International Atomic Energy Agency

Decommissioning of Nuclear Facilities

Decommissioning Planning

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Lesson Objectives

- Describe the requirements for and methods for the managing waste from decommissioning
- Review IAEA waste classification system
- Review waste streams that might be encountered during decommissioning
- Review waste characterization
- Review waste management practices
- Discuss long term waste storage and disposal approaches

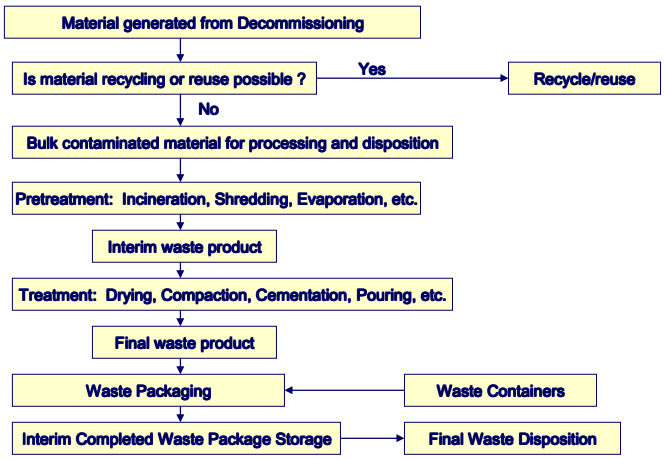
Radioactive Waste Programme Objectives

- Prevent unauthorized release of radioactive material
- Recognize the need for distinct radioactive waste vs. non-radioactive waste management streams
- Reduce waste volume
- Segregate wastes into categories for processing, disposition and transport
- Manage waste in accordance with optimization principles
- Assure that final waste products meet requirements for off-site treatment, transport and ultimate disposition

Radioactive Waste Programme Objectives (cont'd)

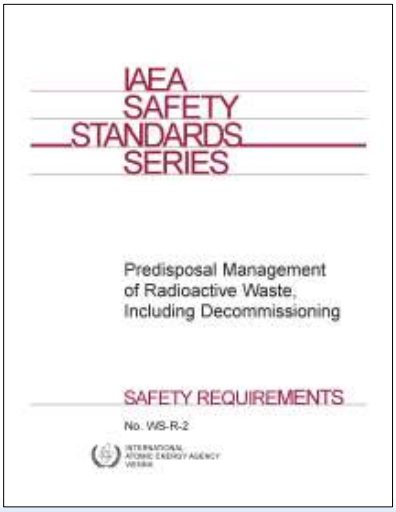
- Must maintain on-site waste management and control systems – whether original plant or temporary systems
  - Gaseous effluent controls and monitoring
  - Liquid waste processing and monitoring
  - Solids management systems
  - Secondary waste management systems

Typical Methods to Manage Decommissioning Waste



Agency Requirements for Pre-Disposal Management (WS-R-2)

- All waste steps prior to disposal
- The goal is to avoid and reduce, as practicable, generation of radioactive waste
- Approach
  - Delay and decay
  - Concentrate and contain
  - Dilute and disperse
- Waste processing
  - Pretreatment
  - Treatment
  - Conditioning



Agency Requirements for Pre-disposal Management (WS-R-2; cont'd)

- Waste processing to include disposal option strategy
- Facility "as defined as decommissioned"
- Objective
- Scope
- Infrastructure for Radioactive Waste Management (GS-R-1)

IAEA Solid Radioactive Waste Classification System

Waste Classes	Typical Characteristics	Disposal Options
Exempted Waste (EW)	Activity levels at or below national clearance levels which are based on an annual dose to members of the public of < 0.01 mSv	No radiological restrictions
Low and Intermediate Level Waste (LILW)	Activity levels above clearance levels and thermal power below about 2 kw/m^3	Near surface or geological disposal facility
•Short Lived Waste (LILW-SL)	Restricted long lived nuclide concentrations. Limitation of long lived alpha emitting nuclides to 4000 Bq/g in individual waste packages and an overall average of 400 Bq/g per waste package	Near surface or geological disposal facility
•Long Lived Waste (LILW-LL)	Long lived nuclide concentrations exceeding limitations for short lived waste	Geological disposal facility
High Level Waste (HLW)	Thermal power exceeding 2 kw/m^3 and long lived nuclide concentrations exceeding limitations for short lived waste	Geological disposal facility

