Industrial view on radioactive waste

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Note
In this document the references are coded by Q-numbers (e.g. Q2). Each reference has a unique number in this coding system, which is consistently used throughout all publications by the author. In the list at the back of the document the references are sorted by Q-number. The resulting sequence is not necessarily the same order in which the references appear in the text.

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Table 1 Main underground research facilities

View of the International Atomic Energy Agency (IAEA)

Within the framework of its Joint Convention project the IAEA published a series of reports *Radioactive Waste Management Data Base - Status and Trends*, for instance [IAEA-*wmdb-st-4* 2005] Q659, discussing envisioned international agreements on waste management. In these reports the IAEA describes numerous regulations and waste classifications.
These WMDB reports do not mention contributions other than from the USA, Europe and Japan. It remains unclear wether the non-contributing countries would comply with the regulations proposed by the IAEA.

The contents of the reports are dealing with formulation of possible regulations, with legal, administrative and managerial aspects and with recommendations 'what should be done'. The texts are not easily accessible and are full of new acronyms for notions and concepts that are already subject of discussions on waste management during decades. In the 60 years of its existence the IAEA apparently did not succeed in formulating unambiguous regulations for nuclear waste management.

Many, if not all definitions and recommendations given by the IAEA in the WMBD reports leave the door open for ad hoc interpretations and for adaption of regulations to economic needs. Each country and nuclear agency remains free to follow its own views. How stringent are these 'internationally agreed regulations and standards', and what safety improvements do they provide?
None of the regulations and recommendations are coupled to clear and unambiguously quantified standards, instead vague classifications of radioactivity levels are mentioned, such as: 'insignificant level' and 'acceptable level'. How are such levels defined? Who defines these levels? How are the levels measured? Who measures and how frequent?

How reliable are, for example, the measurements to distinct between LILW-SL (Short-Lived Low and Intermediate Level Waste) and LILW-LL (Long-Lived LILW), which methods are used, how independent are the inspections?
How is the classification 'Below Regulatory Concern' defined? Which unambiguous numerical criteria are to be applied?
In its document [IAEA-*wmdb-st-1* 2001] Q656 the IAEA uses the terms 'exclusion', 'exemption' and 'clearance'. The hardly understandable texts offer ample room for ambiguities and ad hoc interpretations.
Clearing waste, classifying/managing it as VLLW (Very Low Level Waste), or some combination of clearance and VLLW classification is likely to be a nationally based, cost-benefit decision. There are no internationally agreed definitions for clearance levels.

Dismantling wastes are not separately discussed, despite their huge volumes. Especially the amounts of waste resulting from the dismantling of reprocessing plants might be very large, probably millions of Mg, in addition to the heavy contamination of the debris by all kinds of radionuclides from spent fuel.

Noteably absent in the WMBD reports are standards based on quantified physical and chemical properties of the materials present in different waste categories; such standards are prerequisite for an unambiguous classification of radioactive wastes.

The IAEA reports seem to suggest that internationally agreed regulations are sufficient to warrant the safety of nuclear power. No recommendations are mentioned to monitor compliance with stringent regulations, such as independent international inspections and evaluations.

Radioactive waste disposal

According to [IAEA-wmdb-st-1 2001] Q656 there are two basic strategies for radioactive waste disposal:

- 'isolate and confine'
- 'dilute and disperse'.

The first strategy involves the emplacement of waste into a disposal facility that is intended to isolate the waste from humans and the environment and to prevent or limit releases of potentially harmful substances (toxic metals, radionuclides, organics) such that human health and the environment are protected.
The second strategy involves deliberately dispersing the waste into the environment in a manner intended to dilute harmful contaminants in the waste to levels that are considered 'acceptable' according to internationally agreed standards.

The three major options for disposal currently used or planned by IAEA Member States are:

- surface/near surface facilities
- rock cavities (at several tens of meters to a few hundreds meters depth)
- deep geologic repositories (typically at depths of more than a few hundred meters).

Surface/near surface disposal is and will most likely continue to be the most common disposal practice. No repositories for high-level waste and spent fuel are yet in operation in any Member State; this expensive option remains a major challenge in radioactive waste management.

Retrievability or 'Long-Term Storage' versus Disposal
Originally the approach of deep geological disposal was developed to remove waste from the human environment to ensure that it remains isolated from the environment and inaccessible to humans for the very time scales corresponding to the slow decay of long-lived radionuclides. The concept utilizes multiple barriers, such as the waste form, container(s), overpack(s), sealant(s), backfill, buffer(s), and the geosphere.
The term storage implies retrieval at any time in the future is intended
The term disposal implies retrieval is not intended; it does not mean that retrieval is not possible. Disposal with retrievability is receiving wider attention.
Annex F explains for what reasons spent fuel cannot be regarded as a potential energy source, so retrievability is a useless option.

Accumulation effects

The strategy of 'dilute and disperse' ignores the effect of accumulation of radionuclides in the environment, food and drinking water. The discharges of one LWR during one year may seem innocuous and acceptable, but what about the discharges of 400 reactors during 40 years? These operating discharges come on top of the discharges due to small and large accidents and the massive discharges of reprocessing plants.
On which scientific arguments and figures are 'acceptable according to internationally agreed standards' defined? If these 'standards' are based on the background level of radioactivity a sliding scale will result, because the background level is steadily rising as a consequence of the operating discharges and the releases from large nuclear accidents.

Reprocessing plants are discharging significant amounts of fission products and actinides in the gaseous effluents (+ aerosols) and liquid effluents, year after year. Locally hazardous concentrations of radionuclides may be built up. These discharges come on top of the discharges by nuclear power plants.

In publications of the nuclear industry no mention is found of the problems evoked by the growing amounts of radioactive waste, awaiting definitive isolation from the human environment. At this moment some 12 million atomic bomb equivalents of radioactivity from civil nuclear power plus several millions bomb equivalents from military nuclear activities are piled up globally in temporary facilities, and each year some 300 000 bomb equivalents are added to this pile.

