International Atomic Energy Agency

Decommissioning of Nuclear Facilities

Decontamination Technologies

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Lesson Objectives

- Review basic objectives of decontamination techniques and processes
- Review selection criteria and factors for consideration in selecting a decontamination process
- Review some typical decontamination technologies and experiences

Definitions

- Decontamination is defined as the removal of contamination from surfaces by
  - Washing
  - Heating
  - Chemical or electrochemical action
  - Mechanical action
  - Others means
- Sometimes, it can also concern the removal of radioactivity situated deep into the material (mostly for concrete).

3 Primary Reasons to Decontaminate

- Remove the contamination from components to reduce dose level in the installation (save dose during dismantling)
- Minimize the potential for spreading contamination during further dismantling
- Reduce the contamination of components to such levels that may be:
  - Disposed of in a lower category (lower cost)
  - Recycled or reused in the conventional industry (clearance of material)

Applicability of a technology

- There is no single technique to address all kinds of problems
- The selection of technologies depends on:
  - The type of facilities (power plant, fuel cycle facility, research facility)
  - The type of isotopes which are involved
  - The activity level of the equipments and parts which are concerned
  - The physical/chemical properties of the equipments/parts to be dismantled (e.g. concrete vs. metal), and of the radioisotopes and contamination layer.

Secondary Waste Generation

- Generally, decontamination techniques are producing "secondary" waste like abrasive particles, liquid effluents, fumes & aerosols
- A method to capture trap it and control this material is important since
  - It can have influence worker safety (e.g. production of aerosols; handling of this waste, etc)
  - It can impact waste management (more waste to be disposed of)

Cost of the technology

- The investment cost and operating cost of a decontamination system is often marginal or at least only a small part compared to the total cost
- The decision to decontaminate (either before or after dismantling) must be taken after a detailed cost/benefit analysis including all aspects involved

Decontamination can thus be done before and/or after dismantling

- Decontamination BEFORE dismantling has as main objectives:
  - The dose rate reduction around the concerned component(s) (*Radioprotection objective)*
  - To reduce the risk of contamination spread during further dismantling of the component *(Safety objective)*
- Decontamination AFTER dismantling has as main objectives:
  - To change the waste category for the disposal of the component *(Waste category & cost objective)*
  - To eventually be able to reuse or recycle the material *(free release objective)*
  - Potentially to reduce the dose rate during further waste handling

Decontamination before Dismantling (metallic structures)

Objectives : Reduction of Occupational Exposure

Pipe Line System Decontamination
Closed system

- Chemical Method
- Mechanical method

Pool, Tank
Open system

- Hydro jet Method
- Blast Method
- Strippable coating Method

Decontamination after Dismantling (metallic structures)

Objectives : Reduction of radioactive waste or recycling

Pipes, Components
Open or closed system

- Chemical Immersion Method
- Electrochemical Method
- Blast Method
- Ultrasonic wave Method
- Gel Method

Decontamination of concrete and buildings

Objectives : Reduction of radioactive concrete waste or Release of building

Concrete Surface

- ➢Mechanical Method
  - ➢Scabbler
  - ➢Shaver
- ➢Blast Method
- ➢Innovative techniques

Concrete Demolition

- ➢Jackhammer
- ➢Cutting/sawing
- ➢Drill & Spalling
- ➢Explosives

Selecting a specific decontamination technique

- **Need to be considered**
  - **Safety**: Not to increase radiological or classical hazards
  - **Efficiency**: Sufficient DF to reach the objectives
  - **Cost-effectiveness:** should not exceed the cost for waste treatment and disposal
  - **Waste minimization**: should not rise large quantities of waste resulting in added costs, work power and exposure
  - **Feasibility of industrialization:** Should not be labour intensive, difficult to handle or difficult to automate.

Parameters for the selection of a decontamination process

- Type of plant and plant process
- Operating history of the plant
- Type of components: pipe, tank
- Type of material: steel, Zr, concrete
- Type of surface: rough, porous, coated…
- Type of contaminants: oxide, crud, sludge…
- Composition of the contaminant (activation products, actinides… and radionuclide involved)
- Ease of access to areas/plant, internal or external contaminated surface
- Decontamination factor required
- Destination of the components after decontamination
- Time required for application
- Capability of treatment and conditioning of the secondary waste generated

Some examples about the type of material

- **Stainless steel**: Resistant to corrosion, difficult to treat, needs a strong decontamination process to remove several µm
- **Carbon steel**: Quite porous and low resistance to corrosion, needs a soft process but the contamination depth reaches several thousand µm (more secondary waste)
- **Concrete**: The contamination will depend of the location and the history of the material; the contamination depth can be few mm to several cm.