Estimated LLW and ILW from Reactor Operations and Decommissioning (m^3)

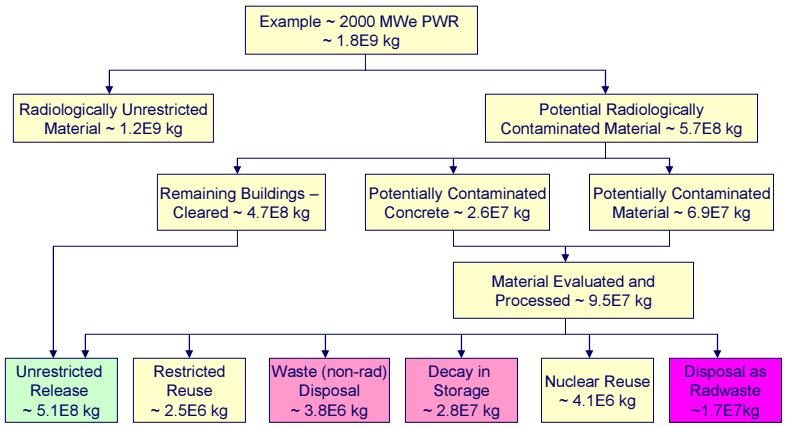
	Canada	Germany		Sweden		United States	
Reactor size and type	4 x 515 MWe PHWR	1200 MWe PWR	800 MWe BWR	900 MWe PWR	1000 MWe BWR	1000 MWe PWR	1000 MWe BWR
Waste from 25 yr operations *	6900 – 27500	6100 – 11000	6000 – 20000	6300	7500	21700	40000
Decommissioning Waste	10000	6900	12400	6700	15000	15200	16300
Total Waste *	16900 – 37500	13000 – 17900	18400 – 32400	13000	22500	36900	56300
Decommissioning waste as percent of total waste	30 – 60%	40 – 50%	40 – 70%	50%	70%	40%	30%

·Ranges in some estimates indicate potential effects of incineration and/or compaction treatments

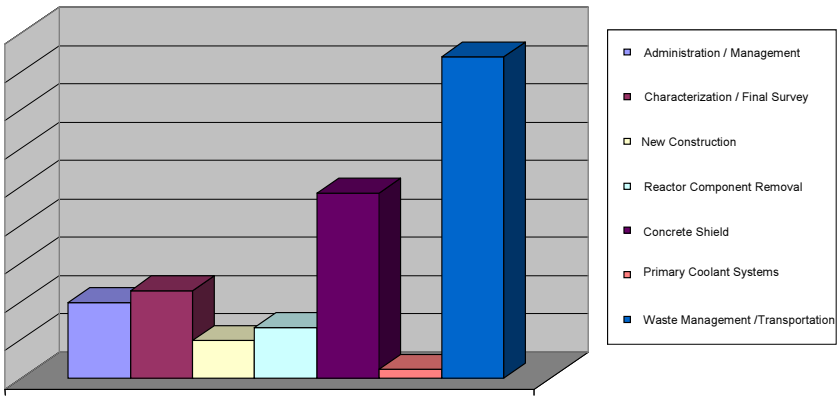
Example Dismantled Material from PWR Decommissioning

- Carbon Steel – 50%
- Concrete – 31%
- Stainless Steel – 9%
- Non-Ferrous Metals – 2%
- Insulation – 2%
- Motors/Wiring/Electrical Parts – 1%
- Other Materials – 5%

Example of NPP Decommissioning Waste Volumes



Radioactive Waste Example Costs for Research Reactor Decommissioning



Total Reactor & Systems D&D of $ 8 Million

Note: An additional $ 6 Million is associated with labs, office complex and control room for a total decommissioning of $14 million.

