IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Security Considerations for Back End of Nuclear Fuel Cycle for Small Modular Reactors (SMRs)

Presented by
Tariq Majeed
Nuclear Material Security
IAEA/NS/NSNS

Presentation Content

- Nuclear fuel cycle
  - Front-end nuclear fuel cycle facilities and activities
  - Back-end nuclear fuel cycle facilities and activities
- Security considerations for nuclear fuel cycle back-end facilities and activities for SMRs
  - Spent fuel storage facilities
  - Interim spent fuel storage facilities
  - Reprocessing activities
  - Transport of spent fuel
  - Nuclear waste storage
    - Interim storage
    - Permanent storage
  - Conclusions

Nuclear Fuel Cycle

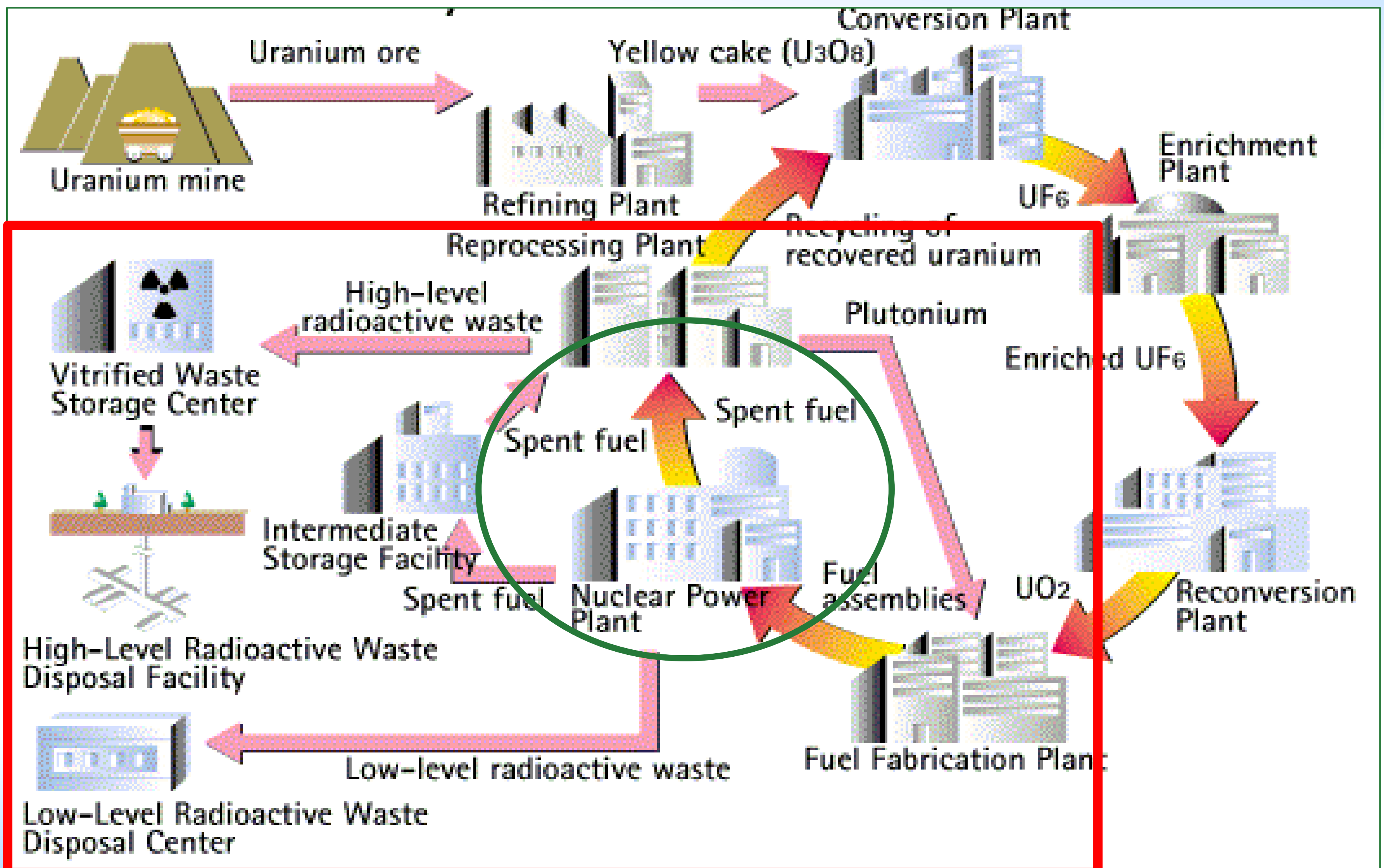
- Nuclear fuel cycle facilities and activities include:
  - Front-end facilities and activities:
  - Back-end facilities and activities
- Front end nuclear fuel cycle facilities and activities include
    - Mining and processing of uranium and thorium ores;
    - Conversion and enrichment of uranium;
    - Reconversion and fabrication of nuclear fuels of all types;
    - Interim storage of fissile material and fertile material before and after irradiation;
  - Production of nuclear energy for power, research and other purposes;

Nuclear Fuel Cycle-1

- **Back-end nuclear fuel cycle facilities and activities include:**
  - **Spent fuel storage and management**
  - **Interim storage of spent fuel**
  - **Transportation of spent fuel**
  - **Reprocessing of spent nuclear fuel**
    - **From thermal reactors and fast reactors;**
  - **Nuclear waste conditioning, effluent treatment and facilities for interim storage of waste**
  - **Storage of nuclear waste**

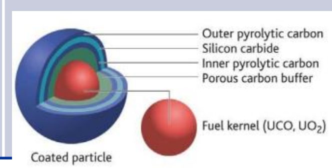
The nuclear fuel cycle

Front-end of nuclear fuel cycle



Back end of nuclear fuel cycle

Nuclear Fuel Designs by SMR Technology

	Light Water Cooled SMR Designs	High Temperature Gas-Cooled SMRs	Liquid-metal cooled fast neutron SMRs	Molten-salt SMRs
Coolant	Light water	Helium	Sodium, lead-bismuth or lead	Fluoride salt coolant
Moderator	Light water or heavy water	Graphite	No moderator	Graphite
Fuel (typical design)	Less than 5% enriched uranium (land based) Up to 20% enriched uranium (marine based)	Up to 20% enriched uranium in coated particle fuels  	15-20% enriched uranium in U-(Pu)-Zr alloy (sodium cooled) (U-Pu)N (lead/lead-bismuth-cooled)	Thorium or low enriched uranium fuel salt, dissolved into coolant

Near Term → Intermediate Term → Long Term

Ref: Output from a virtual CM organized by the NFCMS' Fuel Engineering Team (Mr Ki-Seob Sim) on 9-11 November 2020