Some examples about the type of surface

•**Porous**: Avoid wet techniques which are penetrant.

•**Coated**: Do we have to remove paint ? (contamination level, determinant for the use of electrochemical techniques)

•**Presence of crud**: What are the objectives ? (reduce the dose or faciliting the waste evacuation)

•**High roughness**: Will we be able to measure surface contamination afterwards ?

Some examples about the treatment of secondary waste

➢ Availability of a facility to treat secondary waste from decontamination (chemical solutions, aerosols, debris, …)

➢ Final products (packaging, decontaminated effluent,…) have to be conform for final disposal.

➢ In decontamination processes, the final wastes are concentrated, representing a significant radiation source.

Some examples about required decontamination factor

Primary circuit of BWR and PWR reactors

	DF
Soft decontamination process	
Outer layer : Fe_2O_3, Iron rich	1-5
Intermediate layer (CRUD) : $FeCr_2O_4$, Cr_2O_3, Chromium rich	5-50
Thorough decontamination process	
Base alloy : Fe, Cr, Ni	50-10,000

Some examples about the type of components

Pipes, tanks, pools…

- Decontamination in a closed system? (avoids the spreading of contamination…)
- Decontamination in an open system after dismantling? (secondary waste…)
- Connection to the components, dose rate, total filling of the component, auxiliary systems…

We will now look at two different materials: metals and concrete

- The techniques and processes applied are quite different
- The accessibility is often very different

Overview of decontamination process for metals

- Chemical processes
  - In closed system (APCE, TURCO, CORD, SODP, EMMA, LOMI, DFD, Foams or various reagents…)
  - In open system on dismantled components (MEDOC, Cerium/nitric acid, CANDEREM, DECOHA, DFDX or various reagents, HNO3, HCl, HF,…)
- Electrochemical processes (open or closed system)
  - Phosphoric acid, Nitric acid, Oxalic or citric acid, sulfuric acid or others process
- Physical processes (open system)
  - Wet or dry abrasives, Ultrasonic cleaning, High Pressure Water, CO2 ice blasting, others…

Full system and closed system Decontamination

- Objectives
  - Reduce the dose rate and avoid spreading of contamination during dismantling
  - Typical decontamination factor 5 to 40
- Application
  - Decontamination of the primary circuit (RPV, PP, SG and auxiliary circuits) of reactors directly after the shutdown
  - Decontamination of components in a closed loop
- Practical objectives
  - Remove the crud layer of about 5 to 10 µm inside the (primary) circuit or the concerned loop

Chemical process

- <u>Chemical process commonly used</u>

Siemens (D)	CORD Chemical Oxidizing Reduction Decontamination based on the used of permanganic acid (AP).
England	LOMI Low Oxidation State Metal Ion (AP)
Russia	APCE Process based on the use of permanganate in alkaline solution
Westinghouse	NITROX or CITROX based on the use of nitric or citric acid.
EPRI	EPRI DFD (Decontamination For Decommissioning) based on the use of fluoroborique acid.

Guidelines for selecting appropriate FSD

- Set the objectives in terms of Decontamination Factor
- Define the type of material: Acidic solution is not appropriate for carbon steel
- Analyze the volume of secondary waste: prefer to use regenerative process (Lomi, DfD, CORD…)
- Pay attention to the composition of secondary waste: avoid organic element like EDTA (Complexing agent)
- Determine the type of oxide layer: Select an oxidizing process for high chromium content in the CRUD
- Be aware of the capability of treatment and conditioning of the secondary waste generated (Evaporation, IEX, precipitation, filtration…)

Chemical decontamination: different processes are existing

- Multi-step processes (soft)
  - Same kind of processes : LOMI, CORD, CANDEREM
- Processes in one single step (hard decontamination process)
  - Cerium IV process : SODP, REDOX, MEDOC
  - HNO_3/HF
  - HBF_4 : Decoha, DfD.