Typical Waste Streams

- Waste Categorization
  - Low activity
  - Intermediate activity (short and long lived)
  - High Activity
- Low Specific Activity (LSA) Waste Classifications
  - LSA-I
  - LSA-II
  - LSA-III
- Package Categories
  - Type A
  - Type B (U)
  - Type B (M)
  - Type C
  - Industrial Type 1
  - Industrial Type 2
  - Industrial Type 3

Primary Decommissioning Waste Streams

- Burnable waste (protective clothing, wood)
- High level massive metallic waste (reactor internals, pressure vessel, primary coolant pumps)
- Low to mid level metallic waste (smaller pumps, tanks, piping, valves, structural supports)
- Concrete waste – Activated as well as surface and subsurface contaminated
- Light compactable material (insulation, asbestos)
- Special waste (contaminated lead, mixed waste)

Typical Waste Streams (cont'd)

- **Hazardous Non-Radioactive Waste**
  - **Asbestos**
  - **Poly-Chlorinated Bi-phenols (PCBs) – transformers, paints, etc.**
  - **Heavy metals (Pb, Zn, Ag, Hg, Cd, etc.)**
  - **Solvents**
  - **Chemical listed material**
  - **Toxic substances**
  - **Corrosives**

Primary Waste Streams

Reactor internals and components

Primary Waste Streams (cont'd)

Neutron activated radionuclide contaminated research experiments and targets

Primary Waste Streams (cont'd)

Heavy vessel materials, heat exchangers, large rotating equipment, large tanks

Primary Waste Streams (cont'd)

- **Mechanical / Electrical Equipment**
  - Glove boxes
  - Pumps, valves, fitting
  - Exhaust ventilation/hoods
  - Piping (exposed and embedded)
  - Ducting
  - HVAC
  - Transformers/motors
  - MCC's, duct chases, electrical cables
  - Waste management systems
  - Hot laboratories facilities
  - Cranes, handling equipment
  - Hot machine shops and fabrication/maintenance
  - Fuel pool equipment and systems

Primary Waste Streams (cont'd)

Biological shield walls, fuel pool

Primary Waste Streams (cont'd)

Structural concrete (walls and floor), steel, paint coatings, rebar, studs, roofing and building material

Primary Waste Streams (cont'd)

Pipe chases and shafts

Primary Waste Streams (cont'd)

Tanks

Primary Waste Streams (cont'd)

Interior facility floor drains, sumps

Primary Waste Streams (cont'd)

Exterior drainage and storm sewers

Primary Waste Streams (cont'd)

Contaminated soil (under concrete slabs)

Secondary Decommissioning Waste Streams

- Characterization waste
- Preparation waste
- Decontamination waste
- Contaminated tools and equipment
- Protective clothing
- Shielding material

Secondary Waste Streams

Characterization/survey sample waste - Core drillings (reactor walls, floors)

Secondary Waste Streams (cont'd)

Characterization/survey sample waste (cont'd)

- Soil Samples
- Water Samples
- Sample Media (smears, containers)

Secondary Waste Streams (cont'd)

- **Preparation Waste Streams**
  - Filter medias (air/particulate, liquids)
  - Lubricants, fluids, oils
- **Decontamination Waste Streams**
  - Solvents
  - Scabbling material/debris
  - Liquids/decontamination fluids
  - Absorbents
  - Abrasive media
  - Vacuum material

Secondary Waste Streams (cont'd)

- Contaminated equipment and tools (potential)
  - Fuel handling and reactor internal tools
  - Hand tools
  - Decontamination equipment
  - Lifting & rigging
  - Scaffolding / man lifts
  - Special equipment, robotic equipment
  - Temporary lighting
  - Personnel access tents and control area super-structure

Secondary Waste Streams (cont'd)