Most of these bomb equivalents are contained in spent fuel and other contained wastes, stored at an increasing number of temporary storage sites. Due to unavoidable degrading processes (ageing) following from the Second Law, worsened by the nuclear radiation, the containment of the radioactive materials deteriorates with time. Predictable consequences of accumulation of radioactive waste combined with the ageing processes are, among other:

- increasing rate of dispersion of radioactive materials
- accumulation of dispersed radioactive materials at the storage sites and in the environment, at an increasing rate
- increasing loss of adequate knowledge of the contents of the waste packages
- increasing risks of large scale dispersion caused by natural disasters, terroristic actions and ignorance
- rising costs to maintain each nuclear bomb equivalent of radioactivity in the wastes in a ‘safe’ condition, and consequently application of cheaper (but less effective) ‘solutions’ for storage
- increasing number of repositories required, rising costs to isolate the backlog of radioactive waste in the least risky way
- increasing incentive to adapt the regulations to political and/or financial conditions, particularly relaxation of standards, for example of allowed radioactive concentrations in drinking water and food, and of clearance standards of radioactive materials for unsrestricted reuse.

View of the World Nuclear Association on radioactive waste

The World Nuclear Association (WNA), which may be seen as a representative of the nuclear industry, states in its publication *Radioactive Waste Management* [WNA 2016a] Q540:

- Nuclear power is the only large-scale energy-producing technology which takes full responsibility for all its wastes and fully costs this into the product.
- The amount of radioactive wastes is very small relative to wastes produced by fossil fuel electricity generation.
- Used nuclear fuel may be treated as a resource or simply as a waste.
- Nuclear wastes are neither particularly hazardous nor hard to manage relative to other toxic industrial wastes.
- Safe methods for the final disposal of high-level radioactive waste are technically proven; the international consensus is that this should be geological disposal.

Apparently the World Nuclear Association does not see any radioactive waste problem. The statements of the WNA turn out to be untenable, as they prove to be based on disregarding well-known facts and on questionable arguments.

Full responsibility?

The first point is contradicted by the facts addressed in this study. For example, the decommissioning and dismantling of the existing nuclear power stations and reprocessing plants are the responsibility of the governments and will become a public charge. Only in case of new nuclear build in a few countries operating companies are responsible and liable for the decommissioning and dismantling of nuclear power plants. For which countries is this rule valid? How many new nuclear power stations are being built in those countries at this moment? What about the existing nuclear legacy?

Small amounts?

The assertion that the amounts of radioactive waste would be very small seems to be founded on a very narrow definition of 'radioactive waste', probably this WNA statement refers to the amount of spent fuel only. Worldwide some 300 000 Mg of spent fuel is stored in cooling pools and in dry casks. This figure may sound small compared to the masses of solid wastes resulting from coal burning, but the notion 'waste' comprehends more than just a number of tons. The volume and mass of spent fuel is out of proportion to the magnitude of the hazards it provokes compared to the hazards of coal waste. During the disasters of Chernobyl and Fukushima jointly an equivalent of some 100 Mg spent fuel might be dispersed into the environment. The consequences were and still are globally observable.
Apparently wastes from uranium mining, from reprocessing of spent fuel and from dismantling of nuclear power plants and reprocessing plants are not recognised as 'waste', despite their volumes and masses of hundreds of millions to billions of Mg. How does nuclear-generated electricity compare with gas-fired? Why compare nuclear with fossil-fuelled generation? Why not compare nuclear with renewables?

Resource?

The view that spent nuclear fuel could be treated as a resource turned out to be based on fallacies and ignorance of the Second Law of thermodynamics, as is explained in Annex F.

Not particularly hazardous?

How does the WNA define the notion 'hazardous'? How does the WNA see the consequences of the severe nuclear accidents? On which scientific arguments is this statement based?

Technically proven?

The view that safe disposal methods for radioactive waste would be technically proven is in conflict with the fact that nowhere in the world a geologic repository is operational, so a proof based on empirical evidence is not yet possible. Or does the WNA refer to the surface and shallow burial storage facilities?

Economic preferences and nuclear security

Economic preferences and commercial choices can greatly increase nuclear security risks, for example by relaxation of the official standards for operational routine discharges of radionuclides into the environment by nuclear power plants and reprocessing plants. Due to ageing the frequency of leaks and spills will rise at an accelerating rate and so will the costs to repair the leaks and to prevent their occurrence. Raising allowable radioactive discharge limits for the nuclear operators keeps their costs down, while resulting in higher exposure standards for the general public, often by large factors, without scientific justification. Relaxation of exposure standards may be expected in the case of future nuclear accidents, as occurred after the Fukushima disaster. Another example is the relaxation of standards for clearance of radioactive construction materials for unrestricted use in the public domain. This will become a hot issue when heavily contaminated nuclear installations are dismantled; safe guardianship and disposal of the massive amounts of radioactive debris and scrap will be expensive.
Economic reasons can push the trend of lifetime extension for nuclear power stations beyond the designed lifetime of 40 years. It is not clear how the owners of the plants and the supervisory institutes incorporate the unavoidable ageing and the bathtub function (see reports m21 *Nuclear safety* and m38 *Nuclear power and the Second Law*) in their security assessments, nor how independent and how effective the inspections are.

The strained relationship between economics and nuclear safety is in the French Roussely report [Roussely 2010] Q427 expressed as follows:

> La question du risque nucléaire acceptable, ou plus généralement du risque technologique acceptable, est un débat de société à part entière pour lequel la ou les réponses à donner sont naturellement du rôle du Politique. Force est néanmoins de constater que la notion même de compétitivité du nucléaire et l'hétérogénéite des règles de sûreté selon les Etats renforcent l'actualité de ce débat et la nécessité de préciser certaines exigences de sûreté. La seule logique raisonnable ne peut pas être une croissance continue des exigences de sûreté.

In English translation:

> The question of what is an acceptable nuclear risk, or more generally an acceptable technological risk, is a debate that concerns the entire society and for which the answer(s) obviously belongs in the political domain. However, one must note that the concept itself of competitiveness of nuclear power and the heterogeneity of the security rules according to each country reinforce the relevance of this debate and the need to specify certain security requirements. The continued increase of security requirements cannot be the only reasonable rationale.