Advantages of chemical decontamination

- Chemical decontamination allows the treatment of complex geometry material (hidden parts, inside parts of tubes,…)
- With strong mineral acids, DF over 10^4 can be reached allowing the clearance of material
- With proper selection of chemicals, almost all radionuclides may be removed
- Chemical decontamination is a known practice in many nuclear plants and facilities (experience…)
- There are existing treatment processes for handling the effluents

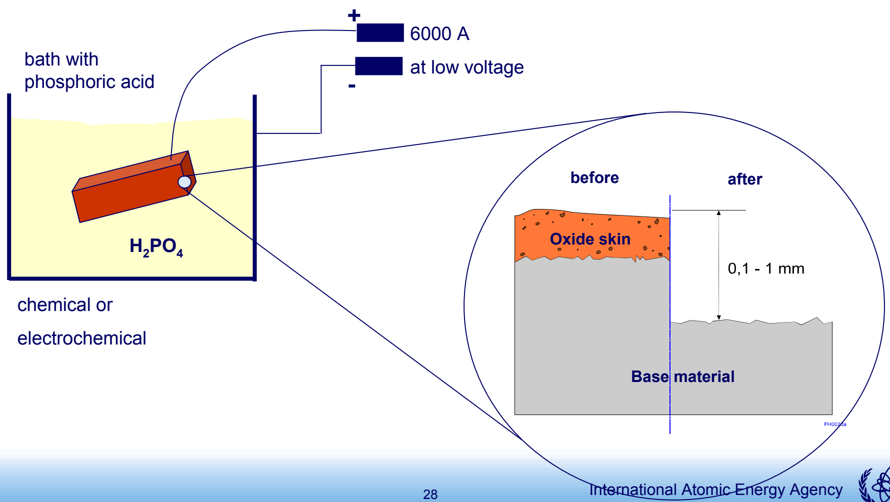
Disadvantages of chemical decontamination

- The main disadvantage is the generation of secondary liquid waste which requires appropriate processes for final treatment and conditioning
- Protection against chemical hazard with high corrosive products (Acid, gas,…) and by-products (H_2, HF, …)
- Chemical decontamination is mostly not very effective on porous surfaces

Electrochemical decontamination

- Electrolytic polishing is an anodic dissolution technique electropolishing with H_3PO_4
- Material to be decontaminated is the anode, the cathode being an electrode or the decon tank itself
- Objectives :
  - remove "hot" spots
  - lower dose rate
  - decategorization of material

Principle of electropolishing



Stainless Steel being put in Acid Bath – Before & After

The secondary waste generation is reduced thanks to regeneration of Phosphoric Acid

- Recycling of Phosphoric acid by
  - Adding oxalic acid
  - Precipitate the dissolved iron as iron oxalate
- Reuse acid for decontamination
  - Extracting the iron oxalate
  - Evaporation
- Thermolysis of iron oxalate
  - Heating the iron oxalate
  - Transformation into iron oxide for final storage

Advantages of electropolishing methods

- Quick processing time *(about 2h/batch or piece)*
- High reliability, high efficiency
- Low amount of secondary waste (thanks to the recycling/regeneration)
- Maximal recycling of products

Disadvantages of electrochemical methods

- The process needs the use of an electrode as cathode. For complex geometries, the decon tank cannot be used and shaped electrodes are needed.
- The piece to decontaminate, being the anode, needs to be electrically linked to the electric source and may not be painted or coated.
- Even with recycling, after a while, the solutions become saturated and require appropriate processes for final treatment and conditioning (like in chemical methods)
- Protection against chemical hazard with high corrosive products (Acid, gas,…) and by-products (H_2, HF, …)

Mechanical decontamination: another way to decontaminate

- **Mechanical decontaminations are often less aggressive than the (electro-)chemical ones but they are a bit simpler to use.**
- **Mechanical and chemical techniques are complementary to achieve good results**
- **The two basic disadvantages**
  - **The contaminated surface needs to be accessible**
  - **Many methods produce airborne dust.**

Typical Mechanical Decontamination Methods and Processes

✓Cleaning with ultrasonics

✓Projection of CO_2 ice or water ice

✓Pressurized water jet

✓Decontamination with abrasives in wet or dry environment

✓Mechanical action by grinding, polishing, brushing

Cleaning with ultrasons mostly an auxiliary effect to other process

- The cleaning in ultrasonic bath is only applicable for slightly fixed contamination
- Does not allow to remove the fixed contamination
- This technique is commonly used in combination with detergent (Decon 90, …)
- However, it is mainly used to enhance the corrosion effect in chemical decontamination processes (Cerium, HF, …)