Worker protective clothing

- Disposable (shoe covers, gloves, paper, tape)
- Re-useable (boots, respirators, coveralls)

Secondary Waste Streams (cont'd)

- Contaminated shielding material
  - Temporary
  - Permanent

Characterizing Waste Streams

- The goal of waste stream characterization is to estimate the radionuclide concentrations in order to support proper waste packaging, transport and disposal
- Sampling
  - Non Intrusive
    - Contact dose
    - Fixed and smear sampling
  - Intrusive
    - Grab samples
    - Crud samples
    - Materials scrapings
- Methods of assay
  - Gamma spectroscopy
  - Liquid scintillation
  - Gross alpha or beta

Characterizing Waste Streams (cont'd)

- Direct sampling of every package the most precise, however is often very time consuming and expensive
- Estimation based on easily measured variables
  - Correlation to exposure rates or gamma energy flux
  - Assumes homogeneous waste streams
- Must sample/analyze representative media from waste stream, validate the homogeneity of the waste stream
- Determine waste geometries (drums, boxes, sea vans)
- Select easily measurable indicator variable (e.g., gamma exposure or ^{60}Co flux
- Model using shielding codes/calculations to correlate measured variable to package nuclide concentrations

Characterizing Waste Streams (cont'd)

- Considerations
  - Sample geometry and densities
  - Number of samples
  - Representative samples
  - Identification and documentation of locations
  - Determine background contributions and interferences
  - Ability to detect appropriate limits
- Data Tracking
  - Data may change for same location
  - Be clear on the use of units

Characterizing Waste Streams (cont'd)

- Inventory of waste packages
  - Segregate low and high level wastes
  - Maintain accurate records of inventory
  - Maintain accurate records of disposal
  - Try to handle only once – place waste into ultimate disposal container
- Lessons learned
  - Watch for cross contamination
  - Source check instruments at the beginning and end of shift
  - Use correct instruments for expected radiation types
  - Training for personnel – use consistent survey techniques
  - Activation analysis assumes material used is known

Waste Minimization

- Processes/examples for waste pre-treatment, handling and treatment
  - Assay
  - Segregation
    - By activity and curie content/pedigree
    - Liquids: tank age, effluent releases, recycle materials
    - Solids: type, source
    - Airborne material
    - Personnel Protective Equipment (PPE)
    - Equipment for recycle
    - Decontamination area

Waste Minimization (cont'd)

- Pre-treatment
  - Liquids
  - Solvents
  - Mixed waste
- Treatment
  - Size reduction
  - Chemical treatment
  - Filtration / micro-filtration
  - Resin treatment / effluent polishing
  - Decontamination

Waste Treatment and Conditioning

- Conditioned waste characteristics
  - Monolithic
  - Homogeneous
  - Low contaminant leaching
  - Good stability
  - Good mechanical strength

Gaseous Waste Treatment Options

- Filtration is the primary treatment as radioactive decay will typically limit effectiveness or need for gaseous system delay holding tanks and carbon banks for iodine removal.
- May still need moisture separators for gaseous tritium removal

Liquid Waste Treatment Options

- Filtration – primary means to remove suspended solids
- Ion exchange resin (bead or resin) a key means to remove solids and ionic species – can be adversely affected by surfactants, organics or chelating agents potentially used in plant decontamination
- Evaporators – useful in some applications – diminished effectiveness if suspended solids are present
- Solidification – direct encapsulation in concrete or absorption

Solid Waste Treatment Options

- Consist primarily of volume reduction (VR) and decontamination
- Volume Reduction
  - Compaction – VR of 2:1 to 5:1
  - Supercompaction – VR of up to 12:1
    - Compaction concerns: need for controlled ventilation, dealing with wet, explosive or pyrophoric wastes, and compaction resistant or irregularly shaped objects

Solid Waste Treatment Options (cont'd)