Nuclear safety issues

According to the nuclear industry the safety record of nuclear energy is better than for any other major industrial technology. It is unclear how to reconcile this claim with the practice of the nuclear disasters of Mayak, Chernobyl and Fukushima.
The publications of the nuclear industry regarding nuclear safety base the claim on model studies with a very limited scope: only light water reactors (LWRs) of American or European design are investigated. Not included in the investigations are:

- other types of reactors
- phenomena following from the Second Law of thermodynamics
- human factors
- economic considerations
- consequences of natural disasters
- consequences of terroristic actions
- vulnerability of other components of the nuclear process chain, such as reprocessing and interim storage of spent fuel.

Only strictly technical failures are taken into account. The possibility of disastrous consequences on continental scale of a, technically spoken, minor failure is apparently no issue. Health effects of large-scale contamination are downplayed and denied.

Radioactive contamination of the environment by operating discharges, leaks, small accidents, occurring at every nuclear power plant, is neglected. Also ignored are the effects of accumulation of radioactive materials in the environment during decades of operation from hundreds of nuclear power plants. Radioactive contamination is ireversible.

Liability
The Price-Anderson Act was enacted in the USA in 1957 as a supplemental ‘insurance policy’ for nuclear power plants. With this act, providing equal liability protection regardless of risk, the cost of additional safety features becomes a financial impediment for a nuclear plant owner. New nuclear reactors must be excluded from liability protection under the Price-Anderson Act [Lochbaum 2004] Q76:

> If new reactors are truly so safe that the public need not be protected from technological disaster, then they are also so safe that their owners need not be protected from financial disaster.

This kind of liability protection may be seen as a disincentive for safety, preventing safety upgrades from being incorporated into new reactor designs.
In France a similar liability protection is valid, as the reactor operator EdF and the reactor vendor Areva both are state companies. How is the situation in other countries?

Unknowns

The distinction the IAEA reports make between various categories of waste, such as 'low level', short-lived, long lived and 'high-level' waste, are not based on unambiguous quantified standaards and may likely have economic roots, for the final disposal options as envisioned by the nuclear industry for the most wastes other than spent fuel - shallow burial and/or above-ground storage for 'only' 4-10 centuries - are much cheaper than a deep geologic repository. This view raises a number of questions and doubts.

Looking back in history, how robust could the integrity of a human construction expected to be after 400-1000 years?

How can be guaranteed that the waste containers will remain leak free for 4-10 centuries and will not be susceptible to erosion, ageing and unsuspected chemical reactions.
Is the IAEA aware of the unavoidable Second Law phenomena?

How can be guaranteed that a perfect separation of the billions of tonnes of radioactive wastes into 'low-level short-lived' and other categories is possible? How about the chance that wastes containing hazardous long-lived radionuclides will be mixed up with wastes containing exclusively short-lived radionuclides accidentally, by incompetence, or intentionally to save costs or to make profits?

How would future generations keep the knowledge of the exact locations, composition and properties of the stored 'not-to-worry-about' radioactive wastes generated centuries ago. Message to the future?
How sure can we be that future generations will have the political drive, sufficient economic resources and skilled workforces at their disposal to perform the demanding tasks our generation could not handle. It should be noted that these activities do not provide any financial return on investments.

How can be guaranteed that during the next 4-10 centuries no unexpected and harmful events will occur at the waste disposal sites, for example natural disasters, wartime activities, terrorism?

ANNEX

Radioactive waste management

This section comprises a selection of quotes from official publication (marked by double dotd), brief summaries of some parts of those publications, and critical questions from the author (marked by [svl]).

Joint Convention

•• [IAEA-jc 2016] Q665

Background

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the first legal instrument to directly address these issues on a global scale, was opened for signature on 29 September 1997, the first day of the 41st regular session of the IAEA General Conference. It entered into force on 18 June 2001.

The Joint Convention applies to spent fuel and radioactive waste resulting from civilian nuclear reactors and applications and to spent fuel and radioactive waste from military or defense programmes if and when such materials are transferred permanently to and managed within exclusively civilian programmes, or when declared as spent fuel or radioactive waste for the purpose of the Convention by the Contracting Party. The Convention also applies to planned and controlled releases into the environment of liquid or gaseous radioactive materials from regulated nuclear facilities.

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•• [IAEA-infcirc546 1997] Q662

ARTICLE 1. OBJECTIVES

The objectives of this Convention are:

(i) to achieve and maintain a high level of safety worldwide in spent fuel and radioactive waste management, through the enhancement of national measures and international co-operation, including where appropriate, safety-related technical co-operation;

(ii) to ensure that during all stages of spent fuel and radioactive waste management there are effective defenses against potential hazards so that individuals, society and the environment are protected from harmful effects of ionizing radiation, now and in the future, in such a way that the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations;

(iii) to prevent accidents with radiological consequences and to mitigate their consequences should they occur during any stage of spent fuel or radioactive waste management.

ARTICLE 2. DEFINITIONS

ARTICLE 3. SCOPE OF APPLICATION

1. This Convention shall apply to the safety of spent fuel management when the spent fuel results from the operation of civilian nuclear reactors. Spent fuel held at reprocessing facilities as part of a reprocessing activity is not covered in the scope of this Convention unless the Contracting Party declares reprocessing to be part of spent fuel management.

2. This Convention shall also apply to the safety of radioactive waste management when the radioactive waste results from civilian applications. However, this Convention shall not apply to waste that contains only

naturally occurring radioactive materials and that does not originate from the nuclear fuel cycle, unless it constitutes a disused sealed source or it is declared as radioactive waste for the purposes of this Convention by the Contracting Party.
3. This Convention shall not apply to the safety of management of spent fuel or radioactive waste within military or defence programmes, unless declared as spent fuel or radioactive waste for the purposes of this Convention by the Contracting Party. However, this Convention shall apply to the safety of management of spent fuel and radioactive waste from military or defence programmes if and when such materials are transferred permanently to and managed within exclusively civilian programmes.
4. This Convention shall also apply to discharges as provided for in Articles 4, 7, 11, 14, 24 and 26.
••

•• [NTI 2015] q664
Convention Provisions
The Joint Convention is the first international instrument that deals with the safety of management and storage of radioactive waste and spent fuel in countries with and without nuclear programs. It also considerably elaborates on and expands the existing IAEA nuclear safety regime and promotes international standards in this area. The Convention is aimed at achieving and maintaining a high level of safety in spent fuel and radioactive waste management, ensuring that there are effective defenses against potential hazards during all stages of management of such materials, and preventing accidents with radiological consequences.
(more)
••

•• [NEWMDB 2016] Q666 = [https://newmdb.iaea.org/about.aspx] 19 Jan 2016

The Net-Enabled Radioactive Waste Management Database (NEWMDB)

The NEWMDB contains information on national radioactive waste management programmes, radioactive waste inventories, radioactive waste disposal, relevant laws and regulations, waste management policies, and plans and activities.
The principal objectives for the NEWMDB are to:
- improve access to radioactive waste management data;
- provide a system for maintaining the international "memory" of such information;
- provide readily accessible reference material to both the Member States and the Agency's Technical Assistance programme, Waste Management Technical Review and Assessment Programme (WATRP), and other programmes;
- provide a means to research and assess the development and implementation of national systems for radioactive waste management in Agency Member States, and
- provide a tool to Member States that supports the reporting requirements of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Joint Convention).

