WASTE TREATMENT & CONDITIONING

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Steps in waste management

The life cycle of radioactive waste generally consists of several steps:

Pre-treatment: collection; segregation; decontamination, fragmentation

Treatment: volume reduction, radionuclide removal from waste, change of physical and chemical composition

Conditioning may include immobilization of the waste in cement, bitumen or glass matrix and enclosure of the waste in containers

Disposal envisages emplacement of waste in an appropriate disposal facility without the intention of retrieval

Technical options for waste processing

- **Volume reduction is the main purpose of treatment of solid waste**
- Solid wastes are generally segregated into **combustible, compactible and non-compactible waste forms**
- Treatment of solid wastes that are not combustible or compactible generally requires some **segmentation** in order that standard types of disposal container can be used
- **Low force compaction** is the least expensive and an easier to operate volume reduction process than high force compaction
- **High force compactors (super-compaction)** can give somewhat better reduction factors. Compaction units are also amenable to automation, which can improve operational efficiency and radiation protection aspects
- **Incineration** of combustible wastes gives a large overall volume reduction and produces a stable waste product (ash) which can be readily immobilized using a variety of methods which employ different matrices, such as concrete and bitumen
- Where the cost of disposal is very high, the **melting of metals** could be considered as a means of reducing the volume considerably. The cost effectiveness of this approach can be improved if the metal can be used as additional shielding for other waste

The main waste treatment methods

for solid waste:

- Compaction
- Cementation
- Supercompaction
- Incineration
- Smelting
- Plasma incineration

The main waste treatment methods

Liquid waste treatment:

- Filtration
- Ion exchange
- Evaporation
- Sedimentation and decantation

Further conditioning:

- Cementation of spent resins, concentrates and sledges
- Bituminization
- Incineration of organic solvents and lubricants

Compaction

- Used for filters, plastics, textile, wood, insulation materials and other compressible wastes
- Form of final package:
  - Waste balls wrapped into polyethylene film
  - Drums with the waste

The compressible waste bales are placed in a landfill in Sweden

Low force compaction

Low force (in-drum) compaction aims at reducing the volume of dry, compactable waste such as paper and plastic by compressing the waste in a 200 L drum so the compressed waste is ready for long term storage

Low force compaction is the least expensive and an easier volume reduction process than high force compaction.

Compaction units are also amenable to automation, which can improve operational efficiency and radiation protection aspects

The compaction module compresses the waste in the drum, adds more waste to the drum, compresses it again and repeats the process until the drum is full

High force compaction (supercompaction)

Highest volume reduction which is close to theoretical density of materials

Compactors are amenable to automation, which improves operational efficiency and radiation protection

Compaction force typically 1200-1500 tons

Compacts the waste which is placed inside of drums

Applicable to :
-glass, ceramic, polymer and rubber materials
-metal waste up to several mm
-contaminated equipment
-soil, construction waste, insulating materials

Supercompaction

- The waste is placed into metallic drums and pressed with high power press
- The drums are pressed into cylindrical pellets
- Few pellets are placed into containers and filled with grout

Cementation

- Has the longest traditions
- Simple and not expensive
- Universal method widely applied for waste conditioning
- Good performance of waste matrix - cementitious grout performs several safety functions:
  - Protection against corrosion
  - Confining barrier
  - Chemical barrier (after degradation, alkaline environment increase retention of most radionuclides)
- Waste is grouted in metallic drums or concrete containers
- Usual Portlandcement is commonly applied for production of grout
- However, better quality and longevity can be achieved when slag cement is applied

Cementation (2)

- Porosity of waste matrix has to be minimized
  - Optimal cement/ water ratio must be controlled
  - Vibration by vibrating plate is applied to reduce porosity of the grout
- The cemented packages have to stay without disturbances for certain curing time
- Danger of overheating of the matrix
- The metallic waste has to be properly segregated and certain metals excluded (Al, Zn)
- Cementation of aches is complicated due to possible presence of Al particles

