

International standards for safe management of radioactive waste

المعايير الدولية للإدارة الآمنة للنفايات المشعة

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Abstract:

Most modern industries rely on nuclear energy, the threat posed to humans and nature by radioactive waste is particularly a result of the ionizing radiation released during the radioactive decay of this material. The methods of managing radioactive waste are from the easiest to the most difficult, on the physical, technological level. However, the treatment of international law and IAEA did not differentiate between types of radioactive waste. All radioactive waste poses a threat to international peace and security. It is therefore necessary a safely manage radioactive waste accumulated.

key words: management, radioactive waste, nuclear energy, IAEA, nuclear Security, nuclear peace.

المخلص :

تعتمد معظم الصناعات الحديثة على الطاقة النووية ، والتهديد الذي تشكله النفايات المشعة على الإنسان والطبيعة ناتج بشكل خاص عن الإشعاع المؤين المنبعث أثناء التحلل الإشعاعي لهذه المواد. تختلف طرق إدارة النفايات المشعة من الأسهل إلى الأصعب، على المستويين المادي والتكنولوجي. لم تختلف معاملة القانون الدولي والوكالة الدولية للطاقة الذرية لأنواع النفايات المشعة. لأن كل أنواع النفايات المشعة تشكل تهديدا للسلم والأمن الدوليين. لذلك من الضروري إدارة النفايات المشعة المتراكمة بأمان.

الكلمات المفتاحية: إدارة، النفايات المشعة، الطاقة النووية، الوكالة الدولية للطاقة

الذرية،الأمن النووي، السلم النووي.

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Introduction:

Radioactive materials are naturally present in the environment as they can be manufacturer. However, manufactured radioactive materials are more dangerous, despite their beneficial uses in medicine, industry and agriculture. However, the use of radioactive materials results in radioactive wastes in various gaseous, liquid and solid forms. Radioactive waste arises from the generation of electricity in nuclear power plants, as well as from nuclear fuel cycle operations such as fuel manufacturing and other activities, such as mining and processing uranium and thorium ores. In some countries, spent nuclear fuel declared as radioactive wastes, as it is unexpected to continue to use. In other countries, spent nuclear fuel is a resource intended for reprocessing. The reprocessing itself will generate highly radioactive and heat-generating waste, which creates various types of nuclear waste. In addition to other types of radioactive waste, such as metal cladding that is removed from the fuel elements, radioactive waste can also be generated from equipment, equipment, and even workers 'clothing in nuclear reactors before processing. The waste is radioactive because the atoms in the waste are unstable and release radiation automatic ionizing during the stabilization process. This ionizing radiation can have potential harmful effects. Therefore, it is important to manage waste safely in order to protect people and the environment, and to help prevent waste from becoming a burden on future generations. Attention must pay to legal and applied safety standards to protect against the effects of radioactive waste. In addition, for the danger that radioactive waste has, it treated in a safe way, and this is compliance with international safety standards for radioactive waste disposal, and environmental protection.

- So, what are the radioactive waste management that maintains international safety and security?

Our study proceeded with the adoption of the analytical method for identifying and analyzing legal and material facts, and dividing our article into two parts, in the first section we will address the concept of radioactive waste, while in the second section, the management methods for radioactive waste.

Section I: The concept of radioactive waste

Radioactive wastes are wastes that contain radioactive material and are usually byproducts of nuclear power generation and other applications of nuclear fission or nuclear technology, such as research and medicine. Radioactive waste

is hazardous to human health and the environment and regulated by government agencies.

A) Definition of radioactive waste:

Many international agreements have referred to radioactive waste. As the first article of the Paris Convention 1960: Radioactive products or waste, means any radioactive material produced in or made radioactive by exposure to the radiation incidental to the process of producing or utilizing nuclear fuel. However, does not include nuclear fuel or radioisotopes outside a nuclear installation. Which have reached the final stage of fabrication to be usable for any industrial, commercial, agricultural, medical, scientific or educational purpose¹.

Generally, the Basel Convention²; does not address radioactive waste. Article 1(3) of the Convention states, "Wastes, as a result of being radioactive, are subject to other international control systems, including international instruments, applying specifically to radioactive materials, are excluded from the scope of this convention"^{3, 4}. According to this language, the Basel Convention does apply to radioactive waste until another "international control system" developed to govern these materials⁵.

For the World Health Organization, the definition came simple as it deals with nuclear energy for its peaceful uses only, and therefore, nuclear waste defined as "Radioactive waste such as products contaminated with radionuclide. Including, radioactive diagnostic materials, radiation therapy materials"⁶.