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Historical perspective (USA)

[IAEA-wmdb-st-1 2001] Q656 p 8

changes that have occurred in radioactive waste management in the last five decades

p 23: Table 2-II: Responsibility for radioactive waste management in some Member States (e.g. COVRA)

Classification of radioactive waste

[IAEA-wmdb-st-4 2005] Q659

Radioactive waste classification varies widely at the national level.
The proposed common classification scheme objective to “eliminate some of the ambiguity that now exists in classification schemes for radioactive wastes” was only partially achieved - ambiguity regarding the classification of radioactive wate still exists in many IAEA Member States.

Exclusion, exemption and clearance
[IAEA-wmdb-st-4 2005] p24 25: svl: incomprehensible text; unclear what distinction between naturally occurring and artficial radionuclides.

A generic exclusion/exemption level for natural radionuclides is set at 1 Bq/g for all radionuclides except K-40. For K-40 a value of 10 Bq/g applies.
There are situations where exposures from material with activity concentrations below the agreed eclusion/ exemption values would necessitate consideration by the regulatory control.

Uranium mining and mill (UMM) wastes

Uranium mining and mill wastes, due to the long lived radionuclides they contain, can make a significant environmental impact on air, soil, surface water and groundwater. UMM wastes also contain hazardous chemicals from milling operations as well as ore processing waste materials. The radioactivity remaining in residue materials after recovery of uranium is about 85% of the radioactivity of the original mill feed.
(svl: if no Th present !).
There is no consensus on the extent of site remediation that is required. Given the scale of the remediation operations on UMM sites, the cost of additional exposure and the cost of the remediation have to be balanced against the environmental benefits. Solutions are likely passive, low cost, low intensity and low mainetance solutions. [p.29]

UMM tailings reclamation in the USA
Three regulatory agencies that have the most impact on reclamation of conventional UMM (svl and unconventional? what are that?) tailings: RNRC, EPA and state environmental regulatory agencies.
Basicly the NRC acts as he lead agency if the material is defined as:
‘source material’: that contain 0.05% or more of U, Th or any combination thereof [svl and if less than 0.05%?)
‘byproduct’ [svl: incomprehensible definition p.30.]

NRC regulations provide the basic requirements for the operation and the reclamation of UMM tailings sites:
• Erosion stability: the tailings must be covered so that the radiological hazard is controlled for 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years.
• Radon releases: the cover must act to keep average radon releases less than 740 mBq/m^{2}s (20 pCi/m^{2}s) over the life of the cover.
• Soil decontamination: areas subject to decontamination must be cleaned up to the extend that Ra-226 levels in the upper 15 cm of soil are no more than 185 mBq/g (5 pCi/g) above background.
[svl in what chemical form? soluble? mobile? what about other decay products?]
• Groundwater restoration: groundwater contaminated by seepage from the tailings must be cleaned up to standards for various heavy metals and radionuclides that are site specific, but generally tied to EPA drinking water standards [svl: these proved to be flexible!].
• Property transfer: upon completion of site reclamation the mill site and tailings lands must be transferred

to the United States or to the State. [svl: liabilities! who declares the site reclamation to be complete?]

p 32: 2 examples of tailings reclamation: Lucky Mc mine and Shirley Basin mine.

Naturally Occurring Radioactive Material (NORM) waste

IAEA defines NORM as:
Material containing no significant amounts of radionuclides other than naturtally occurring radionuclides. The exact definition of 'significant amounts' would be a regulatory decision. [svl !]
Materials in which the activity concentrations of the naturtally occurring radionuclides have been changed by human made processes are included. These are sometimes referred to as technically enhanced NORM or TENORM. (svl elsewhere also TE-NORM).

NORM wastes commonly result from the extraction and processing of natural resources, such as oil and gas, coal and mineral resources as well as other activities (see •• below). These residues have developed over the past three decades from a little known issue to one that is receiving a considerable amount of attention for the following reasons:
- there are large amounts of such material
- there are potential long term hazards because NORM wastes are comprised of long lived radionuclides with relatively high radio-toxicities
- there is a higher likelihood for members of the public to be exposed to NORM contained in wastes and products than for many other sources of radiation. [svl !!, again only radiation, nothing about UMM]
- their wide spread occurrence in many industrial and societal areas [IAEA-wmbd-st-3 2003] Q658 p 33
- the vast number of legacy sites [IAEA-wmbd-st-3 2003] p 33

Technologies to condition and dispose of NORM residues exist, but their economic applicability largely depends on the volumes of material arising.
Given de the long half lives of the relevant radionuclides (mainly the uranium series) the question of long term stewardship and monitoring arises and is increasingly being discussed.
Taking action to address what can be a daunting challenge may require significant resources.

Example p 32: radioactive scale in China Clay refining in Cornwall, UK. Raw material mainly kaolinite; proximity of high grade uranium ores gives rise to the risk of their entrainment with the clay during extraction and concentration by subsequent treatment.

•• [IAEA-wmbd-st-3 2003] Q658 p 32:
Radioactive residues are found not only in fuel cycle activities, but also in a range of other industrial activities, namely:
- mining and milling of metallo-ferrous and non-metallic ores
- production of non-nuclear fuels, including coal, oil and gas
- extraction and purification of water for the generation of geothermal energy, as drinking and industrial process water, and paper and pulp manufacture as examples
- production of industrial minerals, including phosphate, clay and building materials
- use of radionuclides, such as thorium, for properties other than their radioactivity

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Critical questions

If these naturally occurring radioactive materials (NORM) pose health hazards, how does the IAEA judge about uranium mining and mill (UMM) wastes and large scale contamination by artificial radionuclides, due to authorized and unauthorized releases into the environment?

