Lessons Learned in Post Accident Management of Contaminated Material and Radioactive Waste

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SOURCES OF CONTAMINATED MATERIAL AND WASTE

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Wastes arising of cleanup of different types of areas

- Rural areas
  - Agricultural lands, grassy areas, few buildings & roads
  - Waste types: Soil, organic material, vehicles, building and road material
  - Waste volume:
    - Soil ~50 000 m3 per Km2 for 5 cm layer removed
    - Transportation volume of soil higher due to reduction in density of removed material
    - Organic waste from crops: ~50 000 m3 per Km2

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Wastes arising of cleanup of different types of areas

- Urban areas
  - Residences, commercial buildings, roads, parks, vacant land, vehicles, etc.
  - Waste include decontamination liquids from cleanup
- Forests
  - Large volumes of organic waste if defoliated
  - Trees and stumps to be removed to allow equipment access for cleanup
- Water systems
  - Decontamination unlikely for large water systems
  - Soil and organic material if cleanup is carried out

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Factors affecting Waste Characteristics

- The inventory and quantity of radionuclides in the facility at the time of accident
- The facility design
- The accident scenario
- Meteorological conditions
- Selective deposition of radionuclides
- Decay
- The manner in which clean-up is carried out

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Factors affecting quantity of waste from clean-up

- The extent, depth and nature of contamination
- The characteristic of environment affected (urban, forest, agriculture etc.)
- The decision on handling the affected area e.g. stabilization, interdiction or clean-up
- Clean-up methods
- Clean-up criteria applied

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Liquid wastes

- The large volumes arising from decontamination of buildings, roads, equipment
- Typically low concentrations
- Could be directed into roadside ditches, holding areas
- The contaminated soils could be collected and disposed

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Treatment, Conditioning, Storage & Disposal

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Liquid wastes treatment

- Evaporation
- Chemical precipitation
- Ion exchange
- Filtration
- Sorption
- Membrane methods

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Treatment of aqueous radioactive waste

In most cases treatment of aqueous waste aims at splitting it into two fractions:

1. A large stream, the level of contamination of which is sufficiently low to permit its discharge to the environment and

2. A small stream of concentrate containing the bulk of radionuclides.

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Organic liquids.

The objectives of organic liquid waste treatment may be:

- Conversion to a solid form;
- Conversion to an inorganic form to facilitate conditioning,
- Volume reduction;
- Decontamination for reuse;
- Conversion to an organic form compatible with cementation;

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Solid wastes

- Contaminated Soil
- Concrete, building materials
- Crops, trees,
- Collection and Segregation
- Volume reduction could be pursued
- Clean-up of 40km2 zone produces about 2x10 E6 m3 of LLW to be transported and disposed

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Contaminated material treatment

- Treatment is to reduce volume
- Characterization of material needs to be done before and after the treatment
- Characterization before is to ensure acceptance of contaminated material by treatment facility or clearance
- Characterization after is to ensure either conditioning (immobilization step) or to determine storage/disposal options

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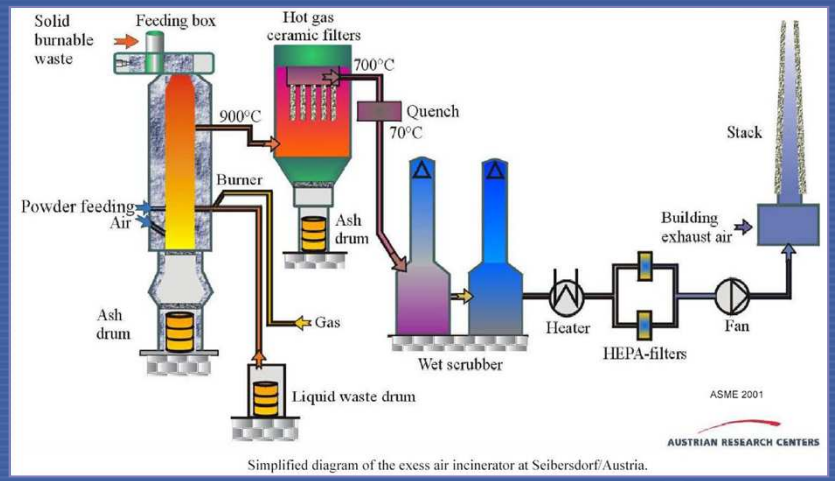
Incineration

Incineration normally achieves the highest volume reduction and converts the waste to a form which is suitable for subsequent immobilization and disposal.



Simplified diagram of the exess air incinerator at Seibersdorf/Austria.

Typical VRF (volume reduction factor) of an incineration process ranges within 50 - 100 for solid radioactive waste whereas for liquid waste it is within 500 - 1000.