Drums with cemented spent resins in Ignalina NPP

Mobil cementation facility

Containers applied for cemented waste

- The mixed waste can be poured into drums
- Concrete containers are mostly applied
  - Reinforced with carbon steel bars
  - Fiber reinforced concrete
  - *Reinforced with stainless steel?*
  - *Reinforced with synthetic bars?*
- Metal containers

In Spain the grout is injected through holes in container lids

Smelting of scrap metal

- Advantages:
  - Homogenous distribution and effective immobilization of radionuclides in the ingots
  - Volume reduction factor from 5 to 40
  - Form and shape of ingots is suitable for further disposal (stable matrix)
  - Simplified characterization of radioactive materials with complex geometries
  - Precise measurement of radionuclide activities
  - Partial decontamination

Distribution coefficients during melting /QUADE, U., MULLER, W., 2005/

	Melt	Slag	Dust
Mn-54	60	39	1
Fe-55	99	1	0
Co-60	88	11	1
Ni-63	90	10	0
Sr-90	1	97	2
Ag-110m	1	32	67
Cs-137	1	60	39

- About 90% of Ni and Co are left in ingots after smelting

Smelting of metals

Melting may provide an essential step when releasing components with complex geometries, simplifying monitoring procedures for radioactive metal characterization. Significant fraction of the radioactive contaminants will be removed and concentrated in the slag

In addition to its decontamination effects, the problem with inaccessible surfaces is eliminated and the remaining **radioactivity content is homogenized** over the total mass of the metal. Thus, melting can be a last step in the decontamination and release of components with complex geometries **after these pieces have been decontaminated**.

A particularly advantageous consequence of melting is its decontamination effect on ^{137}Cs, a volatile element that has a half-life of 30 years. During melting, ^{137}Cs **accumulates in the dust collected by ventilation filters** and is removed.

The dominant remaining nuclide in the for most reactor scrap is ^{60}Co ($T_{1/2}$=5.27 y). Other remaining nuclides have even shorter half-lives, so the reactor scrap with reasonably low activity **can be stored for release in the foreseeable future**.

Smelting of metals

- Waste volume reduces due to reduction of voids and partial decontamination of the metal. Ingots are a primary product of smelting.
- Prevailing amount of Co, Cr, Fe, Ni, Zn, Mn radionuclides stay in the metal ingots while Sr and Cs concentrate in slag and dust
- The secondary waste (slag and dust) composes 1-4% of the smelted waste only
- The secondary waste (filters and slag) has to be further treated and immobilized as a radioactive waste

Plasma pyrolysis

Containers for Very Low Level shot lived radioactive waste disposal to be used in Lithuania

- Half ISO containers filed with waste (pieces of concrete, metal)
- Boundless of compressed waste (organics and other compressible wastes)
- Big bags with ion exchange resins

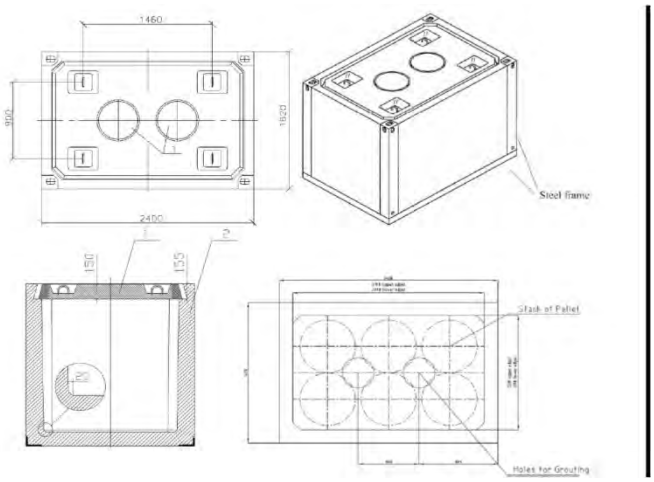
Cost of conditioning

In general, each of the cost elements to be estimated will have the following cost components:

- Labour costs, i.e. the costs associated with people required to execute the process, build the building, drive the transport vehicle etc.
- Material and equipment costs (e.g. building materials, equipment such as pipes and heat exchangers, tunnel boring machines, transport and work equipment, etc.)
- Other costs (e.g. utilities, supplies, etc.)