[svl: by defining and discussing NORM artificial contamination falls outside the scope of, for example soil contaminated by nuclear disasters is apparently not defined as 'waste' ?]

What about the biological properties of dozens of kinds of r artificial adionuclides?

Very Low Level Radioactive Waste (VLLW)

p 35 Some IAEA Member States adopted the classification of large volume, low activity waste as VLLW. There may be partial or complete overlap of this waste class with UMM waste and NORM waste in classification schemes used by other Member States.

VLLW may be generated in a wide range of activities within the nuclear fuel cycle, hospitals, research and industry. In particular, the decommissioning of nuclear facilities can also give rise to large volumes of VLLW. Presently, there is no internationally agreed definition of VLLW. The definition can vary from one Member State to another but it is generally accepted that VLLW is a subset of LILW and has activity at levels that some jurisdictions may class as exempt or cleared from nuclear regulatory control.
While it is clear that VLLW does not pose a sufficient enough radiological risk to warrant disposal in an engineered LILW repository, disposal has taken place or is planned for LILW repositories in some Member States. In some other (e.g. Sweden, Japan, France) in dedicated VLLW repositories that have minimal engineering.

General waste classification scheme

[IAEA-wmbd-st-3 2003] Q658 p 24: Table 3-1
Summary of the assessment of the Agency's proposed general waste classification scheme
Exempt Waste (EW) activity levels at or below clearance levels
there is no internationally agreed definition for clearance levels
disposal options: no radiological restrictions
Low and Intermediate Level Waste (LILW)
activity levels above clearance levels
thermal power below about 2 kW/m^3,
no international consensus on this thermal power level
Short-Lived (LILW-SL) restricted long lived radionuclide concentrations
only guidance for restricting the concentration of alpha emitting radionuclides,
no explicit guidance for other long lived radionuclides
disposal option: near surface or geological disposal facility
Long-Lived (LILW-LL) long lived radionuclide concentrations exceeding limitations for LILW-SL
disposal option: geological disposal facility
High Level Waste (HLW) long lived radionuclide concentrations exceeding limitations for short lived waste
thermal power above about 2 kW/m^3,
geological disposal facility
(Safety Guide mentioned) ... a great deal of ambiguity ragarding the classification of radioactive wast still

exists in Agency Member States.

•• [IAEA-wmdb-st-1 2001] Q656

Historically, Member States have developed and used a veriety of waste classification schemes for their radioactive waste. Commonly used waste classes include:
Low-Level Waste (LLW)
Intermediate-Level Waste (ILW)
Low- and Intermediate-Level Waste (LILW)
Heat-Generating Waste
High Level Waste (HLW)
Alpha Bearing Waste
Trans Uranic Waste (TRU)
Spent, Sealed Radioactive Sources (SRS), sometimes referred to as disused sources
Spent Fuel (SF)
Decommissioning Waste (DW)
Uranium Mine and Mill Tailings (UMMT)
Other classifications that have been used include *de minimis*, Below Regulatory Concern, and Very Low-Level Waste (VLLW), which have been used to classify waste with the lowest level of radioactivity.

p 27 Table 3-I The IAEA's proposed waste classification scheme
idem als above, +:
LILW-SL limitation of long lived alpha emitting radionuclides to 4000 Bq/g in individual waste packages and to an overall average of 400 Bq/g per waste package.

BSS = Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources

p 29: Exclusion. One reason for not regulating is that regulation would achieve nothing: natural phenomena, no identifiable responsible legal person [svl: room for different interpretations?]
Exemption: description [svl: incomprehensible, ample room for interpretation?], example smoke detectors
p 30 Clearance (under review at the IAEA). Practices may produce wastes or by-products. Some of these materials may have very low radiological risks and may be cleared for release from any further regulatory controls. referred in BSS as clearance. It is the responsibility of the national Regulatory Authority to establish the requirements for clearance and to verify compliance with the requirement.

Closely related to clearance: issue of VLLW. report for EU Member States (1999, see refs) conclusions:
• Very Low Level Wastes is not a formally existing category of wastes, except in France, where a specific VLLW site is planned.
• VLLW is of such low activity that it is not desirable, for financial reasons, to dispose of them in LLW repositories.
• The Experts suggested avoiding the disposal of the large volumes of VLLW in LLW sites. ALternatives are specific disposal in VLLW sites or conditional release of these materials (not wastes) and controlled recycling as input for the production of new metal, or for the construction of roads.

Clearing waste, classifying/managing it as VLLW, or some combination of clearance and VLLW classification is likely to be a nationally based, cost-benefit decision.

[svl: background radioactivity increases by clearance => exclusion!]

[svl: standards with Bq/g not mentioned in later reports. How is radioactivity measured? only gamma, unit Sv/h?]
end ••

p 28: Figure 3-1: One of the waste class matrices defined by the Country Co-ordinator for Hungary
Matrix name: PNPP

LLW	100% LILLW-SL	0	0
MLW	0% LILW-SL	10% LILW-LL	0
HLW	0%	80%	20% HLW

LLW	low level waste	A < 5x10E5 Bq/g
MLW	medium level waste	5x10E5 Bq/g < A < 5x10E8 Bq/g
HLW	high level waste	A > 5x10E8 Bq/g

Figure 3-2: One of the waste class matrices defined by the Country Co-ordinator for the USA
Matrix name: USNRC

Class A LLW	100% LILW-SL	0	0
Class B LLW	100% LILW-SL	0	0
Class C LLW	75% LILW-SL	25% LILW-LL	0
greater than Class C LLW	0%	100% LILW-LL	
HLW	0%	0%	100% HLW

Spent nuclear fuel: waste or resource?