- Decontamination technologies
  - Chemical decontamination agents
    - Solvents, detergents, surfactants
    - Acids or alkalis
    - Complexing or chelating agents
    - Oxidizers
  - Physical decontamination
    - Dry abrasive blasting
    - Grinding and rotary hammers
    - Blasting with nonabrasive media
  - Metal melting – specialized usage

Solid Waste Treatment Options (cont'd)

- Other Volume Reduction Options
  - Shredding units – VR of 3:1
  - Baling units – used to improve ease of waste handling
  - Incineration – VR up to 100:1
    - Incineration concerns – primarily waste segregation issues
      - Corrosive material
      - Non-combustibles
      - Explosives and pyrophorics
      - Medium and high level waste
      - Ash handling

Waste Volume Reduction Considerations

- Compaction
- Broker secondary segregation

Waste Volume Reduction Considerations (cont'd)

- Resin technology
- Decontamination methods for low waste generation

Waste Volume Reduction Considerations (cont'd)

- Material recycling

Waste Storage

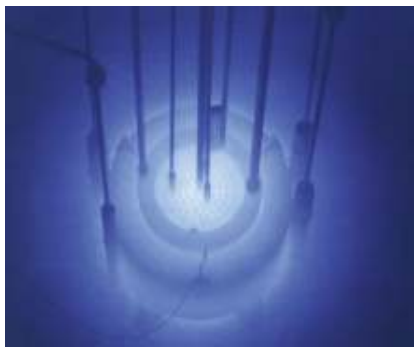
- Interim (low and intermediate activity waste stored on site)
  - Criteria for radiation protection
  - Facility protected from the elements
  - Packaged waste stored outdoors
    - Weather deterioration
    - Animal intrusion

Waste Storage (cont'd)

- Longer term storage (low and intermediate activity waste on-site or other non-disposal site)
  - Waste Acceptance Criteria (WAC)
  - Waste forms, assay and inventories
  - Waste packaging and compliance to IAEA transportation regulations
  - Criteria for radiation protection
  - Facility/waste packages protected from the elements

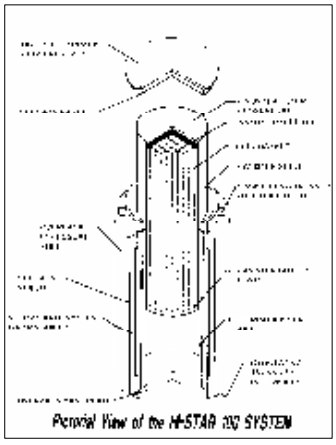
Spent Fuel Storage

- **Management Options**
  - **Typical spent nuclear fuel processing**
  - **ISFSI (Independent Spent Fuel Storage Installation)**
  - **Leaking fuel/canister encasement**
  - **Dry cask storage**
  - **Wet fuel storage**

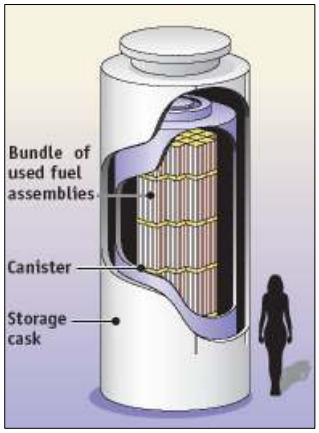


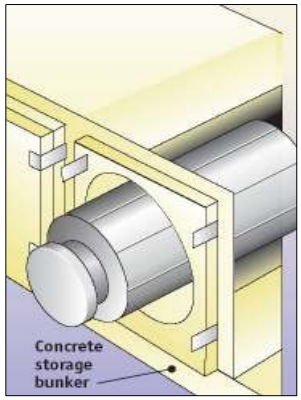
Traditionally spent fuel management is not considered a part of decommissioning

Spent Fuel Storage (cont'd)