As well, depending on the stage of the cost estimating process a contingency amount should be added either to each cost element estimated or to the overall cost estimat

KTZ 3,6 container for NSR in Lithuania



French type fiber concrete containers

CBF-C1 or C2
fiber-reinforced concrete container with precast lid for sealing

CBF-C2S
fiber-reinforced concrete container with inner steel tank for cement-solidified liquid waste, qualified in 2006

CBF-C2P
Fiber-reinforced concrete container for 9 waste boxes in three steel pipes,

Cost of conditioning
Examples for different cost of Melting in Countries

Duratek USA

Duratex operate a 20 ton including furnace (7200 kW) at it's centralized facility in Oak Ridge, Tennessee. The metal is melted and cast into shield Blocks that are reused by the Department of Energy (DoE) as biologic protection in R&D accelerators and decommissioning works. Therefore, the metal sent to Duratex in the nuclear industry and remain in USA.
Criteria: All material must meet Duratex WAC
Dose rate : Max 200 microSv/h for steel, 50 microSv/h for lead.
The metal and secondary waste remain in USA
Prices for 2006: from 7 to 22 $ per kg

Cost of conditioning
Examples for different cost of Melting in Countries

Studsvik Sweden

Studsvik operates one induction furnace of 3 ton capacity and one electric are furnace (0,6 ton Al) for melting of radioactive metallic waste. The objective of the process is to end up with metal that are possible to release and to recycle for reuse in the normal steel and metal industry.
Criteria: All material must meet Studsvik WAC
Dose rate : 200 micro Sv/h, hot spots 500 microSv/h.
Free release after melting:
- 0,5 Bq/g for beta, gamma including less than 0,1 for alpha.

Prices in 2004: from 2.5 to 4.1 Euros per kg

Cost of conditioning
Examples for different cost of Melting in Countries

Siempelkamp, Germany

Siempelkamp uses a 3,2 ton electric medium- frequency furnace (Carla) for melting of radioactive waste. For processing reasons, Siempelkamp accepts quantities of 20 tons and more shipment.
Criteria:
All material must meet Siempelkamp WAC.
Dose rate: not in their WAC.
Specific actvity : 200 Bq/g max, for nuclear fuel nuclides (U-233, Pu 235, Pu- 239, Pu-241) – 100 Bq/g max, for H-3, C-14, Fe-55, Ni-63 -2000 Bq/g max.
Prices in 2001: from 2.5 to 4.0 Euros per kg

Cost of conditioning
Examples for different cost of Melting in Countries

Socodei, France

Centraco uses a 4 ton capacity induction melting furnace for melting of French Scrap. Metal coming from abroad has yet never been processed, but possibility exists. All secondary waste must return to waste generators.
Criteria:
All material must meet Socodei WAC
Dose rate: 2 mSv/h (transport)
Specific activity: 50 (to 350) Bq/g max alpha, 20000 Bq/g beta/gamma
Prices around 6-8 Euros per kg

Thank you!

WASTE CHARACTERIZATION

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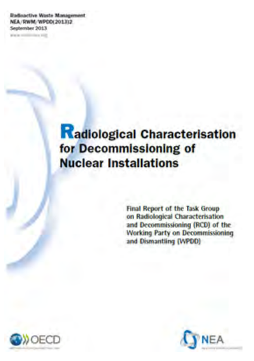
18 November 2015, France

Definition /by IAEA/

- **Waste characterization:** Determination of the physical, chemical and radiological properties of the waste to establish the need for further adjustment, treatment or conditioning, or its suitability for further handling, processing, storage or disposal