[IAEA-wmdb-st-1 2001] Q656 p 31-34
Some IAEA Member States have policy of direct disposal, once through fuel cycle model,
other have a policy to reprocess their spent nuclear fuel: resource, closed fuel cycle.
Spent fuel typically: 94.3% U, 1,15% Pu and 4.55% waste products (other actinides, fission products and unwanted impurities).
Waste products HLW; vitrification is a well established opertion that has been rigorously examined and approved by regulatory authorities in several countries. Removal of U and Pu reduces the volume of HLW, but leads to the production of LILW.
Orininally reprocessing was the only considered management option for spent fuel. Later on direct disposal was recognised as an attractive alternative for various reasons:

- non-proliferation aspects
- limited market for MOX fuel
- cancellation of fast breeder programmes
- expected cost benefit
- technical and economical difficulties with reprocessing smaller quantities of some fuel types
- public concern over reprocessing facilities.

p 33 *transmutation*
Partitioning challeging aspect of the transmutation strategy, particularly separation of actinides and lanthanides chemically similar, very difficult to separate efficently; needed to reach goal of actinide transmutation. Lanthanides mostly non-radioactive
transmutation of long lived actinides eliminates long term radioactive hazard while producing short-term radioactive hazard instread

DUPIC fuel cycle Direct Use of spent PWR fuel In CANDU)

Sources of radioactive waste

[IAEA-wmdb-st-1 2001] Q656 p 37 ff
Nuclear Fuel Cycle (NFC) waste in Europe by volume Figure 4-1:
2/s LILW-SL
1/3 LILW-LL
1% HLW and SF

Decommissioning
December 2000: 93 commercial NPPs in 16 countries in some phase of decommissioning
IAEA research database: 650 research reactors, 292 operational in 58 countries
358 shut down, of the 109 decommissioned

UMMT
no international consensus on:
- definition of a 'site'
- definition of 'contaminated'
- 'how clean is clean?'

p 46 Figure 4-6: Estimated annual amounts of TE-NORM and "Commercial LLW' in the USA

metal mining	4G Mg
coal ash	85M Mg
oil/gas	6.5M Mg
water treatment	3M Mg
phosphates	40M Mg
geothermal	0.5M Mg

p 47 Table 4-III Representative NORM concentrations in selected materials ; only as a rough indicator

scale in pipes and other equipment for handling oil/gas and formation waters	
	background ~ 15 000 000 Bq/g (average 1000 to 100s of thousands
sludges in natural gas supply equipment	background ~ 40 000
sludges from ponds of produced water	10 000 - 40 000
uranium mining overburding [svl: not tailings !]	100 - 20 000 (only radium reported) (average of ~5 000 total radionuclide concentration)
coal fired power plant ashes	200 - 25 000 Bq/kg, typically closer to lower value
drinking water treatment waste	sludges ~ 600 Bq/g (only Ra-226 reported) resins ~ 1 300 000 Bq/g (only Ra-226 reported)
phosphate fertilizer (biomass energy)	5000 - 25 000
other mineral processing waste (including aluminium, rare earths, etc)	
	background ~ 400 000 [svl ??] (generally 100 - 5000)

Radioactive waste minimization and processing
[IAEA-wmdb-st-1 2001] Q656 p 51 ff

IAEA definition:
The process of reducing the amount and activity of radioactive waste to a level as low as reasonably

achievable, at all stages from design of a facility or activity to decommissioning, by reducing waste generation and by means such as recycling and reuse, and treatment, with due consideration for secondary as well as primary waste.
in text: … in both terms of volume and activity …
typical practical steps; see p. 53

Waste minimization may offer financial savings, but it may also introduce new hazards or modify those already associated with a facility.

clearance
recycle/ reuse
p 55 Bar diagrams general waste minimization 1980-1997 PWR and BWR in USA: [svl: factor >10x ! how possible??], and in France 1985-1996 [factor 3x how??]

Techniques
1 Store radioactive waste for sufficient time over which their radioactivity decay. could simplify and increase effectiveness of subsequent waste treatment and/or conditioning processes, or lead to the clearance of the waste from regulatory control
2 Recycle and reuse metals + some types of civil construction materials (concrete), arising from refurbishment and decommissioning of nuclear facilities. The main economic benefit arises from savings achieved in avoided disposal costs, rather than through material reuse or recycling directly.
3 Various treatment methods. For example, for large volumes of aquous waste containing low concentrations of radiochemical and chemical contaminants, advanced membrane and micro-filtering (e.g. titanium dioxide microfiltration systems) processes are being developed. Can provide high-quality effluent water for discharge.
4 Incineration and supercampaction. Incineration of solid wate and many types of low-level organic wastes; for example, used oil and exchange resins can be transformed into stable, homogenous mineral forms suitable for final conditioning and disposal.

definitions
Treatment. Operations intended to benefit safety and/or economy by changing the characteristics of the waste. Three basic treatment objectives are a) volume reduction, b) removal of radionuclides from the waste, and c) change of composition of the waste.
Conditioning. Operations that produce a waste package suitable for handling, transport, storage and/or disposal. Conditioning may include the conversion of the waste to a solid waste form, enclosure of the waste in containers and, if necessary, providing an overpack.

The current, commonly used methods for conditioning LILW include:
- compaction, super compaction, and incineration (solids)
- chemical precipitation, evaporation, ion-exchange, and membrane separation (liquids)

The current, commonly used methods for conditioning LILW include:
encapsulation/immobilization, e.g. grouting, bituminization, cementation, polymerization (solids), polymerization (liquids and ‘wet’ solids, such as ion exchange resins, sludges and slurries)

Radioactive waste storage

IAEA defines storage as [p 60, i!]:
The holding of spent fuel or of radioactive waste in a facility that provides for its containment, with the

intention of retrieval.
Storage is by definition an interim measure, and the term 'interim storage' would therefore be appropiate only to refer to temporary, short-term storage when contrasting with the longer-term fate of waste. Storage as defined above should not be described as interim storage.

Storage of LILW prior to disposal varies considerably amongst Member State:
- availability of disposal facilities and depends on:
- waste management infrastructure
- segregation of waste containing short lived radionuclides that are stored until radioactivity has decayed to the point where the waste is exempt from regulation as radioactive material
- economic factors

p 62 -
Table 6-I: estimated storage times for LILW-SL prior to disposal; varies 0->50 years
Table 6-II: estimated storage times for LILW-LL prior to disposal; varies 1-5 - 50-100 years
Table 6-III: estimated storage times forHLW and SF prior to disposal; varies 0 - 50-100 years
Figure 6-1 aerial photo COVRA (NL)
6-2 Castor casks at Brennelement Zwischenlager Ahaus GMbH (Germany)
6-3 Encapsulated Product Store (EPS) building - Sellafield (UK)

Radioactive waste disposal

[IAEA-wmdb-st-1 2001] Q656 p 66 ff

There are two basic strategies for radioactive waste disposal:
- 'isolate and confine'
- 'dilute and disperse' [!!]