Example of ultrasonic emitters encased in thimble

Projection of CO_2 ice (or water ice): useful for slightly contaminated surfaces

Example of application on a turbine shaft

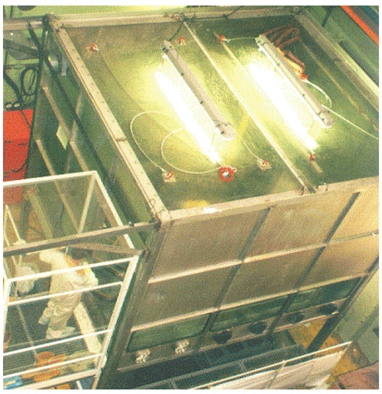
- CO_2 ice pellets are projected at high speed against the surface
- The CO_2 pellets evaporate and remove the contamination
- The operator works in <u>ventilated</u> suit inside a ventilated room to remove CO_2 and contamination
- Needs some decontamination tests before selecting the process (not efficient for deep contamination)

Decontamination with abrasives: a good complement to chemical decon

- Uses the power of abrasives projected at high speed against the surface
  - Wet environment: fluid carrier is water
  - Dry environment: fluid carrier is air
- Imperative to ensure the recycling of the abrasive to reduce the secondary waste production
- Needs a suitable ventilated system to remove contamination and aerosols.

Examples of wet abrasive blasting for decontaminating large pieces

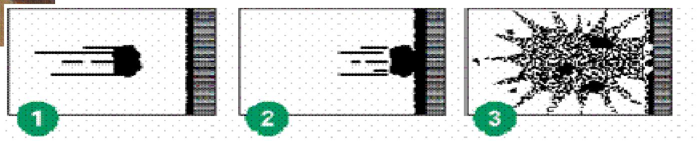
Ventilated cabinet for handling large pieces



Operator at work

Abrasives in dry environment
either manually….

- Decontamination (Metal, plastics, concrete…)
- Decoating
- Cleaning
- Degreasing
- Working in enclosed area



Comparison of the wet and dry sandblasting


Metal after dry blasting

- Choose an abrasive with a long lifetime (recycling)
  - Minerals (magnetite, sand, garnet,…)
  - Steel pellets, aluminum oxide
  - Ceramic, glass beads
  - Plastic pellets
  - Natural products
- Wet and dry techniques allow to recycle the abrasive by separation
  - Filtration or decantation in wet sandblasting
  - On declogging filter (ventilation) in dry sandblasting
- The air contamination in dry sandblasting is much more important (risk of cross contamination…)
- The presence of water, in wet sand blasting, enhance the corrosion process on mild steel (rust is a contamination trap).

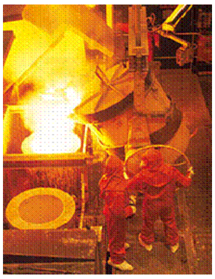
Advantages/Disadvantages abrasive-blasting

- **Advantages**
  - **Effective and commercially available**
  - **Removes tightly adherent material (paint, oxide layer…)**
- **Disadvantages**
  - **Produces a large amount of secondary waste (abrasive and dust…)**
  - **Attention to be paid not to push the contamination deeper in porous material.**
  - **Needs access to the concerned surface**

Mechanical action by grinding, polishing, brushing

- **Large range of abrasive belts or rollers available on the market**
- **Ideal to remove small localized contaminated surface on all kind of metals**
- **Due to the production of dust, to be used in a ventilated enclosure, the operator wears protection clothes**

Melting of metals: also a way to decontaminate (segregation)



- The melting of metal can also be considered as a "decontamination" technique as:
  - ^{137}Cs are eliminated in fumes and dust
  - Heavy elements coming from oxides are eliminated in slag (radioactive waste)
- The melting technique is used for
  - The recycling of material in nuclear field (container,..)
  - The clearance of ingots after melting (measurement of activity easier, homogenization, …)

Advantages of melting

- Advantages of redistributing and segregating radionuclides in ingots, slag and dust: decontamination effect
- Essential step when releasing components with complex geometries (allows the measurement after melting)

Some other techniques potentially useful in decommissioning

- Sponge jet blasting: small sponges, impregnated with abrasive material are propelled against the surface to decontaminate. Useful for slightly contaminated accessible surfaces
- Chemical foams and gels: decontamination agents (acid) are mixed with organic foam which is applied to a surface with a spray nozzle. The foam allows increased residence time of the decon agent on the work piece. Gel (with similar decon agent included) can be applied easily on accessible surfaces. Both processes are mostly used for local decontamination or on large vertical surfaces (like e.g. pool liners) or inside large tanks and spaces (where filling with liquid solutions should not be efficient.
- Strippable coating: is used mostly on large flat surfaces. Allows to remove only slightly fixed surface contamination. Easy to use.
- Laser ablation: still under development. Not yet very efficient.