Spent Fuel from SMRs

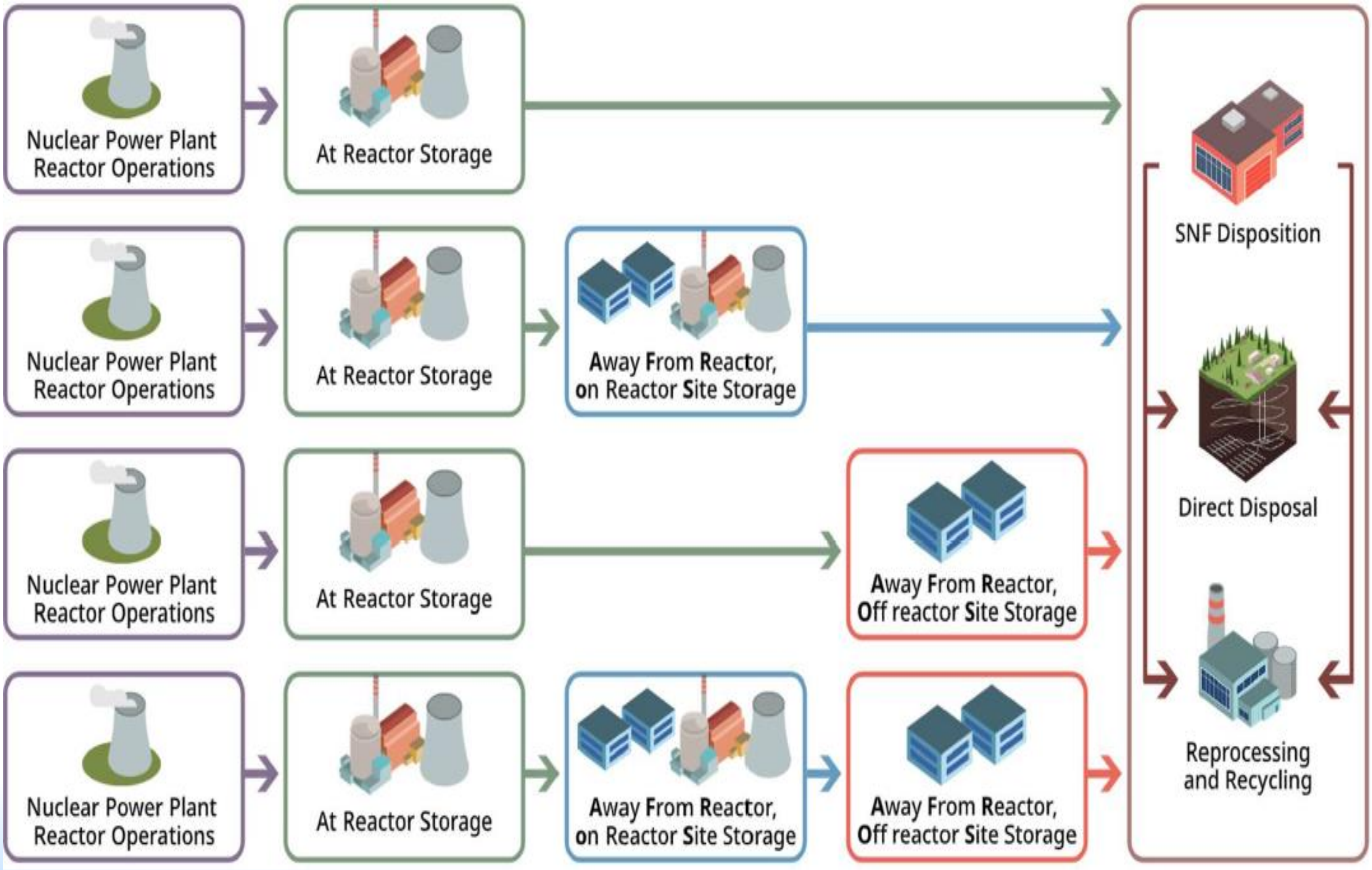
- Spent nuclear fuel will be generated from the operation of SMRs of all types and needs to be securely protected after removal from reactor core. In general,
- Spent fuel is
  - Highly radioactive at the time of its discharge from reactor core
  - Considered as waste if not recycled
    - Called once through fuel cycle
  - A potential future energy resource if recycled
    - Called a closed fuel cycle

Objectives of the Storage Technology for Spent Nuclear Fuel

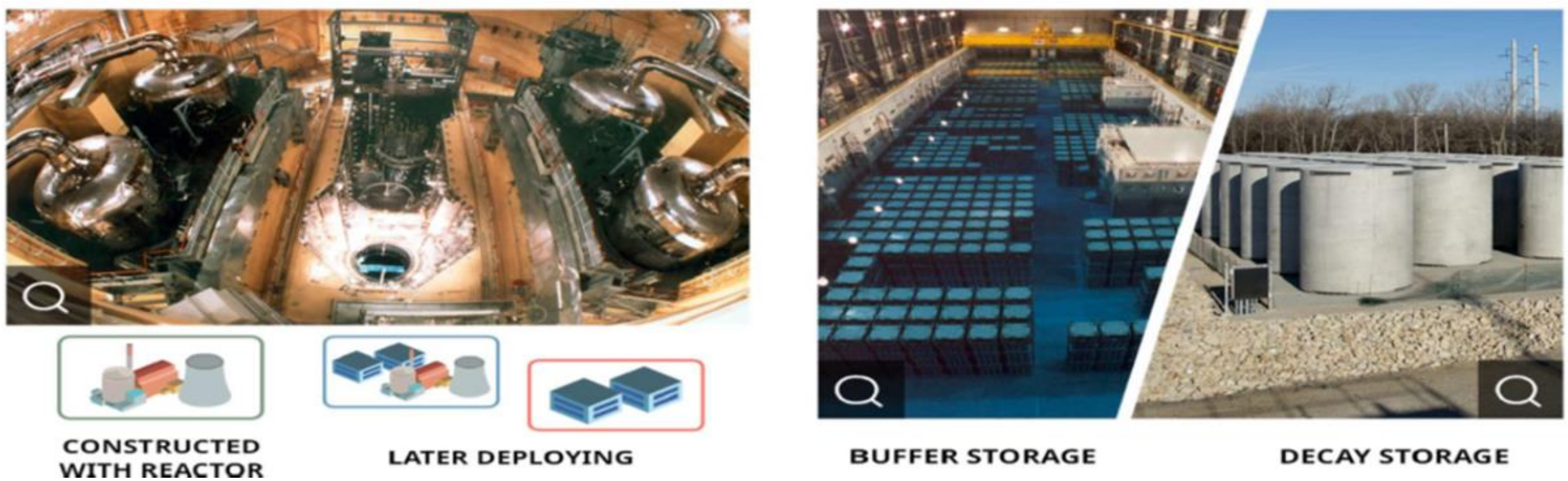
IAEA

- Storage technologies for spent nuclear fuel have three primary objectives:
  1. Cool the fuel to prevent heat-up to high temperatures from radioactive decay.
  2. Shield workers and the public from the radiation emitted by radioactive decay in the spent fuel and provide a barrier for any releases of radioactivity.
  3. Prevent criticality accidents.
- The storage arrangements will differ for different types of fuels from SMRs