According to the International Atomic Energy Agency (IAEA), radioactive waste is any material that contains a concentration of radionuclide⁷, greater than deemed safe by national authorities, and for which no use foreseen⁸. Because of the wide variety of nuclear applications, the amounts, types and even physical forms of radioactive wastes vary considerably: some wastes can remain radioactive for hundreds or thousands of years, while others may require storage for only a short decay period prior to conventional disposal⁹. In according to; facilitate communication; and information exchange among its member states¹⁰.

Radioactive waste is an inevitable by-product of the application of ionizing radiation. Substantial amounts of radioactive waste are generated through civilian applications of radionuclide in medicine (for diagnosis and treatment), in research and industry (for example, for finding new sources of petroleum or producing plastics), or agricultural applications (notably for the conservation of foodstuffs)¹¹. A major source of non-military waste is nuclear power generation¹², including various steps in the nuclear fuel cycle such as fuel fabrication, power plant operation, reprocessing, and the decommissioning of nuclear facilities¹³.

The radioactive waste produced by nuclear power generators represents a small fraction of the total toxic wastes generated in countries that use nuclear energy to generate electricity, but at the same time this waste has the highest levels of radioactivity"¹⁴.

B) Sources of radioactive waste:

Radioactive waste comes from different sources. This is because radioactive waste differs in its source from one country to another. In countries with nuclear power plants, nuclear armament or nuclear fuel treatment plants, most waste originates from the nuclear fuel cycle and reprocessing of nuclear weapons, the waste generated by the nuclear industries, in the fields of engineering, mining, agriculture, and water desalination. In industrialized countries that consume nuclear energy without the use of reactors or nuclear fuel, other sources include medical and industrial waste. In addition to the naturally occurring radioactive materials that can be concentrated because of processing or consuming coal, oil, gas, and some minerals. Based on the above, we will show the various sources of radioactive waste as follows:

1- **The nuclear fuel cycle:** also called the nuclear fuel chain, is the progress of nuclear fuel through a series of different stages. It consists of steps in the front end, which are fuel preparation, steps in the service period in which the fuel is used during the operation of the reactor¹⁵, and steps at the back end, which are necessary for management and containment, and either safely reprocessing or disposing of spent nuclear fuel. If the spent fuel is not reprocessed, the fuel cycle referred to as the open fuel cycle (or one-time fuel cycle); if the spent fuel reprocessed, it referred to as the closed fuel cycle¹⁶.

2- **Nuclear decommissioning:** is the process whereby a nuclear facility dismantled to the point that it no longer requires measures for radiation protection. The presence of radioactive material necessitates processes that are potentially occupationally hazardous, expensive, time-intensive, and present environmental risks that must addressed to ensure radioactive materials are either transported elsewhere for storage or stored on-site in a safe manner¹⁷. The challenge in nuclear decommissioning is not just technical¹⁸, but also economical, and social¹⁹.

In 2004, in a meeting in Vienna, the International Atomic Energy Agency estimated the total cost for the decommissioning of all nuclear facilities²⁰. Decommissioning of all nuclear power reactors in the world would require US\$187 billion²¹.

3- Legacy waste: created as result of the pressures of war and the world's first civil nuclear reactor, at a time when waste and decommissioning not considered. However, such materials did not become of public concern until the large-scale activities involving uranium and thorium ores and nuclear fission during and after World War II. Efforts to provide disposal sites for radioactive wastes, especially those associated with nuclear weapons and nuclear energy²².

4- Radioactive medical waste: tends to contain beta particles and gamma-ray emitters. In diagnostic nuclear medicine, a small percentage of radioactive material is used. Many of these substances can be eliminated by letting them decompose for a short time before they are disposed of as normal waste²³.

5- Industry: industrial source waste can contain alpha, beta, neutron or gamma emitters. Gamma emitters are used in radiography while neutron-emitting sources are used in a range of applications, such as oil well logging²⁴.

6- Naturally occurring radioactive material: Radioactive materials are prevalent in many soils and rock formations, and consequently in the water that comes in contact. Extraction and processing of these resources may expose or concentrate naturally occurring radionuclides, causing them to be classified as Technologically Enhanced, Naturally-Occurring Radioactive Materials (TENORM)^{25 26}. As an example, we find:

6.1- Coal: contains a small amount of radioactive uranium, barium, thorium and potassium, but, in the case of pure coal, this is significantly less than the average concentration of those elements in the Earth's crust. The surrounding strata, if shale or mudstone, often contain slightly more than average and this may be reflected in the ash content of 'dirty' coals²⁷.