Needs for decommissioning: some guidelines…

- For decommissioning we need several complementary techniques
  - To reduce the dose rate before dismantling
    - Full System Decontamination
  - To treat materials with complex geometries
    - Chemical decontamination
  - To treat materials with simple geometries
    - abrasive/grit blasting or electrochemical decontamination
  - To decontaminate tools or slightly contaminated pieces
    - High pressure water jet
    - Manual cleaning
    - Other mechanical techniques
  - To remove residual ‘hot spot’ after decontamination
    - Mechanical techniques : grinding, brushing
  - To help in the evacuation route of materials
    - Melting of metals

Let us now look at the second main type of material: concrete

• **Stainless steel**: Resistant to corrosion, difficult to treat, need a strong decontamination process to removed several µm

• **Carbon steel** : Quite porous and low resistance to corrosion, need a soft process but the contamination depth reach several thousand µm (more secondary waste)

• **Concrete**: The contamination will depend of the location and the history of the material, the contamination **depth can be few mm to several cm**.

The type and properties of the surface is an important factor

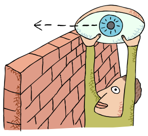
•**Porous**: Avoid wet techniques which are penetrating.

•**Coated**: Do we have to remove paint ? (contamination level, determinant for the use of chemical techniques e.g.)

•**Presence of crud** : what are the objectives ? (reduce the dose or facilitating the waste evacuation)

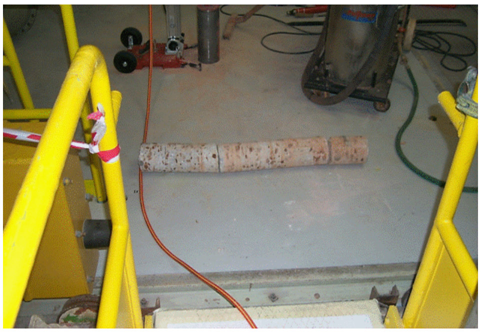
→ Right decontamination technique

A first step before decontamination: characterization of the concrete



- Activated / contaminated ?
- Depth of the contamination ?
- Type of contaminants
  - Dust, spills, vapour…
  - Type of radionuclides
- Sampling programme / Model

Core drilling for sampling



Measurement of cores slices

In general - concrete decontamination is very "dirty"

- Foresee confinement
- Avoid airborne contamination
- Filtration unit
- Collection of dust / water / sludge at the production tool
- Individual protection if needed

Overview of decontamination processes for concrete

- Surface decontamination
  - Scabbling
  - Shaving
  - Milling
  - Cutting/sawing
  - Grinding
  - Sand blasting / (Wet abrasives)
- Demolition techniques
  - Jackhammer
  - Drill/spalling
  - Explosives
- Some "Innovative" techniques

Scabbling:
a commonly used technique

- Scabbling uses tungsten carbide tipped bits for hammering on a concrete surface
- Electrically or pneumatically driven
- Hand held (one head) or multi-headed machines available
- Air aspiration around the tool with various efficiencies reported

	m²/h
Hand held	0.25-0.5
Floor scabbler	4 - 8
automated	up to 15

Examples of scabblers

Shaving: an improvement to scabbling

- Shaving is constituted of a diamond tipped rotary cutting head designed to give smooth surfaces which are easier to measure and ready for painting
- Capable of cutting through bolts and metal objects
- Compared to scabbling:
  - About 3 times higher mean working rate for floor decontamination
  - 30% lower waste production than by scabbling at a comparable decontamination efficiency
  - less physical load on the operators due to the absence of machine vibration

Examples of floor shaver

Courtesy from Belgoprocess

Milling cutter

- For deep contamination penetration (> 1cm), shavers should need several steps
- The use of a milling cutter can be recommended
- Allows single pass for thick (several cm) layer removal