IAEA documents are available

Other reports



Radiological Characterisation for Decommissioning of Nuclear Installations

2. Role and Significance of Radiological Characterisation in Decommissioning and Some Key Aspects of its Implementation

- Radiological characterisation
- Application of radiological characterisation in the various phases of the life cycle of a nuclear installation
- Characterisation as an important input for estimation of costs and liabilities
- Implementation of radiological characterisation
- Techniques used in radiological characterisation
- Definition of clear objectives for radiological characterisation

3. Radiological Characterisation During the Various Phases of a Nuclear Installation

- Coupling and synergies between radiological characterisation in different phases.
- Radiological characterisation before and during operation
- Radiological characterisation during the transition phase
- Radiological characterisation during dismantling
- Radiological characterisation for final survey

Characterization of radioactive waste performed in several stages

- The aim of waste characterization is to define waste properties sufficiently to demonstrate acceptance for successive waste management steps, and ultimately to meet waste acceptance criteria for the disposal facility
- Knowledge of the generation process provides the first estimate of the characteristics of waste
- Direct measurements improve the information on the properties of the waste
  - The initial measurement could be determining the dose rate emitted from the waste
  - Later measurements could be by gamma spectroscopy, and waste could be sampled for further analysis, e.g. alpha, beta spectroscopy and/or chemical analysis

Waste characterization strategy & stages

- Pre- characterization
- Application of *scaling factors* for *difficult to measure* radionuclides
- Characterization of conditioned waste packages
- Verification of compliance

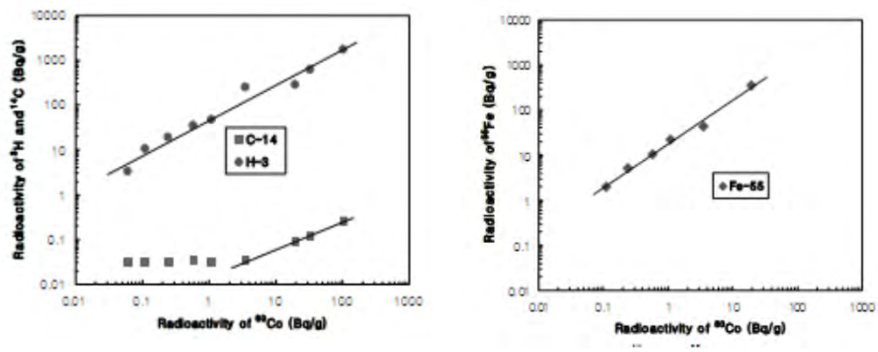
1. Initial characterization

- A survey has to be performed before dismantling (in Russian "KIRO")
- Measurements to be performed:
  - gamma doze rate (mapping)
  - "in situ" gamma spectrometry
  - surface contamination
  - wipe tests
  - taking samples for laboratory measurements
    - gamma, beta, alpha

2. Definition of **scaling factors**

1. Definition of radionuclide list
2. Definition of waste streams
3. Sampling and measurements of radionuclide activity concentrations
4. Theoretical analysis of radionuclide generation processes in various components (waste streams)
5. Definitions of the correlations between "difficult to measure" and reference radionuclides (i.e. Co-60 or Cs-137)
6. Validation of the scaling factors by measurements

Examples of correlations



A Correlation of the ^{60}Co and Beta-emitting Radionuclides in the Activated Concrete of KRR-2

Mun Ja KANG*, Sang Bum HONG, Un Soo CHUNG, Jin Ho PARK, Kun Ho CHUNG, Geun Sik CHOI, and Chang Woo LEE

Origin of radionuclides

- Fe-55 is produced by neutron activation of stable iron nuclides Fe-54 and Fe-56
- Ni-63 is produced by neutron activation of Ni-62 and Cu-63
  - Stainless steel contains about 10% of Ni
- Co-60 is produced in the structural steels and other alloys of nuclear reactor vessels and internal components from neutron activation of Co-59

$$^{59}Co + n \rightarrow {}^{60}Co + \gamma\text{-ray} .$$

$$^{60}Co \xrightarrow[5.2y]{100\%} {}^{60}Ni + \beta^- \text{ (1,480 keV max energy; 314 keV major energy)} + \gamma \text{ (1,170 \& 1,330 keV)} .$$