6.2- Oil and gas: Residues from the oil and gas industry often contain radium and its decay products. Radioactive elements are an industrial problem in some oil wells where workers operating in direct contact with the crude oil and brine can be exposed to doses having negative health effects. Due to the relatively high concentration of these elements in the brine, its disposal is also a technological challenge²⁸.

C) Classification of radioactive waste:

The IAEA instituted a revised waste classification system in 1994 that takes into account both qualitative and quantitative criteria, including activity levels and heat content. The International Atomic Energy Agency has classified radioactive waste as follows²⁹:

1- Exempt waste (EW): Waste that meets the criteria for clearance, exemption or exclusion from regulatory control for radiation protection purposes³⁰.

2- Very short-lived waste (VSLW): Waste that are stored for decay, over a limited period of up to a few years, and subsequently cleared from regulatory control, according to arrangements approved by the regulatory body, for uncontrolled disposal, use or discharge. This class includes waste containing primarily radionuclide with very short half-lives often used for research and medical purposes³¹.

3- Very low-level waste (VLLW): Waste that does not necessarily meet the criteria of EW, but that does not need a high level of containment and isolation and, therefore, is suitable for disposal in near surface landfill facilities with limited regulatory control. Such landfill type facilities may also contain other hazardous waste. Typical waste in this class includes soil and rubble with low levels of activity concentration. Concentrations of longer-lived radionuclide in VLLW are generally very limited³².

4- Low level waste (LLW): Waste that is above clearance levels, with limited amounts of long-lived radionuclide. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near surface facilities. LLW may include short-lived radionuclide at higher levels of activity concentration, and long-lived radionuclide, but only at relatively low levels of activity concentration³³.

5- Intermediate level waste (ILW): Waste that, because of its content, particularly of long-lived radionuclide. Require a greater degree of containment. Isolation provided by near surface disposal. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal. ILW may contain long-lived radionuclide; in particular, alpha emitting radionuclide that will not decay to a level of activity concentration acceptable for near surface disposal during the time for which institutional controls can rely upon. Therefore, waste in this class requires disposal at greater depths, of the order of tens of meters to a few hundred meters³⁴.

6- High level waste (HLW): Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long lived radionuclide that need to be considered in the design of a disposal facility for such waste³⁵. Disposal in deep, stable geological formations usually several hundred meters or more below the surface is the generally recognized option for disposal of HLW³⁶.

Section II: Management Methods for radioactive Waste

The type of radioactive waste disposal varies depending on the types of waste. The type of disposal must be such that the exposure of the public can be kept or below specified limits and can be as reasonably low as possible. This means that an approach from the point of view of radiation protection is important. By considering this as a basic safety requirement, in order to ensure the safety specified by the International Atomic Energy Agency. Therefore, every organization and institution that disposes of radioactive waste must assess the potential impact of waste on the planned disposal system on the public and demonstrate that it will not pose any problem in ensuring safety. The assessment of the impact on the public begins by classifying possible future events into a number of scenarios and determining the conditions that constitute those incidents.

Now that an overview of radioactive waste types has presented, this section describes three radioactive waste management processes: treatment, disposal, and conditioning.

A) Radioactive waste treatment:

Treatment is a process to improve safety and economy by changing the properties of radioactive waste. These include steps such: filtration, ion exchange, coagulation and sedimentation to remove radionuclide, Incineration and compression to reduce volume. Some parts of the waste that considered sanitize by removing radionuclide are no longer radioactive waste.

1- Gaseous radioactive waste Treatment:

Operations involving radioactive material handling may generate airborne radioactive contamination. The basic difference between airborne effluents and radioactive waste in condensed (i.e. liquid or solid) phases is that airborne material has no definite volume and its dispersion in the environment is rapid. Special technologies and equipment used for the localization, collection and treatment of airborne effluents³⁷.

Ventilation and air cleaning systems are a vital part of the general design of any nuclear facility including those of radioactive waste processing. The combination of a well-designed ventilation system with thorough cleaning of exhaust air prevents radioactive contamination of the air in working areas and in the surrounding atmosphere³⁸. In nuclear facilities, in general, air streams from highly contaminated areas such as hot cells and process vessels called off-gas streams. These may contain higher concentrations of airborne radionuclide than the air streams contaminated only from equipment or leakage from a hermetically

sealed area. Off-gas streams must treat prior to mixing with the ventilation air for occupational and environmental safety reasons³⁹.

The general purposes of ventilation and air cleaning systems are:

- To control airborne contamination below safe working levels,
- To filter and monitor the air supply on a once-through basis,
- To maintain directional flow from the point of least contamination potential to the point of greatest contamination potential,
- To clean the exhaust air before discharge to the atmosphere,
- To monitor contaminants in the working areas; and releases to the environment⁴⁰.