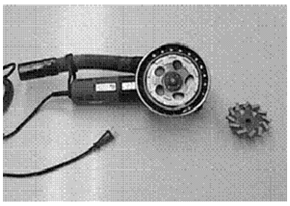
Courtesy from Belgoprocess

If contamination has deeply penetrated in the concrete and on structures easily accessible

- Cutting or sawing can be the solution
  - Using diamond equipped tools:
    - Saws
    - Wires
  - Precise definition of the cutting depth
  - Often needs cooling (water)
  - The cooling water traps most of the aerosols
- Also used for dismantling of large infrastructures

For small items (like blocks e.g.) grinding can be envisaged

- Simple tool easy to use
- Hand held
- Various sizes



BUT

- Labor intensive
- Not convenient for large surfaces
- No included air filtration (needs confinement)

Example: Hand grinding on concrete shielding blocks

For large amounts of small pieces: dry abrasive blasting

- Dry abrasive blasting has proved efficiency for metallic pieces
- OK if carried out in confined/ventilated space

Example of automatic dry abrasive blasting

Courtesy from Belgoprocess

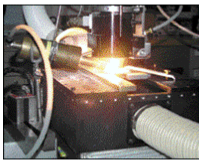
-Used for concrete blocks

-88% of material released

- cost represents about 45% of radwaste cost

Various "innovative" techniques were tested or are in development

- **Laser** ablation (Japan JAERI, US ARNL…)
  - **In development (relatively low efficiency)**
- **Microwave** heating (EC RTD programme)
  - **Tested; poor efficiency; complex set up**
- **Mini-blasting** (Belgium, CSTC)
  - **Tested; difficult to set up; safety issues**
- High pressure **water jetting** (various)
  - **Tested (and used): in some cases let the contamination penetrate deeper in the material**
- **Electrical heating** of the rebars (Belgium, CSTC)
  - **In development; difficult to set up; poor efficiency up to now**
- **Electrokinetic** decontamination (using gel or paste electrolyte)
- **Foam** decontamination
- Microbial degradation (**bio-decontamination**): under development



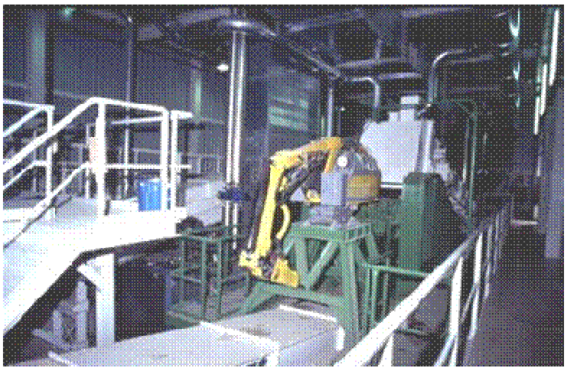
After decontamination, characterize !

- **Important for clearance**
- **100% surface or bulk sampling**
- **Difference between α and β,γ contamination**
  - **α contaminants more difficult to measure - surface roughness can play a role in the measurement process**
  - **presence of flaws, crevices, holes, porosity: leads to measurements uncertainty (mostly with α contamination)**

Clearance Measurements after Decontamination

Another example of characterization for clearance: crushing and sampling

Concrete crushing and sampling machine (*Belgoprocess*)



Some return of experience from actual application (cont'd)

- Often a combination of decon technologies is needed rather than just one particular technology
- Evaluation has to be made for each specific projects. Issues such as dose uptake, waste generation and waste disposal are important factors
- On-site decontamination is to be preferred if not inconsistent with optimization of radioprotection, cost and waste
- For closed systems, one stage decon and treatment processes generally produce the smallest volumes of secondary waste
- Most of the processes are proprietary. Special attention must be paid to the analysis of specific chemical decon solution capabilities and resulting waste prior to selection

Summary

- We have looked at different aspects to select the right decontamination technologies to be applied in decommissioning.
- The aspects of safety, radioprotection, generated waste and effluents and overall efficiency are of primary importance when selecting a decon process.
- There is no "unique" solution for a given problem. Even often a combination of different technologies are needed for a specific project.
- The aspects of secondary waste and effluents is of primary importance when deciding on a strategy and then selecting technologies

References

- IAEA TRS #348
- IAEA TRS #373
- IAEA TRS #395
- IAEA TRS #439
- IAEA TRS #440