The first strategy involves the emplacement of waste into a disposal facility that is intended to isolate the waste from humans and the environment and to prevent or limit releases of potentially harmful substances (toxic metals, radionuclides, organics) such that human health and the environment are protected.
The second strategy involves deliberately dispersing the waste into the environment in a manner intended to dilute harmful contaminants in the waste to levels that are considered acceptable according to internationally agreed standards.

For LILW-SL, a common strategy is to confine the wastes for a time frame sufficient for the radionuclides to decay to insignificant levels (generally a few hundred years). [how is 'insignificant level' defined?]
For LILW-LL much longer confinement times are required. In addition, there is an expectation that some radionuclides in the waste will not decay to insignificant levels before there is any significant degradation of the contents of the disposal facility or of the facility itself. In this case, a defence-in-depth strategy is used, which relies on multiple barriers, both engineered and natural, to ensure that in case of any releases only acceptable quantities of materials are released into the environment in any time period.
[svl 2nd law]

The three major options for LILW disposal currently used or planned by IAEA Member States are:
- surface/near surface facilities
- rock cavities (at several tens of meters to a few hundreds meters depth)
- deep geologic repositories (typically at depths of more than a few hundred meters).

A few conclusions can be drawn for LILW-SL management:
- surface/near surface disposal is and will most likely continue to be the most common disposal practice,

- for various reasons, such as geological, climate and socio-economic conditions or to minimize the risk of inadvertent intrusion into a disposal facility, some Member States have opted to dispose of their LILW-SL in rock cavities or geologic repositories.

svl: remarks on Barnwell USA, Vaalputs (SA), Centre de l'Aube (France), Rokkasho (Japan), Drigg (UK), El Cabril (Spain); hard rock caverns Forsmark (Sweden), Himdalen (Norway), Olkiluoto (Finland)
Table 7-I figures LILW-SL disposal
Table 7-II figures LILW-LL disposal

(p 67) In accordance with the proposed IAEA waste classification scheme, LILW-LL is not considered to be suitable for disposal in near surface disposal facilities because of its higher concentrations of long-lived radionuclides. It is considered for deep geological disposal only.
U conversion + enrichment: U isotopes and Pu isotopes if MOX
NPP operations: additional long-lived such as C-14, Ni-59, Tc-99, I-129 and actinides
in activated metals: for example Ni-63 and Ni-59
primary coolant water: actinides if some defective fuel.
decommissioning wastes: Ni-59, Ni-63, C-14, Eu isotopes a concern.

HLW/SF disposal
No HLW or SF repositories are yet in operation in any Member State; this remains a major challenge in radioactive waste management.
p. 71 Table 7-IV: Main underground research facilities

TRU disposal
TRU, = often: alpha waste
Some Member States TRU is component of LILW-LL, other: LILW-SL + SILW-LL together as LILW, then TRU = part of LILW. World-wide assessment of TRU management difficult.

Retrievability or 'Long-Term Storage' versus Disposal
Originally the approach of deep geological disposal was developed to remove waste from the human environment to ensure that it remains isolated from thst environment and <u>inaccessible</u> to humans for the very time scales corresponding to the slow decay of long-lived radionuclides. The concept utilizes mulriple barriers, such as the waste form, container(s), overpack(s), sealant(s), backfill, buffer(s), and the geosphere.
The term storage implies retrieval at any time in the future is intended
The term disposal implies retrieval is not intended; it does not mean that retrieval is not possible.
Disposal with retrievability receiving wider attention.
[svl: no reasons for retrieval mentioned]

Delays in the implementation of disposal programmes
p 73 concerns
Uncertainty about the 'ultimate disposition' of waste (with concepts such as 'permanent disposal', "retrievable disposal', monitored retrievable disposal', 'assured isolation', "long-term storage', et cetera.) has the potential to simply defer today's problem for future societies.

With deferral the problem of what to do with today's waste remains unresolved. For example, some storage sites are in operation well beyond their originally estimated service times. This has resulted in the degradation of waste packages and the facilities themselves, which may result in releases of radionuclides into the environment. The consequence may be expensive remediation activities, which divert limited resources from disposal programmes.

Table 7-IV: Main Underground Research Facilities

(information compiled by consultants at an IAEA sponsored meeting in 1999)*

COUNTRY	LOCATION	USUAL NAME/TYPE OF FACILITY	TYPE OF RESEARCH	HOST ROCK/ FORMATION	NATURE OF EXPERIMENTS [3]	TIME PERIOD
BELGIUM	MOL	HADES+URF PRACLAY	S [1]	Plastic clay	TCHMR+D	since 1980
CANADA	LAC DU BONNET Manitoba	URL	G [2]	Granite	TCHM	since 1984
FINLAND	OLKILUOTO (in VLJ repository)	Research Tunnel	G	Granite	HM+D	since 1993
FRANCE	FANAY Augères/Tenelles	Galleries in U Mines	G	Granite	TCHM	1980-1990
	AMELIE	Galleries in K Mine	G	Bedded salt	TM+D	1986-1994
	TOURNEMIRE	Test Galleries	G	Shale	CHM	since 1990
GERMANY	ASSE	Test Galleries in K/salt mine	G	Dome salt	TCHM/R + D	1977-1995
	GORLEBEN	URL	S	Dome salt	Characterization in exploration galleries	since 1997 (now halted)
	KONRAD	Test Galleries in Fe Mine	S	Shale	CHM	since 1980
JAPAN	TONO	Galleries in U Mine	G	Sandstone	CHM	since 1986
	KAMAISHI	Galleries in Fe-Cu Mine	G	Granite	Characterization	1988-1998
SWEDEN	STRIPA	Galleries in Fe Mine	G	Granite	TCHM	1976-1992
	ÄSPÖ	HRL	G	Granite	TCHM + D	since 1990
SWITZERLAND	GRIMSEL	GTS at dam tunnel	G	Granite	TCHM	since 1983
	MONT TERRI	Galleries at road tunnel	G	Shale	TCHM	since 1995
USA	NEVADA Test Site	CLIMAX	G	Granite	D	1978-1983
	NEVADA Test Site	"G-Tunnel"	G	Tuffs	THM	1979-1990
	CARLSBAD	WIPP	S	Bedded salt	TCHM/R+D	since 1982
	YUCCA Mtn.	ESF	S	Tuffs	TCHM+D	since 1993
	YUCCA Mtn.	Busted Butte	G	Tuffs	CHM	since 1997