Spent Nuclear Fuel Storage Alternatives

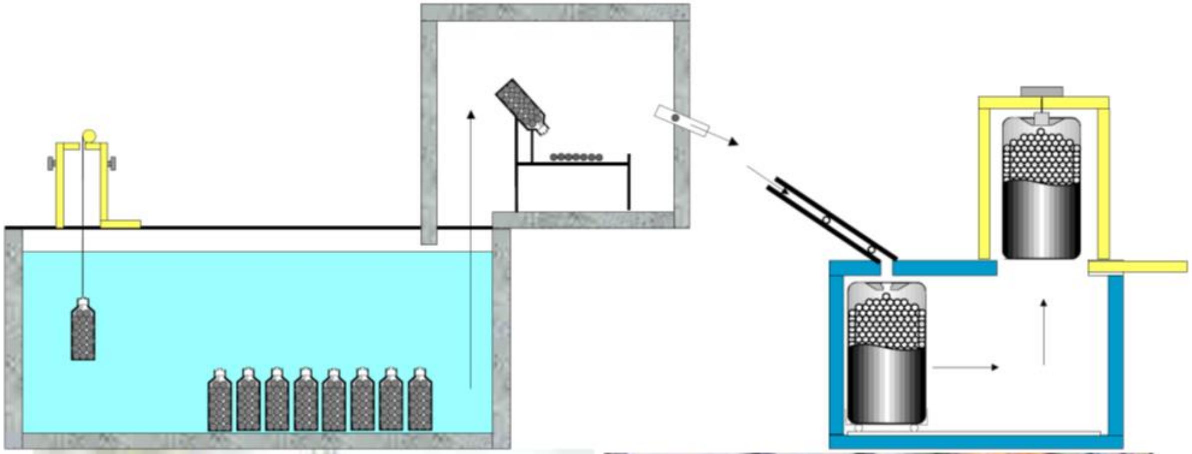


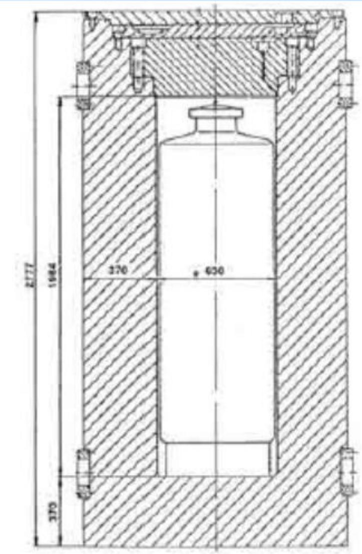
Spent Fuel Storage Alternatives



Dry Metal Cask Storage

Back-End of TRISO Fuel for HTGRs





General Requirements for Nuclear Security for Spent Nuclear Fuel (SNF)

- Establishment of a good security program for SNF for protection of public and environment
- Implementation of physical protection systems (PPS) based on Design Basis Threat (DBT) or Threat Assessment (TA) for
  - Unauthorized removal, and
  - Sabotage of the facility
- Evaluation of the effectiveness of the PPS design
- Performance testing of the PPS and timely response by response force
- Cooperation and coordination with other relevant organizations

Nuclear Security Considerations for Back-End Facilities

- General security considerations
- Development of security plans
- Access control measures
- Technical measures for intrusion detection
- Establishment of CAS
- Response planning to security incidents
- Security requirements related to protection against
  - Unauthorized removal of material, and
  - Against sabotage of the facility

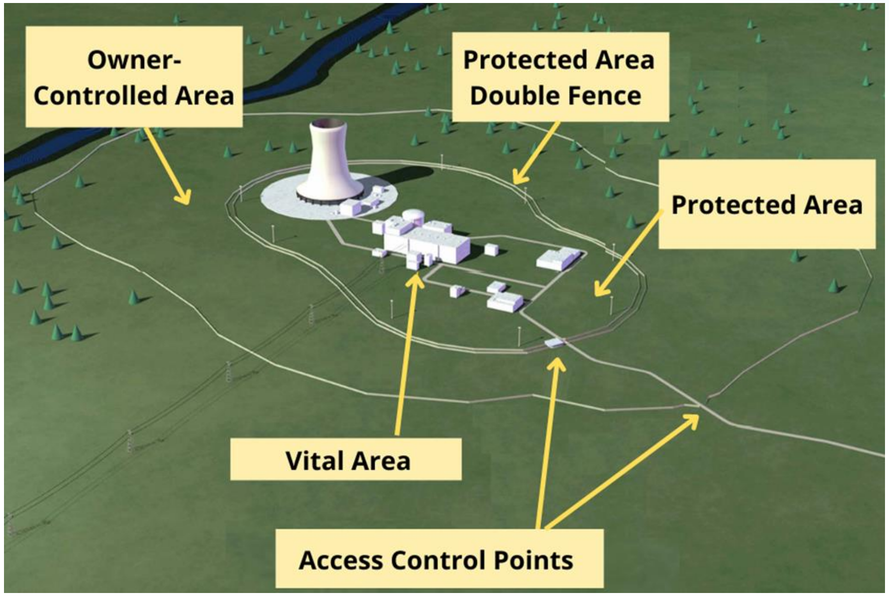
Security Plan for SNF

A detailed security plan should to be developed for all phases of SNF in the back end of NFC (<u>on facility and during transport</u>) including the details of

- **PP regulatory requirements**
- **All applied PPS in terms of technical, organizational aspects**
- **Security personnel (responsibilities, armament, training, and qualification)**
- **Sustainability of PPS equipment,**
- **Security and contingency procedures,**
- **Information management,**
- **Response planning**
- **List of all required tests, audits, and inspections for compliance.**

Technical Measures for Detection

- Based on the SNF storage choice (wet or dry) SNF should be stored in vital areas (VAs) within protected areas (PA)



- Necessary equipment, technical means and procedures for detection of unauthorized intrusion should be provided to control unauthorized access.
- Intrusion detection systems should be installed.

Establishment of Central Alarm Station (CAS)

- A constantly staffed CAS needs to be established for alarms' monitoring, and evaluation, response inception and communication with response forces, and facility management.
- The CAS shall be provided with
  - –A timely means for alarms assessment,
  - –An uninterruptible power supply,
  - –Voice communication means for activities involving detection, assessment, and response (dedicated, redundant and diverse transmission)
  - –Hardened structure and strict access control

Access Control Measures

- Strict access control measures should be implemented for protection of vital areas of SNF storage places
- The access to facility should be
  - Kept to the minimum number as necessary.
  - Appropriately secured and alarmed.
  - Given access to only authorized personnel,
  - Able to detect and prevent unauthorized access
  - Protected against manipulation, falsification, or other forms of compromise.
- All access control points should have
  - Provision to verify the identity of authorized persons
  - Established and maintained records of all individuals
    - who gained access to the VA or
    - who have access to or possession of keys, keycards, and/or other systems, including computer