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Limitations for Incinerators

It is usually required to limit the content of radionuclides in waste:

beta activity by 10^{-4} Ci/kg,

alpha activity by 10^{-5} Ci/kg.

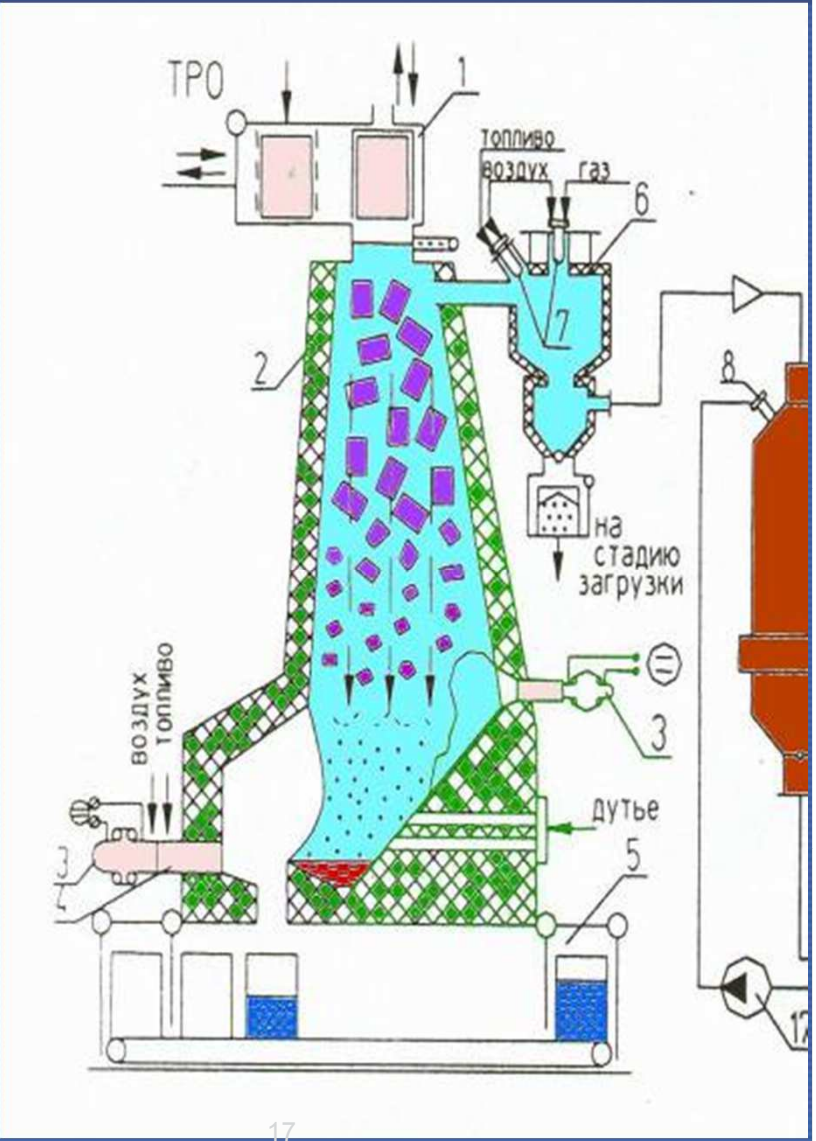
Incineration of combustible waste containing larger quantities of radionuclides requires special off-gas cleaning and maintenance systems involving high investment and operation costs.

Conventional incinerators require waste sorting.

Advanced Incinerators

Advanced incineration systems apply plasma treatment of waste, enabling melting of ash residue into a mineral-like or glass composite material

Particular efficient are shaft furnaces supplied by plasma burners. These treat both organic and inorganic wastes such as glass, ceramics, construction materials, garbage, metal reinforcement, etc. without pre-treatment.