2- Liquid Radioactive Waste Treatment:

The IAEA Co-ordinate Research Project (CRP) on Combined Methods for Liquid Radioactive Waste Treatment initiated in 1997 to identify, through the exchange of information and the results of experimental work, specific combined methods for liquid radioactive waste treatment and to define their applicability and efficiency for processing of different waste streams. Substantial advantages accrued by selecting a combination of two or more processes and their consecutive or simultaneous application for treatment of liquid waste. The multiple or combined process approach may allow resources and materials recovery, provide volume reduction or allow processing of waste in a single equipment unit. Research and development in this field would contribute toward improvement of efficiency, safety and cost of the waste management system⁴¹.

The objective of the Co-ordinate Research Project (CRP) on Combined Methods for Liquid Radioactive Waste Treatment was to outline areas of potential and prospective⁴².

Through conducting of research, exchange of information and results of this research it intended to identify specific combined methods for treatment of liquid radioactive waste and to define their applicability and potential efficiency for particular waste stream processing. Practical experience in the development and operation of pilot and full-scale facilities utilizing combined treatment processes for treatment of liquid radioactive waste considered to be of particular importance and interest. Therefore, for the benefit of all participants of the CRP its programs was oriented not only on the research, but also on the development and application of different new materials and combined methods for treatment of liquid radioactive waste aimed at improving the treatment efficiency⁴³. The program planned to prove, possibly up to a pilot plant scale, the effectiveness of the combined processes for treatment of real radioactive waste⁴⁴.

The following areas identified and recommended for co-operation and joint efforts.

- Use of inorganic sorbents in combination with other treatment processes;
- Use of sorbent mixtures;
- Combined processes for treatment of solutions containing agents and organics,
- Multiple processes for treatment and immobilization of organic liquid waste⁴⁵.

3- Solid radioactive waste treatment:

Solid radioactive waste treatment aimed at an appropriate preparation of the waste that facilitates the subsequent treatment steps.

Treatment actions may comprise:

- Administrative measures;
- Segregation, sorting;
- Packaging for transport to an intermediate storage area or to the treatment facility;
- Size reduction;
- Decontamination;
- Decay storage⁴⁶.

It is obvious from this enumeration that pretreatment must start at the source where the solid waste produced; indeed, the complexity of operating a volume reduction system requires that this management aspect emphasized from the very beginning. There, administrative measures fix the rules for the very first steps of the solid waste management, i.e. collection, sorting, segregation and packaging for transport to buffer storage areas, or directly to the treatment facilities. Emphasis must be placed on an as informative as possible description of the waste, stating origin, nature, activity (isotopes, radiation level), package volume, weight and all further information relevant to the safe execution of the subsequent treatment steps⁴⁷. It is imperative that this information also provided to meet accountability and operational purposes. This, in turn, leads to the need to use adequate measuring techniques to obtain the above information. Indeed, the establishment has to keep a detailed record system that integrates and documents the information obtained in all phases of the waste management system⁴⁸.

B) Radioactive waste conditioning:

Conditioning is a process for converting radioactive waste into safe forms for handling, transporting, storing and disposing of it. Waste solidified, closed in containers, and packaged to convert into waste forms. These steps may be easier to understand when they called "waste form production". Conditioning sometimes called packaging⁴⁹.

As well as all, technological processes ranging from facility decommissioning and conditioning wastes to long-term safety assessment for final geological disposal. As one of the waste-conditioning technologies, for which active research and development have been performed and effects of partitioning and transmutation⁵⁰.

Conditioning techniques designed by the IAEA to slow the release of radionuclide from the disposed waste package into the environment⁵¹. Conditioning puts the waste in a safe, stable and manageable form for transport, storage and disposal. Common forms of conditioned waste for disposal are encapsulated or solidified waste in cement or glass⁵²:

1- Conditioning the radioactive waste with cement:

Cement-based materials are widely used in the nuclear industry for radioactive waste conditioning and disposal. They result from the setting of a mixture of anhydrous cement, aggregates of various sizes, and water. Several categories distinguished depending on whether aggregates are present or not, their size, and the water/cementations ratio⁵³:

- Pure pastes, only consisting of cement and water;
- Grouts, pure pastes or fine mortars with a low sand content and a high quantity of water (water volume > cement volume), which gives them the relevant theology for the pouring that follows mixing;
- Mortars, which contain aggregates (sand) under 6.3 mm in size (generally, the sand volume is higher than the cement volume, which is itself higher than the water volume);
- Concretes include aggregates of a size between 6.3 and 80 mm. In order to increase their tensile strength, they armored with bars or reinforced with short metal fibers⁵⁴.