Response Planning

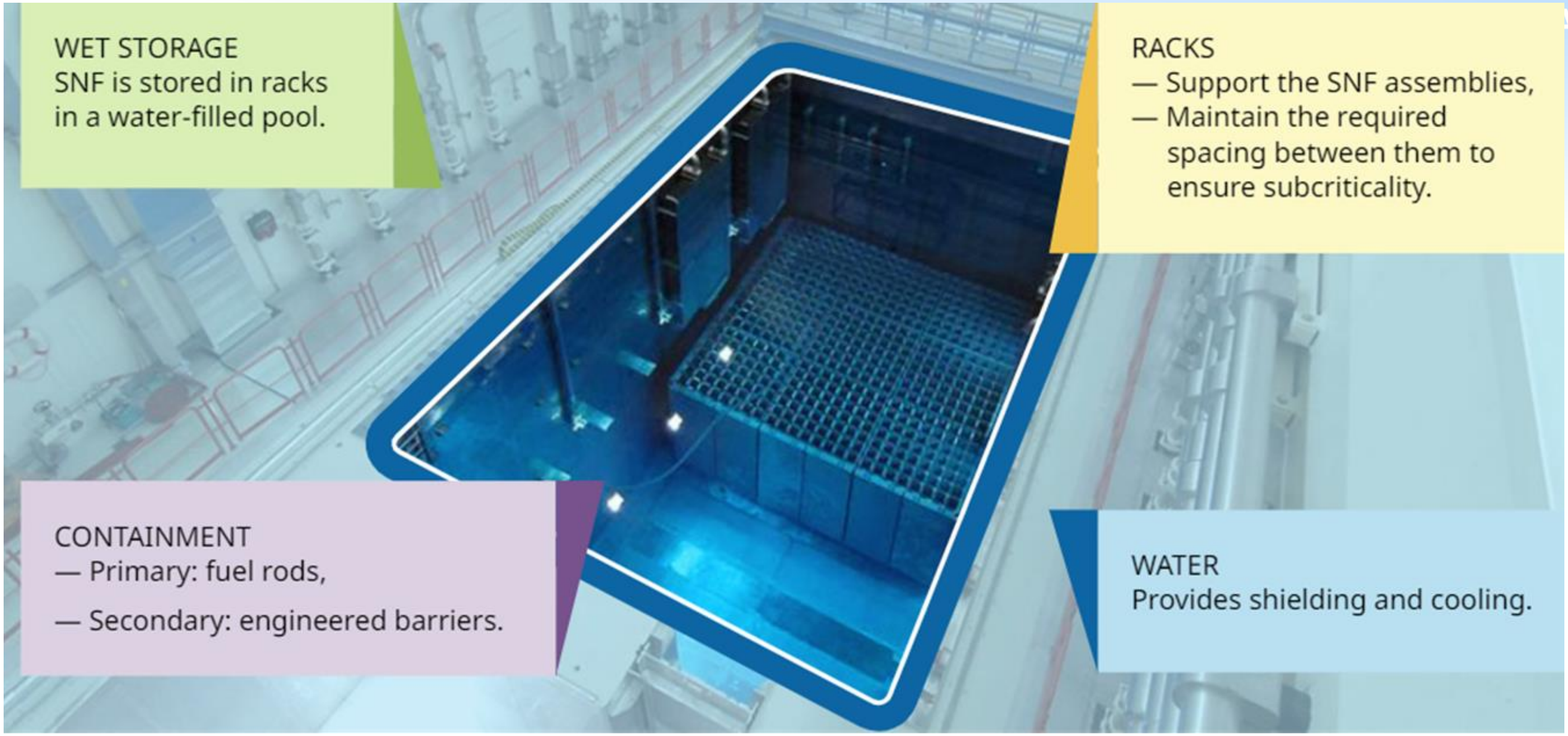
Response planning for SNF protective force for an adequate and timely response to address malicious act against SNF needs a security organization with

- **A 24-hour guarding service and response forces**
  - **Well-defined responsibilities,**
  - **Sufficient personnel, and**
  - **Established and maintained written response procedures**
- **Adequately equipped, trained, qualified personnel**
- **Communications capabilities to communicate with**
  - **CAS personnel, on-site and off-site response forces**
- **Response procedures shall be exercised on a periodic basis, to validate the readiness of the response force.**

Security Requirements related to Protection against Sabotage of SNF

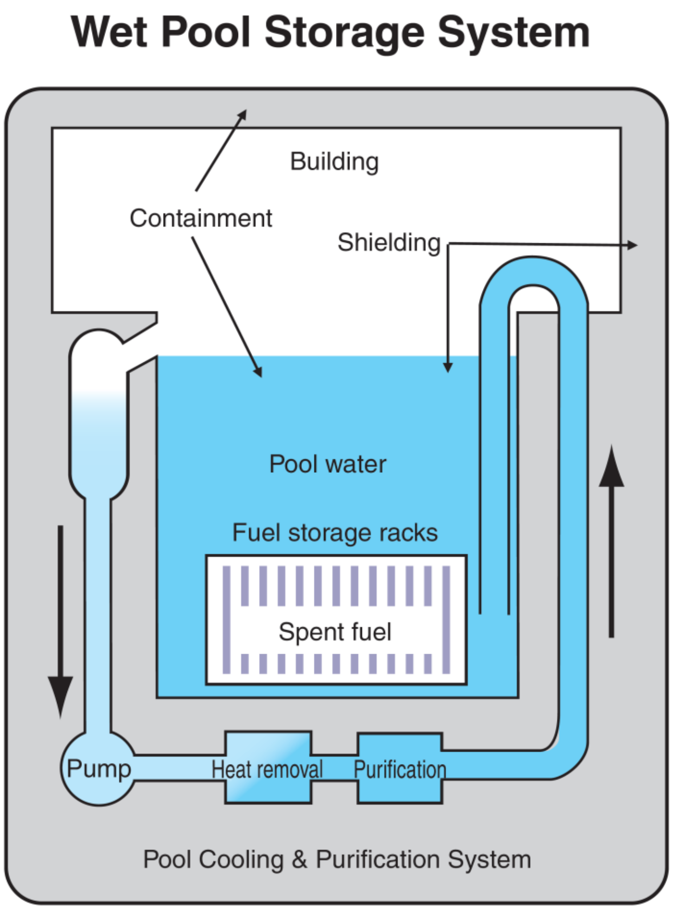
- All materials, structures, system or components (SSCs), should be considered for the potential credible sabotage scenarios (directly / indirectly)
  - By adversaries (external/insiders)
- Effective implementation of PPS against the defined sabotage scenarios needs to be done.
- The response strategy shall be based on denial of adversary access to the sabotage targets
- The robustness of the engineered safety features, the fire protection, radiation protection, and emergency preparedness measures should supplement PPS