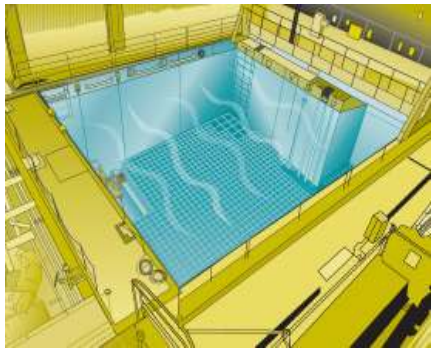
Spent Fuel Storage (cont'd)





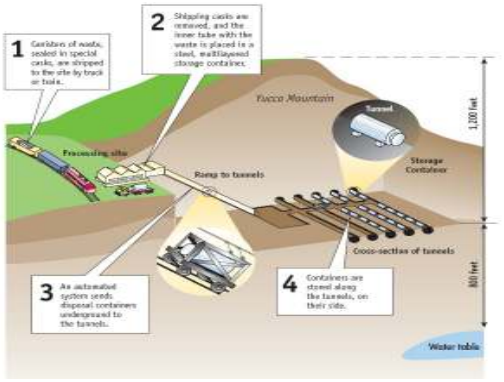
Spent Fuel Storage (cont'd)

- **Typical wet storage pool**



Spent Fuel Storage/Disposal (cont'd)

- Proposed permanent spent fuel storage



Waste Packaging and Handling

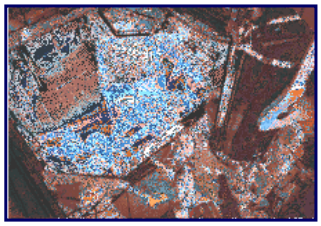
- Preparations are now needed to ship waste to the storage/disposal site
- Packaging considerations
  - Facility handling and storage requirements
    - Exposure control
  - Compatibility and corrosion resistance
  - Packaging ventilation
  - Adequate fire resistance
  - Ease of decontamination
  - Integration with facility material handling equipment
  - Off-site transportation

Waste Packaging and Handling (cont'd)

- Classification of Waste for Transport
  - Amount of radioactivity present
  - Types of radionuclides present
  - Distribution of radioactivity in waste
  - Chemical hazards

Waste Packaging and Handling (cont'd)

- Handling, lifting methods
  - High gamma source material
  - Ingestion risk material
  - Reactor internals, size reduction & cutting tools
  - Rigging (bells, shields, underwater lifting)



Waste Packaging and Handling (cont'd)

- Staging

Waste Packaging and Handling (cont'd)

- Packaging, configuration for cask/package compatibility

Waste Packaging and Handling (cont'd)

- Sizing, weight

Waste Packaging and Handling (cont'd)

- Interim storage
- Final assay, documentation/manifesting
- Transportation

Waste Packaging and Handling (cont'd)

- Final disposal

Waste Packaging and Handling (cont'd) – Overall Issues

- Package shielding requirements
- Size and shape of package
- Special transport requirements (e.g., heavy loads or barges)
- Exclusive or non-exclusive use shipment
- Weight of package often limiting factor

Waste Transport Issues

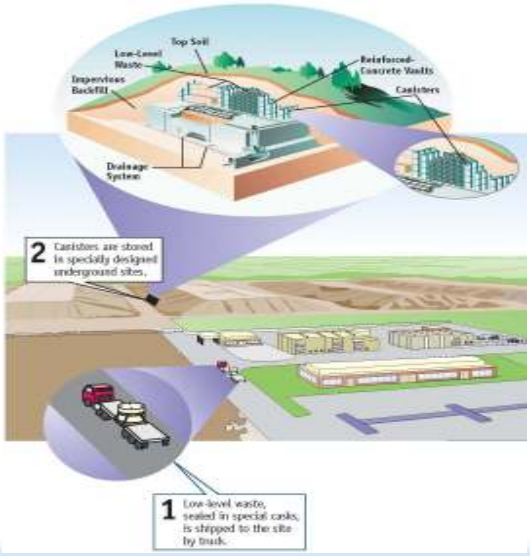
- Packaging type –
  - Industrial Package
  - Shielded cask
  - Surface contaminated object
  - Strong tight container
- Radiation limits
  - Package surface
  - Transport (driver and public exposure)