2- Conditioning the radioactive waste with glass:

It is a proven method for restoring high-level liquid waste (HLW). As well as intermediate level waste (ILW) and low-level waste (LLW). It characterized by high flexibility in terms of the range of forming glass. Moreover, reliability of the paralyis process, productivity of glass, a High durability for final waste. In addition to a small volume of waste generated. However, its limits are high initial investment and operating costs. Complex technology requires highly qualified personnel, and requires control of emissions, and Specific high-energy consumption⁵⁵.

C) Radioactive waste disposal:

The concept of radioactive waste disposal has evolved through wide-ranging international discussions. Since the future use of nuclear energy must base on the safe and rational management of radioactive waste, the prevention of any harm to humans or the environment. It is necessary to give priority to establishing what should be international cooperation in the fields of regulatory texts and modern technological technologies, and it will require participants in this field to possess comprehensive understanding of the overall picture. In order to, preserve the safety of nuclear facilities in the future. Nuclear waste disposal is extremely hazardous and is often an argument against the use of nuclear reactors. The main objective in disposing of nuclear waste is to protect people and the environment⁵⁶. To make sure that it does not produce harmful radiations, practically all wastes are contained and managed – some clearly need deep and permanent burial. Broadly, there many options to a safely dispose of nuclear waste as:

1- Geological Disposal: is the process of selecting appropriate deep final repositories for high level waste and spent⁵⁷. The basic concept is to locate a large, stable geologic formation and use mining technology to excavate a tunnel, or large-bore tunnel boring machines to drill a shaft 500 meters to 1,000 meters below the surface where rooms or vaults can excavate for disposal of high-level radioactive waste⁵⁸. The waste needs to protect for stopping any material from leaking Furthermore, the waste needs fastened to the burial site, also structurally supported in the event of a major seismic event, which could result in immediate contamination. The goal is permanently isolate nuclear waste from the human environment.

Many people remain uncomfortable with the immediate stewardship cessation of this disposal system, suggesting perpetual management and monitoring would be more prudent, according to the long term of radioactive waste life estimating of several hundred thousand years⁵⁹.

2- Reprocessing: is the chemical separation of fission products and unused uranium from spent nuclear fuel. Originally, reprocessing used solely to extract plutonium for producing nuclear weapons. With commercialization of nuclear power, the reprocessed plutonium was recycled back into MOX nuclear fuel for thermal reactors⁶⁰. The reprocessed uranium, also known as the spent fuel material, can re-use as fuel, but that is only economical when uranium supply is low and prices are high. A breeder reactor is not restricted to using recycled plutonium and uranium⁶¹. It can employ all the actinides, closing the nuclear fuel

cycle and potentially multiplying the energy extracted from natural uranium by about 60 times⁶².

3- Transmutation: Also poses a solution for long-term disposal. It specifically involves converting a chemical element into another less harmful one⁶³. Common conversions include going from Chlorine to Argon or from Potassium to Argon. The driving force behind transmutation is chemical reactions that caused from an outside stimulus, such as a proton hitting the reaction materials. Natural transmutation can also occur over a long period. Natural transmutation also serves as the principle force behind geological storage on the assumption that giving the waste enough isolated time allows it to become a non-fissionable material that poses little or no risk⁶⁴.

4- Space Disposal: has emerged as an option, but not as a very viable one. Specifically, space disposal centers on putting nuclear waste on a space shuttle and launching the shuttle into space. This becomes a problem from both a practicality and economic standpoint as the amount of nuclear waste that could shipped on a single shuttle would be extremely small compared to the total amount of waste that would need to deal with. Furthermore, the possibility of the shuttle exploding en route to space could only make the matter worse as such an explosion would only cause the nuclear waste to spread out far beyond any reasonable measure of control⁶⁵. The upside would center on the fact that launching the material into space would subvert any of the other issues associated with the other disposal methods as the decay of the material would occur outside of our atmosphere regardless of the half-life⁶⁶.

Conclusion:

Radioactive waste is a reality with nuclear energy. It must properly address in order to assess the long-term viability of this power source.

All radioactive waste management operations must carried out in accordance with the legal and scientific procedures specified by the International Atomic Energy Agency and the various scientific bodies responsible for nuclear energy, nationally and internationally.

The different types of radioactive waste make their operations different. However, a set of factors should take into consideration when assessing any particular method, including:

- The volume of nuclear waste is large and must take into account.
- The half-life of nuclear waste leads to the need for any policymaker to view the time horizon as effectively infinite because it is better to find a solution that requires minimal intervention once a long-term plan modified. Note that any

errors in estimating the half-life may lead to a threat to international peace and security.