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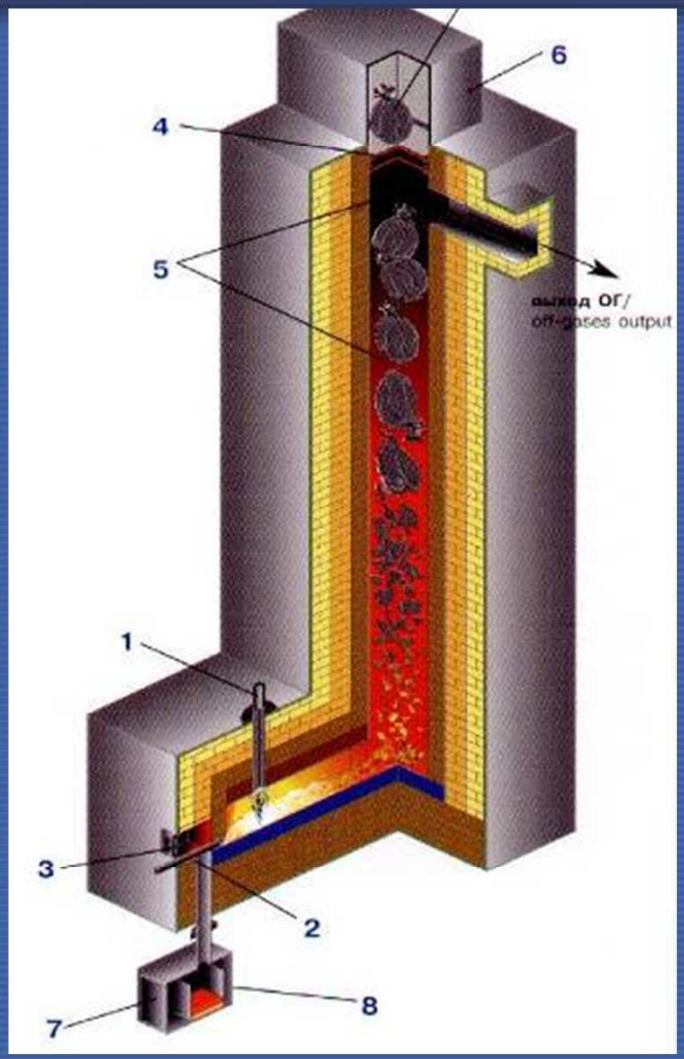
Plasma shaft furnace

Temperatures achieved in shaft furnaces with plasma burners (plasmatrons) are as high as 1400 – 1600 ^{o}C enabling melting (e.g. slagging) of ash residue.

Liquid slagging is the most significant advantage.

Final product is a solid, chemically durable material suitable for long-term storage or final disposal.



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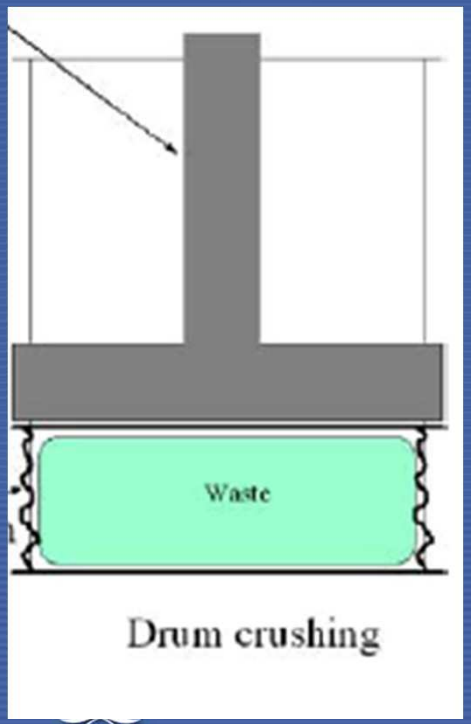
Compaction

Drum crashers apply higher forces and compact waste directly in drums. This avoid possible extension of waste volume and diminishes aerosol emission.



Super-Compaction

The highest volume reduction factor is achieved applying super-compactors. These have compaction force above 1,200- 1,500 tonnes. Super-compactors compact waste directly in drums.

Volume reduction factor depending on the waste composition can be 10 – 15 and up to 100.

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Summary

Solid waste treatment methods.

Treatment methods	Features	Limitations
Low force compaction	• Relatively low cost. • Easy to operate.	• Low volume reduction factor (3-5).
High force compaction (super-compaction)	• High volume reduction factor (up to 100). • Good quality waste form.	• High equipment cost. • Maintenance is costly and frequently required.
Incineration • Excess air • Controlled air • Pyrolysis • Fluidized bed • Slagging • Rotary kiln	• High volume reduction factor.	• Secondary waste resulting from incineration may require immobilization in high integrity matrix (e.g., cement). • Off-gas must be monitored and treated if required. • Trained workforce is required.
Melting and sintering processes	• May facilitate decontamination and waste minimization. • Suitable for recycling and reuse.	• Trained workforce is required. • High cost.

Soil washing

Extracted from IAEA draft document on "Considerations for the application of Mobile Processing Systems for Radioactive Waste Management"

Typical system description:

- Soil washing processes typically consist of several unit operations tied together in an integrated process to separate soil components from contaminating materials, and separate the contaminants from each other. Much of the system is based on commonly available mineral treatment technologies widely used in the mining industry, and has well known scale up parameters.
- Soil washing system can be designed to accommodate a wide variety of soil types, including those with moderately high clay content.