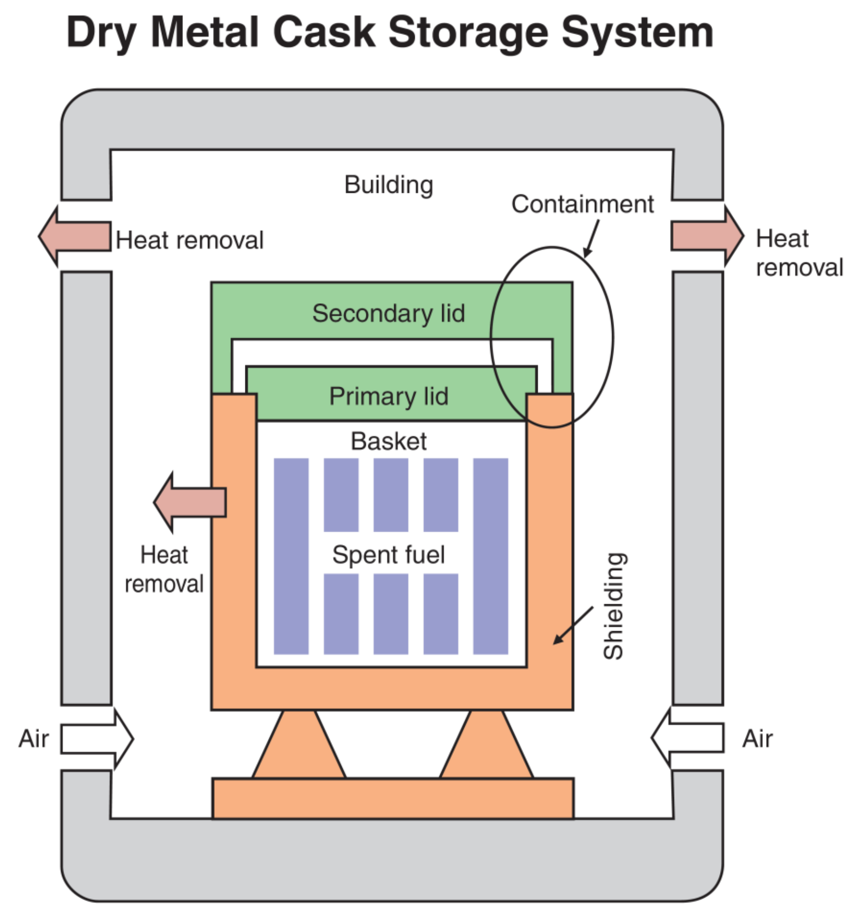
Spent Fuel Storage Pools



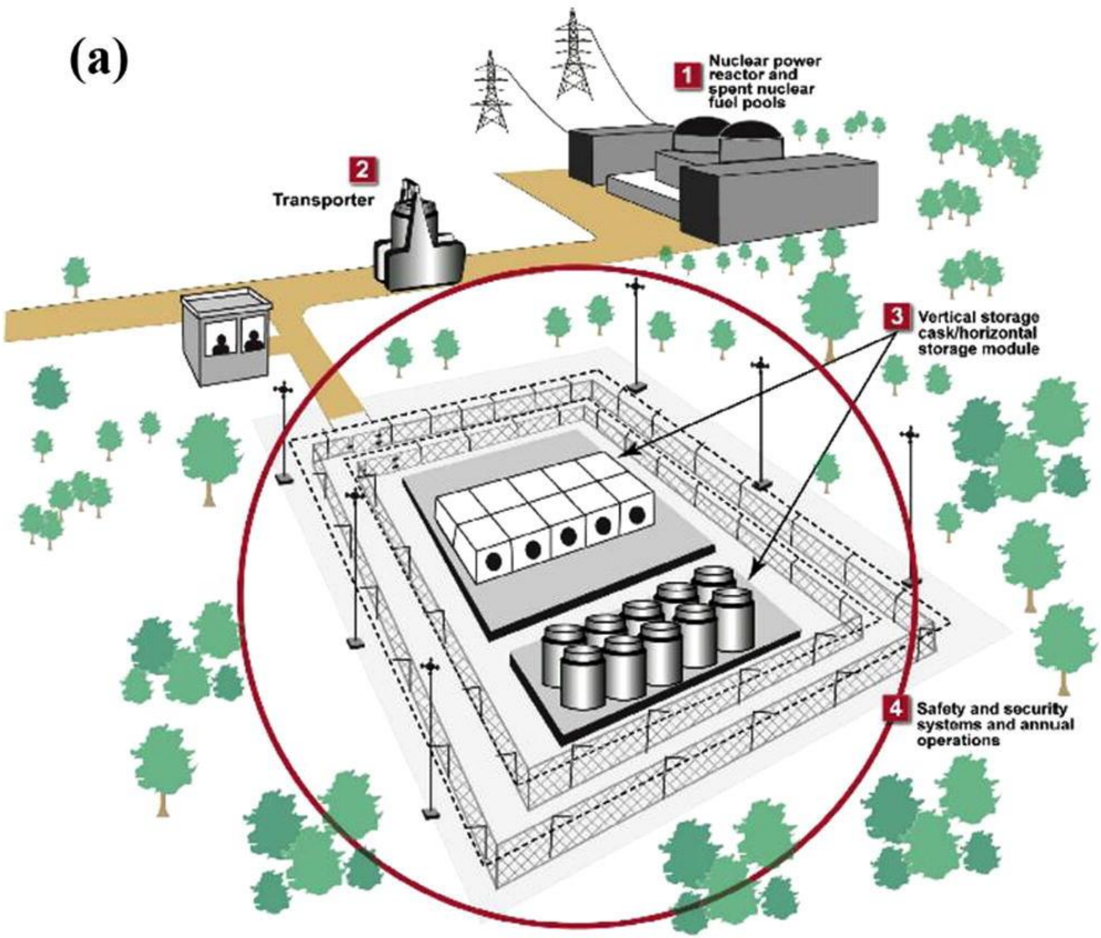
- **The thick concrete and steel reinforced structure that provides main line of defense for**
  - **Preventing radioactive contamination from a reactor accident.**
  - **Prevents leaks form the pools in normal conditions.**
  - **Protection against outside attacks**
  - **All water pipes from top**

