light of timely detection as a goal of nuclear nonproliferation. Nonetheless, whether a material could be used for the manufacture of nuclear explosive devices directly or indirectly might be controversial depending on the strength and effectiveness of the devices. Some material might be clear to determine the necessity of process while others not.

According to the explanations by IPFM, the draft FMCT employs the 'direct use material' of the IAEA's definition in its definition of 'fissile material.' Therefore, the fissile material of IPFM might not correspond to that of the IAEA. For example, the IAEA includes low enriched uranium (LEU) in 'fissile material' as 'isotopes that undergo fission by neutrons of all energies, including slow (thermal) neutrons.' The IPFM does not include LEU in its 'fissile material' since it is indirect use material.

4. Recommendation

By benchmarking best practices, definition of nuclear material could be suggested. The draft should contain explanation for why certain materials are classified under certain terminology and it should be clear and easy to understand for practitioners in nuclear nonproliferation and security. Since the IAEA's definitions and terminologies are widely understood among the experts, it seems to be necessary to fully utilize these definitions.

Below is a draft definition of nuclear material in light of nuclear nonproliferation and security:

[DRAFT]

Article XX.

1. Nuclear material of question in this act means nuclear fissionable material which includes fissile and fertile material.

2. Fissionable material is an isotope or a mixture of isotopes capable of nuclear fission, including fissile and fertile material.

i) Fissile material is isotopes or a mixture of isotopes that undergo fission by neutrons of all energies, including slow (thermal) neutrons such as special fissionable materials, uranium-235, plutonium-241, and neptunium-237.

   a) Special fissionable materials aforementioned are plutonium-239, uranium-233, uranium enriched in the isotopes 235 or 233(including low enriched uranium and high enriched uranium), and mixed oxide (MOX).

   b) Mixed oxide (MOX) is a mixture of the oxides of uranium and plutonium used as reactor fuel for the recycling of plutonium in thermal nuclear reactors and for fast reactors.

ii) Fertile material is a nuclear material which can be converted into a special fissionable material through capture of one neutron per nucleus such as U-238 and Th-232.

3. The nuclear material might include other fissionable material as the Chairman of Nuclear Safety and Security Commission shall from time to time determine.

5. Conclusions

The recommendation showed the draft nuclear material definition in nuclear control. The text will facilitate the understanding of nuclear material in the context of nuclear nonproliferation and security. It might provide appropriate provision for future legislation related to nuclear nonproliferation and security. For effective safeguards and physical protection measures, nuclear material should be presented with in a consistent manner as shown in the case of United Kingdom.

It will be much more helpful if further material engineering studies on each nuclear material are produced. Multi-dimensional approach is required for the studies on the degree of efforts to divert nuclear material to nuclear explosive devices, e.g. IAEA's 'direct use material' and 'indirect use material.'

The state-specific materials should be considered in the case of Canada and France, deuterium and fusible material respectively. Korea does not have any consideration on building any additional heavy water reactors and exporting them. However, since it has actively participated ITER project, control of fusible material such as deuterium, tritium, and lithium-6 might be considered hereafter.

For further studies, diverse aspects of nuclear material should be examined. If so, regulation might detail in quantity, concentration, physical and chemical form, isotopic composition, irradiation status and quality of nuclear material to take more effective measures of safeguards and physical protection.

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