Waste Disposal

- Waste Acceptance Criteria (WS-R-1)
- Waste documentation –radiological assay and inventories, shipping papers
- Waste packaging and compliance with IAEA Transportation Regulations
- Engineered waste disposal facilities – radiological and non-radiological
- Typical waste disposal cells

Waste Disposal

- Typical low and intermediate waste disposal cell



Waste Disposal Considerations

- Disposal facility availability
- Cost
- Waste acceptance criteria
- Political considerations
- Regulatory
- Transportation Issues

Nuclear Reactor on Transporter

Waste Disposal Considerations (cont'd)

- Primary concern is preparation of waste in order to meet disposal facility WAC
- Disposal concerns
  - Compatibility of waste with surrounding media
  - Chemical, mechanical, biological, thermal and radiation stability
  - Low leach rate of contaminants
  - Solid form with low dispersability
  - Radionuclide activity and concentration

Waste Disposal Considerations (cont'd)

- Disposal Concerns (cont'd)
  - Gas generation (radiolytic, biological, chemical)
  - Presence of explosive or pyrophoric material
  - Presence of free standing liquids
  - Chelating agents or organic complexing agents
  - Presence of hazardous material
  - Chemical durability
  - Nuclear criticality

Lessons Learned

- Get the projected volumes right – waste costs a project money
- Understand the Waste Acceptance Criteria and required certifications
- Perform the decommissioning with the end waste package in mind
- Expect “hidden” contamination
- Work for packaging efficiency (weight or activity based)
- Decontamination streams that are treatable on-site
- Carefully evaluate material flow so as to have sufficient staging and lay-down areas

Lessons Learned (cont’d)

- Where possible, use treatment options that are simple, efficient, environmentally friendly and readily available
- Plan for needed use of cranes, package shielding or casks and material handling strategies
- Engineering the waste sizing based on worker efficiencies as well as packaging and transport constraints
- Water turbidity (when performing underwater decontamination, cutting, grinding)
- Plan for releases where not expected

Lessons Learned (cont'd)

- Develop a low-level waste management plan which is based on a comprehensive site characterization effort
- Initiate advance planning projects for major end items (large component removal)
- Include waste packaging,transport and disposition as part of the up-front planning process for all system and equipment removal activities
- Focus on the plant dismantlement and eliminating radioactive material from the site

Lessons Learned (cont'd)

- Develop a comprehensive plan to address the complex technical and regulatory issues for the unrestricted release of material
- Address hazardous waste, mixed waste, and secondary waste in the low-level waste management plan
- Remain in touch with regulatory policies, the available waste disposal options, and the waste acceptance criteria for low-level waste disposal sites
- Develop strategies for the long term storage of radioactive waste which cannot currently be disposed (e.g., spent nuclear fuel)

Conclusions

- Radioactive Waste management is all about optimization
  - Minimize costs
  - Minimize exposure to on-site workers
  - Minimize volume of waste requiring disposal
  - Cost vs. outcome
  - Volume reduction, super-compaction, incineration, consolidation
  - Survey and release (clearance)
  - Use of alternative materials
- Waste management system design must meet facility requirements and treatment goals

Conclusions (cont'd)

- Waste management planning must address all phases of operations and proceed from defined objectives
- Treatment systems must be tailored for specific waste streams
- Selection of waste packaging must address onsite use and storage and offsite transport
- Must consider final waste disposal requirements
- Success is in the planning and use of an optimized process !!!

References

- IAEA WS-R-1
- IAEA WS-R-2
- IAEA DSS 333 (to be published as WS-R-5)
- IAEA Waste Safety Guide WS-G-2.1 thru 2.5
- IAEA SS 111-F
- IAEA SS 111-G-1.1
- IAEA Fundamental Safety Principles, DS298 – approved to be published, 2006
- IAEA TRS #440