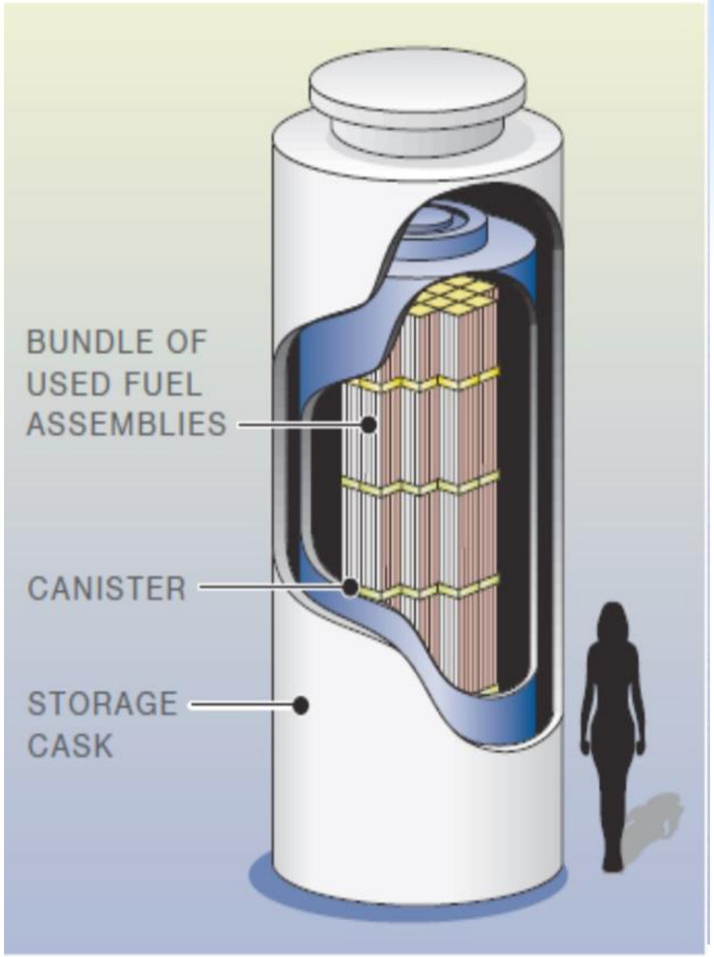
Interim Storage of Spent Fuel





Security Measures for a Dry Storage Facility

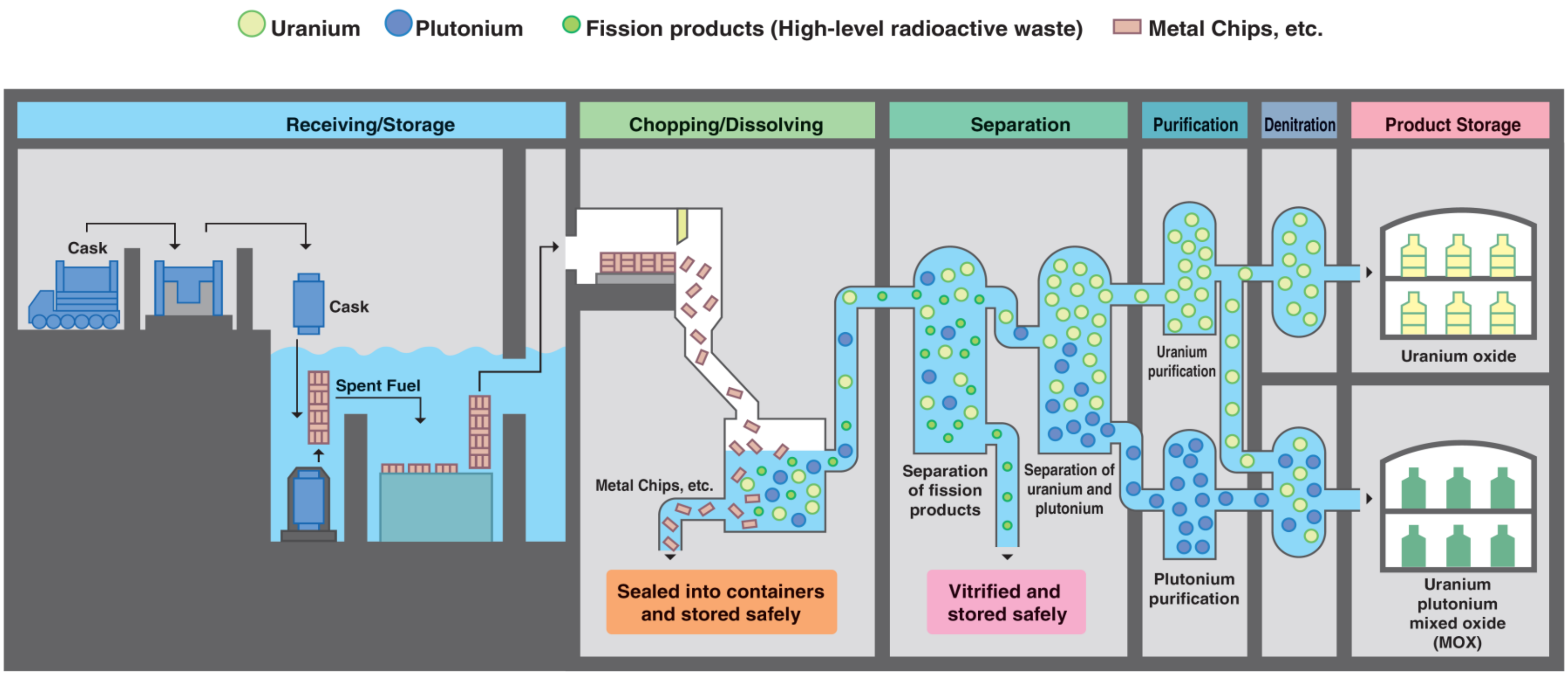


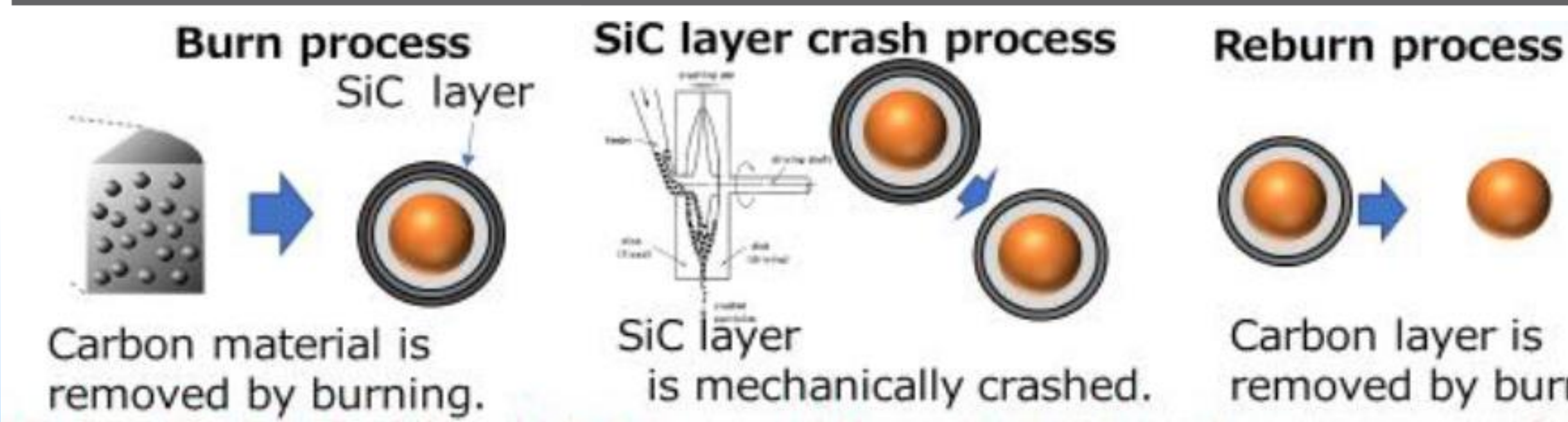


Reprocessing of Spent Fuel from SMRs

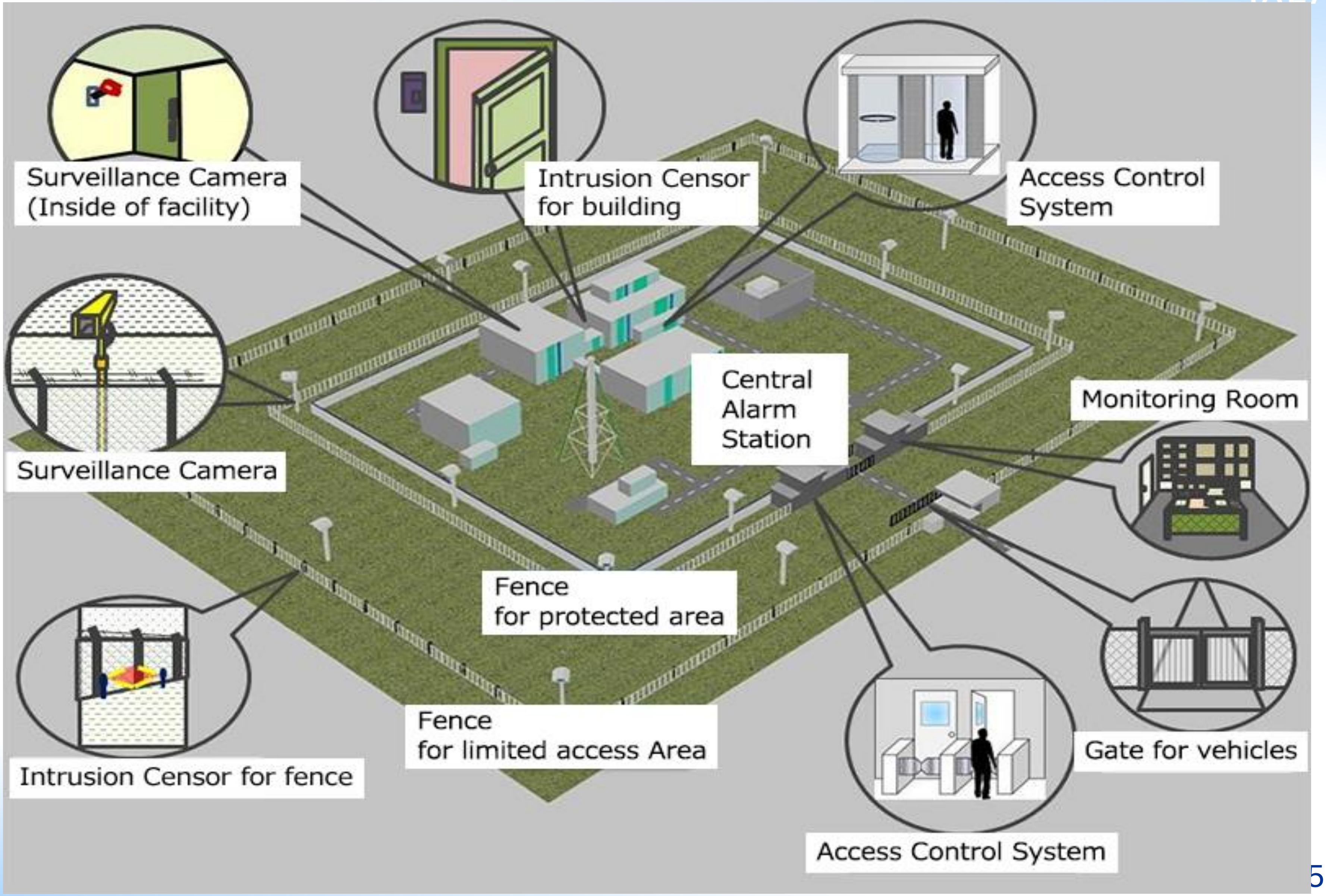
- Reprocessing techniques are different for different types of fuels in SMRs.
- Reprocessing methods are well-established for LWR based SMRs
- Reprocessing techniques for other types of fuels used in different designs of SMRs have also been developed.
- All reprocessing methods involve highly radioactive material handling
- Stringent security measures need to be applied.

Flow of Nuclear and Radioactive Materials during Reprocessing



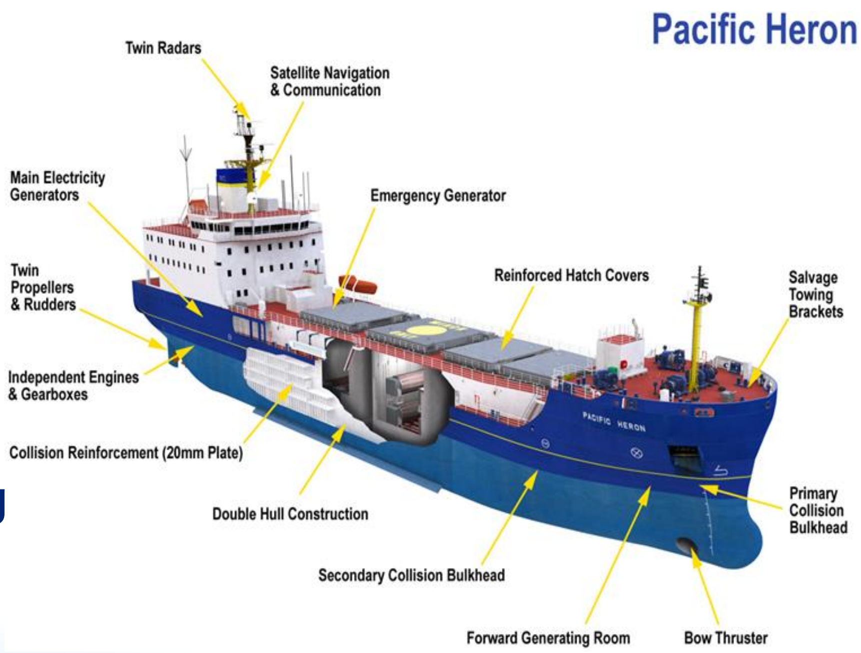


Typical Security Arrangements for Nuclear Reprocessing Facility



Transportation of Spent Fuel

- Transport of spent fuel is an essential part of back-end of nuclear fuel cycle. It requires transport from:
  - On site storage to interim storage
  - Interim storage to
    - Reprocessing plant
    - Dry storage
- Spent fuel is transported by
- Road
  - For all operations to spent fuel storages on land
- Ship
  - For international transport
  - For marine based SMRs
  - For spent fuel movement and refueling



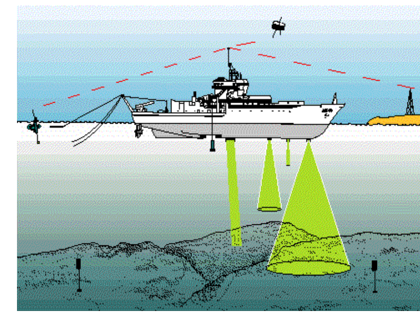
Security Measures for Land Transport

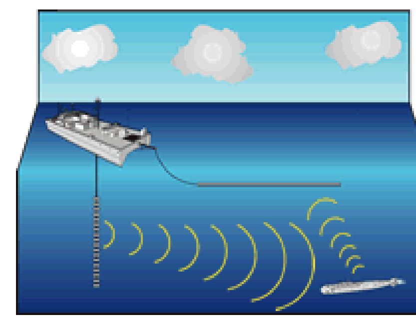
IAEA

- Use of a dedicated transport vehicle
- Securing of vehicle at least 24 hours before operation
- Careful selection of the route, timing of shipment
- Minimizing intermediate stops and delays
- Presence of armed guards on the vehicle
- Accompanying armed escort from departure to arrival
- Satellite tracking of the vehicle
- Use of multiple and secure communication systems
- Continuous monitoring of the transport vehicle location and cargo status by an main operations center
- Preparation of a contingency plan
- Arrange with local law enforcement for response and assistance