- We must understand the sustainability of any plan. Reducing material fission and dealing with the harmful effects that it can have on the environment and living organisms must fully integrate.

Each type of radioactive waste imposes specific practices in the nuclear facility and legally,

Whatever type of radioactive waste, it must deal with as imposed by international organizations,

Radioactive waste can harm the environment and human for an extended period. This is what forces states to respect the applicable safety rules,

The International Atomic Energy Agency must review and update its convention,

The radiation danger is too big for a single country to deal with. All countries are obligated to help deal with radioactive waste,

Despite the gradual flow of radioactive waste from treatment to reuse ...etc. Some stages are not process in legal side.

Even if radioactive wastes have their own rules, but there are some violations.

The solutions to deal with nuclear waste are inadequate or very costly. Solutions must found internationally and nationally.

A new set of laws should develop. To ensure management of radioactive waste, from treatment to disposal.

International cooperation in the field of nuclear industry should be at the level of factories and reactors, and legally.

The International Atomic Energy Agency must send monitors or inspectors with missions specializing in radioactive waste disposal.

Bibliography:

¹ - Article1, § iv, the Paris Convention 1960.

² - *The Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and Their Disposal*, usually known as the *Basel Convention*, is an international treaty that designed to reduce the movements of hazardous waste between nations, and specifically to prevent transfer of hazardous waste from developed to less developed countries.

³ - Article 1,§ 3, the *Basel Convention: Wastes which, as a result of being radioactive, are subject to other international control systems, including international instruments, applying specifically to radioactive materials, are excluded from the scope of this Convention.*

⁴ - Barbara Kwiatkowska & Alfred Soons, (1994), *Plutonium Shipments - A Supplement*, *Ocean Development and International Law*, p; 419 .

⁵ - The language of Article 1(3) would appear to mean that the Basel Convention would apply to radioactive wastes if no international arrangements covering these wastes were in place, and could therefore be included as "hazardous waste" and subject to the Convention, the report on Basel Convention issued by U.S Deputy. Secretary of State Lawrence Eagleburger on 13 May 1991 contains the interesting comment that "the Convention does not regulate movements of low-level radioactive wastes that are covered by other international control systems, such as the Code of Practice of the International Atomic Energy Agency (IAEA).

⁶ - <https://www.who.int/news-room/fact-sheets/detail/health-care-waste>, consulted 12/01/2019.

⁷ - A radionuclide is an atom with an unstable nucleus that subjected to radioactive decay, which results in the emission of gamma rays and subatomic particles. These emissions constitute nuclear radiation.

⁸ - Gian Andrea Pagnoni, Stephen Roche, (2015), *the Renaissance of Renewable Energy*, Cambridge University Press, p 203.

⁹ - *Ibid*, p 204.

¹⁰ - Lutz Struck, safety system related to the transboundary movement of radioactive waste and its compatibility with the WTO trading system, *Nuclear Law Bulletin* No. 73;

¹¹ - Ewan McLeish, (2007), *The Pros and Cons of Nuclear Energy*, The Rosen Publishing Group, Inc, p. 22.

¹² - J. S. Kidd and Renee A. Kidd, (2006), *Nuclear Power: The Study of Quarks and Sparks*, Chelsea House Publishers, p 129.

¹³ - *Ibid*, p 130.

¹⁴ - Carlton Stoiber; et al, (2003), *Handbook on Nuclear Law*, Vienna, p 97.

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¹⁷ - Benjamin K. Sovacool,(2010), *A Critical Evaluation of Nuclear Power and Renewable Electricity in Asia*, *Journal of Contemporary Asia*, Vol; 40, No. 3, p. 373.

¹⁸ - Delita Colette; and others, (2017), *How a benchmark can support the selection, planning and delivery of nuclear dismantling projects*, *Progress in nuclear energy*, August, p 99.

¹⁹ - *Id*, p 112.

²⁰ - IAEA; book, (2004), *Issue of dismantling nuclear facilities around the world*, Vienna, p 10, 11.

²¹ - 71 billion \$ for fuel cycle facilities; Less than \$ 7 billion for all research reactors; \$ 640 billion to dismantle all military reactors to produce weapons-grade plutonium, research fuel facilities, chemical separation facilities for nuclear reprocessing, etc. The total cost of shutting down the world's nuclear fission industry (from 2001 to 2050) was estimated at \$ 1 trillion.

²² - Martin, J.E., Lee, C, (2000), *the legacy and future of radioactive waste management at the millennium*, *journal of radio analytical and nuclear chemistry*, p 155.