* Existing facilities where tests were and/or are still undertaken.
[1] (S) = Site-specific
[2] (G) = Generic
[3] T - Thermal, C - Chemical, H - Hydrogeological, M - Mechanical Tests, R - Radiation tests, D - Demonstration tests
For information on salt formations, see "Characterization of Bedded Salt for Storage Caverns", Recent Hydrogeological Research Published by the Bureau of Economic Geology, http://www.cc.utexas.edu/research/beg/hydro.html

[svl: in the WMDB reports no contributions of Asian countries, nor Russia, Ukraine, etc, only USA, Europe and Japan, would those countries comply with the IAEA proposed regulations??]

[little or progression in ST 2,3, 4 since ST-1]

[many, if not all definitions and recommendations leave the door open for ad hoc interpretations and adaption of regulations to economic needs ! how stringent are 'internationally agreed standards'?]

[dispersion: accumulation! tens of years, 100s of NPPs, steady increase of background radiation and contamination]

[main content of reports is dealing with 'what should be done' and with administrative and managerial aspects and recommendations]

[how reliable are the measurements to distinct between LILW-SL and LILW-LL? methods, independent inspectors?]

Management of radioactive sources

[IAEA-wmdb-st-1 2001] Q656 p 77 ff

At last count, more than ten years ago (!!! how hard they work!), it was estimated that there were over 600 000 sources in existence world-wide (omitting sonsumer products such as smoke detectors).

over 80% industrial gauges, remaining 20% medical sources
predominantly small physical sizes, very high concentrations radioactivity, typically in the GBq to PBq range
Owing to their small pysical size theu are easily lost ar misplaced if not properly managed.
Co-60, Cs-137 for irradiation
Pu-238 power sources
neutron sources Am-241
Ra-226 extensively used in the past

Borehole disposal concept p 82-85

Managing the consequences of past practices
p 86 ff

Chernobyl shelter

The US-EPA Superfund activities in relation to radioactive contamination.

Status of the Dounreay Shaft ans Silo remediation.
[svl: recommendations, no details on contents]

International co-operation for radioactive waste management in the Russian Federation
By 1995 total activity in radioactive waste about $7.4x10^{19}$ Bq (74 EBq)
in addition 8500 tonnes SF stored, total $1.5x10^{20}$ Bq (150 EBq)
[svl => 0.018 EBq/Mg ? low ??]

Status of the Wismut remediation
map U mining + milling sites in Thüringen and Sachsen (former GDR
> 40 years intensive m+m total production > 220 000 tonnes of U, for Soviet Union
adversely affected area of about 100 km^2 , local environmental damage, including widespread soil and groundwater contamination
Figure 9-2 Status June 2000
during initial years little care paid to protection of the health and safety of the workers and the general public and protection of the environment
in 1990 (reunification Germany) production stopped, decommissioning and rehabilitation, 13bn DM committed, by 2000 6.2bn DM invested [www.wismut.de/]

References

Q76
Lochbaum 2004
Lochbaum D,
US Nuclear plants in the 21st century. The risk of a lifetime,
Union of Concerned Scientists, May 2004,
‹ nuclear04fnl.pdf ›
http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nuclear_power/nuclear04fnl.pdf
retrieved 23 Dec 2015

Q427
Roussely 2010
Roussely F,
Synthèse du rapport. Avenir de la filière Française du nucléaire civil,
16 Juin 2010,
file: Synthese-ROUSSELY.pdf,
www.elysee.fr/president/les-actualites/rapports/2010/synthese-du-rapport-sur-l-avenir-de-la-filiere.9375.html
English translation (not always very accurate):
www.psr.org/nuclear-bailout/resources/roussely-report-france-nuclear-epr.pdf

Q540
WNA 2016a
Radioactive Waste Management,
World Nuclear Association.
http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/radioactive-waste-management/.aspx
updated July 2016, retrieved August 2016

Q656
IAEA-wmdb-st-1 2001
Radioactive Waste Management Status and Trends,
IAEA, August 2001
‹ IAEA-WMBD-ST-1.pdf ›
https://newmdb.iaea.org/library
retrieved 13 Jan 2016

Q658
IAEA-wmdb-st-3 2003
Radioactive Waste Management Status and Trends-issue #3,
IAEA, August 2003
‹ IAEA-WMBD-ST-3.pdf ›
https://newmdb.iaea.org/library
retrieved 13 Jan 2016

Q659
IAEA-wmdb-st-4 2005
Radioactive Waste Management Status and Trends-issue #4,
IAEA, March 2005
‹ WMDB-ST-4.pdf ›
http://www-pub.iaea.org/MTCD/publications/PDF/WMDB-ST-4.pdf
and: https://newmdb.iaea.org/library
retrieved 12 Jan 2016

Q662
IAEA-infcirc546 1997
Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management,
International Atomic Energy Agency, Information Circular INFCIRC/546, 24 December 1997
‹ infcirc546.pdf ›
https://www.iaea.org/sites/default/files/infcirc546.pdf
retrieved 12 Jan 2016

Q664
NTI 2015
Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management
http://www.nti.org/treaties-and-regimes/joint-convention-on-the-safety-of-spent-fuel-management-and-on-safety-of-radioactive-waste-management/
retrieved 12 Jan 2016

Q665
IAEA-jc 2016
Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Background
https://www.iaea.org/publications/documents/conventions/joint-convention-safety-spent-fuel-management-and-safety-radioactive-waste
retrieved 19 Jan 2016

Q666
NEWMDB 2016
Net-Enabled Radioactive Waste Management Database (NEWMDB)
https://newmdb.iaea.org/
retrieved 19 Jan 2016