Neutron activation products of Fe and Ni

Target nuclide	Abundance %	(n, γ) cross section	Activation product	Half life	Decay
^{58}Ni	68.3	4.64	^{59}Ni	7.6x10^4 y	EC (Kx=6.9 keV)
^{60}Ni	26.1	2.82	^{61}Ni	Stable	
^{61}Ni	1.13	2.51	^{62}Ni	Stable	
^{62}Ni	3.59	14.25	^{63}Ni	100 y	β-, 66.9 keV
^{54}Fe	5.85	2.3	^{55}Fe	2.73 y	EC
^{56}Fe	91.75	2.6	^{57}Fe	stable	
^{58}Fe	0.28	1.31	^{59}Fe	44.5 d	β-, γ

Atomic ratio: ^{59}Ni/^{63}Ni=6.5:1

Activity ratio: ^{59}Ni/^{63}Ni=1:133

Nickel-63

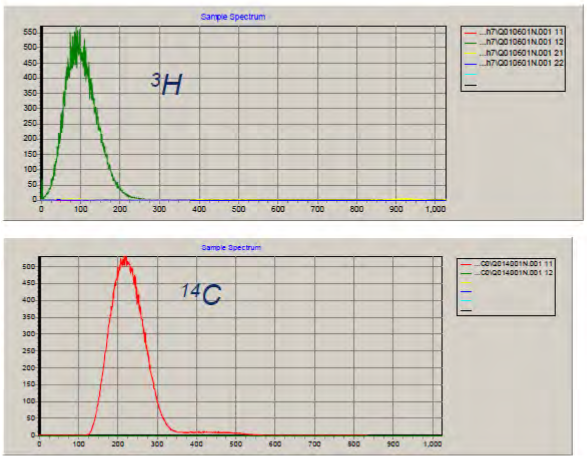
- Half-life: 100.1 years
- Emissions: beta particles with a maximum energy of 66 keV and an average energy of 17 keV
- Maximum Range: 5 cm in air; < 0.01 cm in tissue
- Dose rate to the skin at 10 cm: negligible
- Detection: a wipe survey using liquid scintillation counting is the preferred method for detecting Ni-63
  - G-M detectors will not detect Ni-63 contamination
  - Radiation monitoring badges are not required for Ni-63 users, since the monitoring badges will not detect Ni-63

Production of C-14

- C-14 is produced in the reactor core due to three neutron reactions:
  - $^{13}C(n,gama)^{14}C$
  - $^{14}N(n,p)^{14}C$
  - $^{17}O(n,alpha)^{14}C$
- N-14 is the main contributor

Beta spectrum of ^{3}H and ^{14}C measured by Quantulus Liquid Scintillation Counter

RISØ

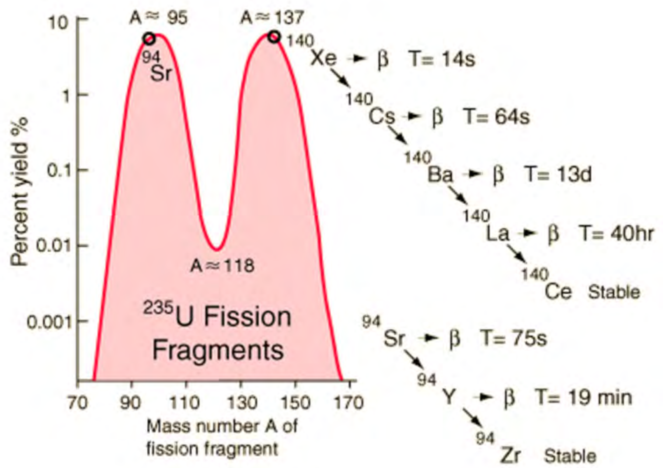


No other impurity nuclides were seen in the H-3 and C-14 spectrum

Fission products: Cs-137 and Sr-90

- Cs-137 and Sr-90 are uranium- 235 fission fragments
- Cs-137 is produced by the sequential beta decays of products that come from the initial production by fission of an isotope of tellurium, Te-137
- Te-137 decays to I-137, which decays to Xe-137, which decays to Cs-137
  - **Half- life of Xe-137 is 3.8 min.**
- Origin of Sr-90 is similar
- However, chemical properties differs significantly