²³ - <https://celitron.com>, blog, how to handle radioactive medical waste disposal in hospitals 12/02/2020.

²⁴ - <http://www.logwell.com/tech/nuclear/indexl>, consulted 26/03/2020.

²⁵ - Substances containing natural radioactivity; known as NORM (Naturally occurring radioactive material). After human processing that exposes or concentrates this natural radioactivity (such as mining bringing coal to the surface or burning it to produce concentrated ash), it becomes technologically enhanced naturally occurring radioactive material; (TENORM) is not regulated as

restrictively as nuclear reactor waste, though there are no significant differences in the radiological risks of these materials.

²⁶ - <https://www.epa.gov/radiatio/technologically-enhanced-naturally-occurring-radioactive-materials-tenorm>, consulted, 12/12/2019.

²⁷ - Mara Hvistendahl, (2007), *Coal Ash Is More Radioactive Than Nuclear Waste*, scientific-American, December.

²⁸ - Khalid Al Nabhani, Faisal Khan, (2019), *Nuclear Radioactive Materials (Tenorm) in the Oil and Gas Industry*, Elsevier, p95.

²⁹ - IAEA, (2009), *Classification of Radioactive Waste, Safety Standards*, series No: GSG-1, Vienna.

³⁰ - IAEA, (2004), *Application of the Concepts of Exclusion, Exemption and Clearance*, IAEA Safety Standards Series, No. RS-G-1.7, Vienna.

³¹ - De Sanctis, E., Monti, S., & Ripani, M, (2016), *Energy from Nuclear Fission. Under graduated Lecture Notes in Physics* .Springer, p 231.

³² - Id, p 231.

³³ - Id, p 232.

³⁴ - Id, p 232.

³⁵ - The ongoing controversy over high-level radioactive waste disposal is a major constraint on the nuclear power's global expansion. Most scientists agree that the main proposed long-term solution is deep geological burial, either in mine or in deep borehole. As of 2019 no dedicated civilian high-level nuclear waste is operational as small amounts of HLW did not justify the investment before. Finland is in the advanced stage of the construction the Onkalo spent nuclear fuel repository planned to open in 2025 at 400-450 m depth. France is in the planning phase for 500 m deep Cigeo facility in Bure. Sweden plans a site in Forsmaek. Canada plans 680 m deep facility near Lake Huron in Ontario. Republic of Korea plans to open a site around 2028. The site in Sweden enjoys 80% support from local residents as of 2020.

³⁶ <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Appendices/Radioactive-Waste-Managements>, consulted 25/3/2020.

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³⁸ - Id, p 175.

³⁹ - IAEA, (2014), *Treatment of Radioactive Gaseous Waste*, IAEA-TECDOC-1744, Vienna, p11; 12.

⁴⁰ - Id, p 13.

⁴¹ - IAEA, (2003), *Combined Methods for Liquid Radioactive Waste Treatment*, IAEA-TECDOC-1336, IAEA, Vienna, p 9.

⁴² - The CRP brought together 14 research teams from 12 countries. The progress in the CRP implementation was discussed at three Research Co-ordination Meetings held in the Republic of Korea (Nuclear Environment Technology Institute, Korean Electric Power Corporation, 18–22 May 1998), in China (China Institute of Atomic Energy 10–14 April (2000) and in Belgium (Nuclear Research Center SCK/CEN 8–19 October 2001). The program of the CRP was oriented not only on the research, but also on the development and application of different new combined methods for treatment of liquid radioactive waste aimed at increasing the treatment efficiency. Some combined processes developed in the frame of this CRP have been applied at pilot plant scale for treatment of actual radioactive wastes.

⁴³ - IAEA, (2005), *Radiation synthesis of stimuli-responsive membranes, hydrogels and adsorbents for separation purposes*, IAEA-TECDOC-1465, Vienna, Austria.

⁴⁴ - Haji-Saeid, M., Sampa, M. H., Ramamoorthy, N., Güven, O., & Chmielewski, A. G, (2007), *The role of IAEA in coordinating research and transferring technology in radiation chemistry and processing of polymers. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, p 52, 53.

⁴⁵ - Id, p 53.

⁴⁶ - For more information: IAEA, (1985), *Operational Experience in Shallow Ground Disposal of Radioactive Wastes*, Technical Reports Series No. 253; Vienna.

⁴⁷ - IAEA, (1992), *Radioactive Solid Waste Treatment and Conditioning*, IAEA bulletin, Vienna, p 16.

⁴⁸ - Id, p 17.