Security Measures for Marine Transport

- Use of a dedicated transport ship
- Provision of security measures to deal with under-water threats, like small submarines, divers
- Careful selection of the route to be used
- No scheduled port call en-route
- Use of armed escorts aboard the transport ship that are independent of the crew
- Accompanied by an armed escort vessel from departure to arrival
- Measures to impede the removal of the cargo at sea
- Use of multiple and secure communications systems
- Monitoring of the transport ship location and cargo status by an operations center





Security Considerations for Nuclear Waste Types

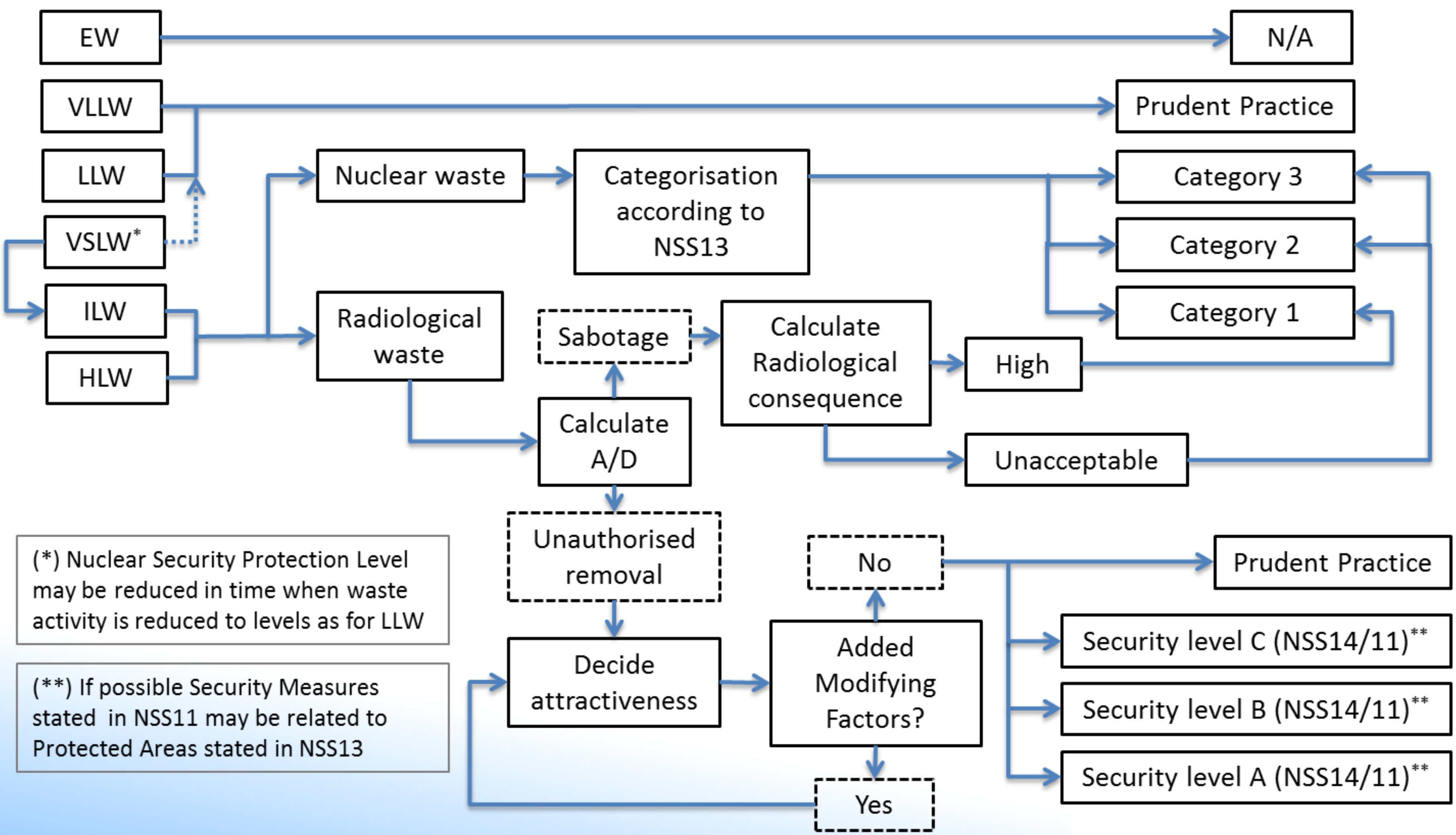
- **Exempt Waste (EW)**
  - No radiological consequences, so no security requirements
- **Very short lived waste (VSLW)**
  - Security measures should be commensurate with the level of activity, until it becomes exempt waste due to decay.
- **Very low level waste (VLLW)**
  - Prudent management practice may be adopted.
- **Low level waste (LLW)**
  - Prudent management practice may be adopted.
- **Intermediate level waste (ILW)**
  - ILW waste requires protection consistent with NSS13 (nuclear materials) and NSS14 (radioactive materials).
- **High level waste (HLW)**
  - Its activity concentration is high enough to generate significant quantities of heat, or waste with large amounts of long lived radionuclides.
  - Needs protection consistent with NSS13 (nuclear materials) and
  - NSS14 (radioactive materials), whether within NPPs, from all facilities

Process Steps for Determining Nuclear Security Measures

Waste Classification

Waste Categorisation for Nuclear Security

Nuclear Security Protection Measures



NSNS's activities related to SMRs

IAEA

- Development of a TECDOC on Security of SMRs, including CMs and a TM (to be published in 2023)
- Establishment of CRPs to share security related information among vendors, designers, regulators and operators
- Joint activities at IAEA with NSNI and SG related to interface with safety and safeguards
  - Development of TECDOCs on
    - Application of Safety Standards to Novel Advanced Reactors (in progress)
    - Security, Safety and Safeguards by Design for SMRs (in progress)
- Technical Meeting on Instrumentation and Control and Computer Security for SMR/MRs organized in coordination with the NSNI and NE

Conclusions

- **Security of back-end of nuclear fuel cycle is important for the secure deployment of SMRs at global level.**
- **Security of spent fuel storage options for SMR designs have their specific challenges**
- **Security during the interim storage, reprocessing facilities, and during transport presents their specific challenges.**
- **Development of new technical documents related to security of SMRs is in progress**
- **NSNS is jointly working with other departments of IAEA (NSNI, NE) for the secure deployment of SMRs at global level**

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Thank you!