Fission fragments



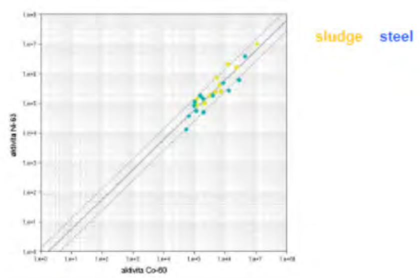
Use of SF

The use of scaling factor:

1. the determination of the scaling factor (correlation factor)
2. determine the concentration of easy to measure nuclide
3. calculate the concentration of radionuclide difficult to measure

$$C_{DTM} = SF_{DTM} * C_{ETM}$$

Scaling factor – Ni-63 to Co-60 – NPP Dukovany



Measurements

- Gama spectroscopy
  - Nondestructive method
- Chemical separation of radionuclides followed by:
  - Beta counting
  - Alpha spectroscopy
  - Mass spectroscopy

Radiological laboratory analysis – important radionuclides

Laboratory destructive analyses for common radionuclides

Laboratory method	Radioisotopes
Alpha spectrometry	Np-237, U-233, U-234, U-235, U-238, Pu-238, Pu-239, Pu-240, Am-241, Cm-242, Cm-243, Cm-244
Beta counting	Sr-90, Tc-99
Gamma or X spectrometry	Fe-55, Ni-59, Co-60, Kr-85, Nb-94, I-129, Cs-137, U-235, Np-237, Am-241
Liquid Scintillation	H-3, C-14, Ni-63, Kr-85, Sr-90, Sm-151, Ra-226, Pu-241
ICP/MS	Tc-99, I-129, Pd-107, U, Th, Np-237
Mass spectrometry	U-233, U-234, U-236, U-238, Pu-238, Pu-239, Pu-241, Pu-242

Typical preparation time before measurement: from hours to days
Typical counting time: from hours to days
Price to detect one radionuclide between 100 and 300 €

Measurement of Ni activities: decomposition of samples

- Metals (steel, Ni-Cr-X alloys, copper, lead, Al alloys)
  - Acid digestion
- Concrete, soil, sediments
  - Alkali fusion followed by water leaching
  - Acid digestion
- Plants, organics
  - Ashing followed by acid digestion

Detecting Ni-63

- After separation the activity is measured by liquid scintillation spectrometer

Measurement of Ni activities: detection of Ni-59

- Ni-59 emits 6.9 keV X-rays
- It can be measured by gamma spectrometers with Ultra Low Energy Germanium detectors
- Activity of Ni-63 correlates with activity of Ni-59
  - Ni-59/Ni-63 = 1/133

3. Characterization of waste packages

Measurement of waste package – total gamma measuring

Total gamma measuring

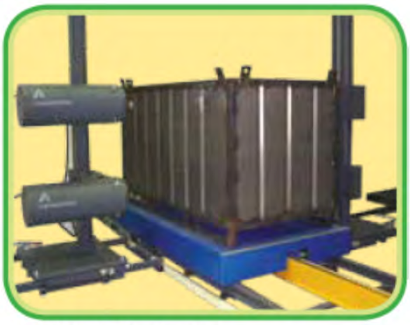
You need a good knowledge of nuclide composition (different gamma photons emissions for individual nuclides, different energy of photons).

Measuring systems with 24 plastic scintillations detectors.