⁴⁹ - Nagasaki S, Nakayama S, (2015), *Radioactive Waste Engineering and Management. An Advanced Course in Nuclear Engineering*; Tokyo, Springer, p 13.

⁵⁰ - Id, p 119.

⁵¹ - Most participants of CRP have used standard well-known methods for determining characteristics of cementitious materials in order to be used for durability calculations. For more information: IAEA, (2007), *Strategy and methodology for radioactive waste characterization. TECDOC-1537*, Vienna,

⁵² - IAEA (2010) *CRP on behaviors of cementitious materials in long term storage and disposal*, http://www.iaea.org/OurWork/ST/NE/NEFW/wts_crp_cement

⁵³ - Alternative characterization techniques for cementations materials, such as neutron imaging and acoustic emission demonstrated as possible techniques to complement the study of the durability of cementations materials. The durability of cementations materials is an important issue and the measuring thereof plays a major part in the understanding of the use of such material. Short-term characterization results can only used as a guideline in the individual member states for development and durability predictions due to the fact of durability testing methodology is not standardized and scarce long-term durability research results on behavior of cementations materials under repository conditions.

⁵⁴ Nuclear Energy Division Monograph,(2009), *Nuclear Waste Conditioning*, Saclay and Groupe Moniteur (Éditions du Moniteur),Paris, p 69.

⁵⁵ - Hyatt NC, Ojovan MI, (2019) *Special Issue: Materials for Nuclear Waste Immobilization. Materials*(Basel), p3.

⁵⁶ - <https://www.conserve-energy-future.com.nuclear-waste-disposal-methods.php>, consulted 12/2/2020.

⁵⁷ - A deep geological repository is a way of storing toxic or radioactive waste within a stable geologic environment, typically 200-1000 m deep. For more information about the geological repository consult: *The Geological Society of London - Geological Disposal of Radioactive Waste*. www.geolsoc.org.uk.

⁵⁸ - Vandenbosch, Robert & Vandenbosch, Susanne E, (2007), *nuclear waste stalemate*. Salt Lake City, Utah university, p 10.

⁵⁹ - It can clearly stat that real progress has been made, and is being made, thanks to the extensive efforts of many experts working in various disciplines within international waste management programs. Technical progress and improved community interactions took longer than expected and

long delays in deep warehouse implementation, see; <https://www.oecd-neo.org/rwm/pubs/1999/2048-geological-disposal>.

⁶⁰ - MOX fuel is a manufacture from plutonium recovered from used reactor fuel, mixed with depleted uranium.

MOX fuel first used in a thermal reactor in 1963, but did not come into commercial use until the 1980s. So far, more than 2000 tones of MOX fuel has fabricated and loaded into power reactors. In 2006 about 180 tones of MOX fuel was loaded into over 30 reactors in Europe. By mid-2016 over 7500, MOX fuel assemblies been used in over 40 reactors. Today MOX is widely used in Europe and in Japan. Currently about 40 reactors in Europe (Belgium, Switzerland, Germany and France) are licensed to use MOX, and over 30 are doing so. In Japan about ten reactors are licensed to use it and several do so. These reactors generally use MOX fuel as about one-third of their core, but some will accept up to 50% MOX assemblies. Japan also planned to use MOX in one-third of its reactors in the near future and Electric Power Development Company (EPDC, operates under J-Power) plans to start up a 1383 MWe reactor with a complete fuel loading of MOX at the Ohma plant in 2024. Other advanced light water reactors are able to accept complete fuel loadings of MOX if required.

⁶¹- <https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx>, consulted; 1/12/2019.

⁶² - Harold Feiveson, Managing nuclear spent fuel: Policy lessons from a 10 country study, Bulletin of the Atomic Scientists, <https://thebulletin.org/2011/06/managing-nuclear-spent-fuel-policy-lessons-from-a-10-country-study>.

⁶³ - Lehmann, W.M, (2000), Nuclear transmutation, Elektrizitaetswirtschaft, IAEA INIS, Jan, p 51-52.

⁶⁴ - <http://www.oecd-neo.org/trw/>, Transmutation of Radioactive Waste, Nuclear Energy Agency, consulted 19/2/2020.

⁶⁵ - Ahmed, Shakir & Reza, Syed & Kibria, Golam, (2016), Radioactive Waste Disposal in Outer Space. And, R. E. Burns, W. E. Causey, W. E. Galloway, and-R. W. Nelson, (1978), Nuclear Waste Disposal in Space, NASA Technical Paper, N° 1225.

⁶⁶ - J. Coopersmith, (2005), Nuclear Waste Disposal in Space: BEP's Best Hope?, AIP Conference Proceedings, <https://aip.scitation.org>.