Gamma measurements tools

Non-destructive assay: Neutron measurement

- Passive total counting: Every neutron emitted is counted. Not specific to any individual actinide. Can be very sensitive due to statistical precision but easily up set by interference from other neutron emitters.
- Active coincidence counting (ANCC): An ever-present random neutron source induces prompt fission in fissile isotopes. Coincidence electronics rejects the random neutrons and only counts those from the fission. Useful for fissile isotopes, primarily U-235 and Pu-239.
- Combined Passive/Active Techniques: Where wastes contain both uranium and plutonium, a combined active/passive method can be used to individually quantify each component. The passive result indicates the Pu-240 and U-238 (if present in large quantity) and the active result indicates U-235 and Pu-239 content.



WM 2500 Box Counter

(100 R/h)

Functions of waste matrix and containers

- Solidification and packaging of wastes enhance the safety of the disposal system
- Packaging is required to provide safety during:
  - transportation of the waste to the disposal site and
  - during its emplacement in the disposal facility

Functions of waste matrix and containers

- During the post-closure phase, the waste package provides both physical and chemical containment of waste contaminants
- The waste package serves as the first barrier in the series of barriers that contribute to radionuclide isolation from the biosphere.
- In the context of repository performance, waste packages generally serve the following functions:
  - Limit the rate of radionuclide and contaminant release
  - Provide mechanical support for other repository components

Standards for concrete testing could be applied for testing of waste matrix

- EN 12390-1:2003 Testing hardened concrete - Part 1: Shape, dimensions and other requirements for specimens and moulds
- EN 12390-2:20t09Testing hardened concrete - Part 2: Making and curing specimens for strength tests
- EN 12390-3:2009 Testing hardened concrete - Part 3: Compressive strength of test specimens
- EN 12390-7:2009 Testing hardened concrete - Part 7: Density of hardened concrete
- EN 197-1:2001 Cement - Part 1: Composition, specifications and conformity criteria for common cements

Mechanical express test in Ignalina NPP

4. Waste package verification

- Nondestructive methods
- Destructive methods

Example of waste package verification at the repository /TECDOC -1129/

Administrative checks	Visual checks	Direct measurements
Completeness of consignment record	External package condition	Weighing
Package identification	Tamper seals	Radiation dose survey
Weight	Package closure	Radiological contamination survey
Activity limits		
Dose rate	Package labelling/ identification	Tightness (torque) testing
Surface contamination		Radiography/tomography
Shipment number		Activity measurement
Special conditions		Container integrity survey
Container type		Destructive testing
Fissile mass		

Visual examination may include

- Examination of external package condition
  - Identifying potential problems prior to initiating off-loading
  - Examination for evidence of waste package damage (dents, punctures, cracks, swelling, etc.), missing bolts, screws, welds
  - Extensive corrosion, evidence of leakage (discoloration)
- Package labelling and identification:
  - All required labels and markings must be in good condition
- Specific external waste package information may be determined by the regulatory body:
  - Weight
  - Radiation field
  - Package manufacturer
  - Waste generator

Visual examination

- Personnel conducting visual examination have to be suitably trained and qualified
- Inspections need to be conducted by use of a formal procedure and the results recorded on inspection forms
- Completed inspection forms have to be filed and available for examination

Direct measurements

Techniques for direct measurement and verification of compliance with waste acceptance criteria provide an increased level of confidence in waste package documentation supplied by the waste generator. These techniques can range from relatively simple and inexpensive methods (e.g. contamination surveys) to more complex methods (e.g. destructive sampling) that are more expensive due to the need for sophisticated equipment, facilities and highly trained and qualified personnel.

Usual compliance checking process

- Definition of general WAC for disposal
  - for planning purpose
- Definition of site/facility specific WAC
  - during SAR phase
- Preparation and approval of waste package specification
  - for each type of WP
- Preparation of waste package passport (or data sheet, or declaration)
  - for each WP
- Compliance is checked before disposal

Conclusion

- Destructive methods are very expensive and they should be excluded or minimized
- It is much simpler to characterize raw (untreated) waste instead of conditioned waste
- So, it is recommended appropriately characterize waste at early stages
- Application of the scaling factors method is advised

Thank you!