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Example: Soil washing unit

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Soil washing unit – system specific limitations

- Size and complexity to mobilize and demobilize
- Cost to construct, operate and maintain
- Initial negative environmental impact
- Typically high in cost
- Soil washing is performed under a complex regulatory framework

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STORAGE

Key functions of storage

- ✓ **To provide safe and secure storage pending easy retrieval of waste for disposal to a suitable repository. Safety includes the operators who will access the store for operational duties and the public.**
- ✓ To ensure ingress and egress control.
- ✓ To provide an environment such that the waste packages do not degrade during the period of storage so that they are safe to retrieve and transfer to the final repository
- ✓ To provide security to prevent inadvertent or malicious entry to the store

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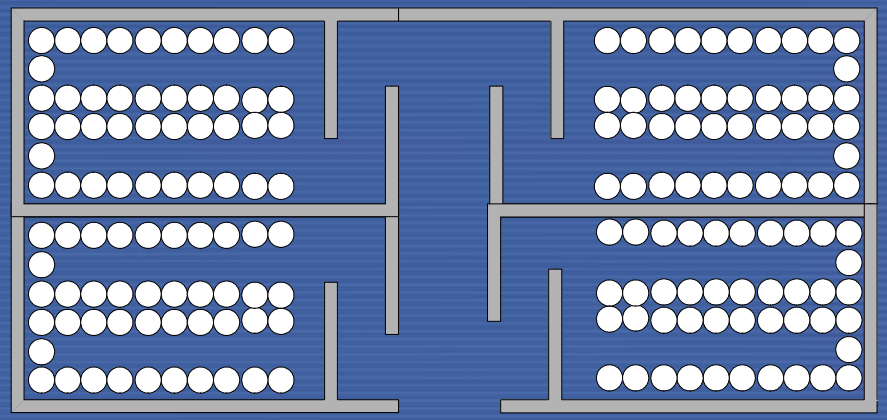
Functional requirements

✓ Shielding (1)

The storage building structure shall provide radiation shielding to limit exposures outside the building

Individual drums can be shielded by other waste drums or by concrete blocks. If larger numbers of drums require shielding, then a shielded area within a dedicated storage building with a labyrinth entrance can be provided.



Entrance via vehicle access doors

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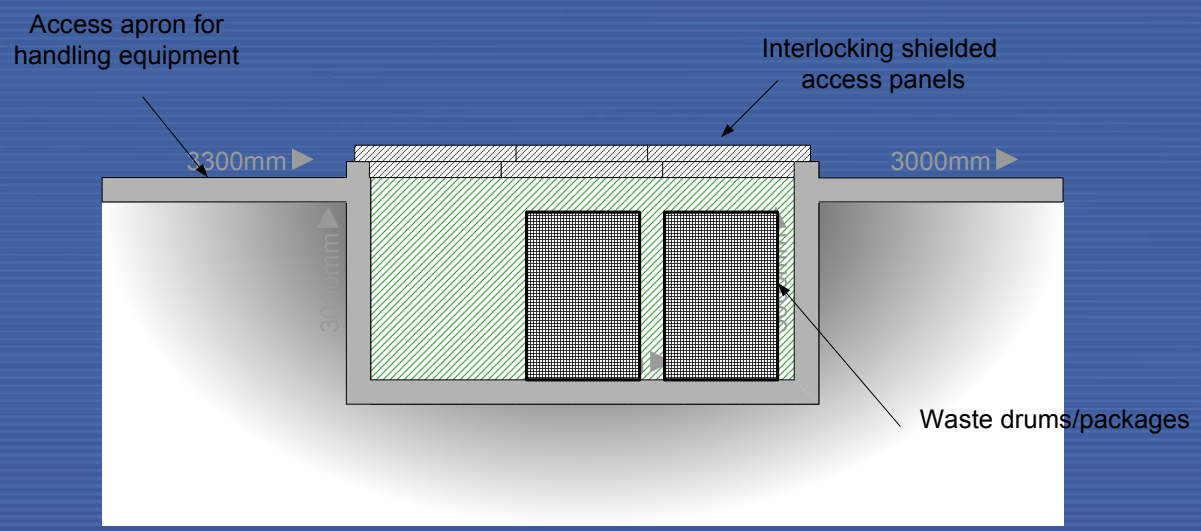
Functional requirements

✓ Shielding (2)

Alternatively, high activity drums/packages can be stored in below ground bunkers within the storage building. The bunkers will have removable interlocking shielded covers to reduce radiation levels above the bunkers. Waste drums/ packages will be placed into the bunkers using, for example, an over head mobile crane or a fork lift truck with jib attachment.



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Temporary storage of collected contaminated material - shielded

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Temporary storage of collected contaminated material - shielded

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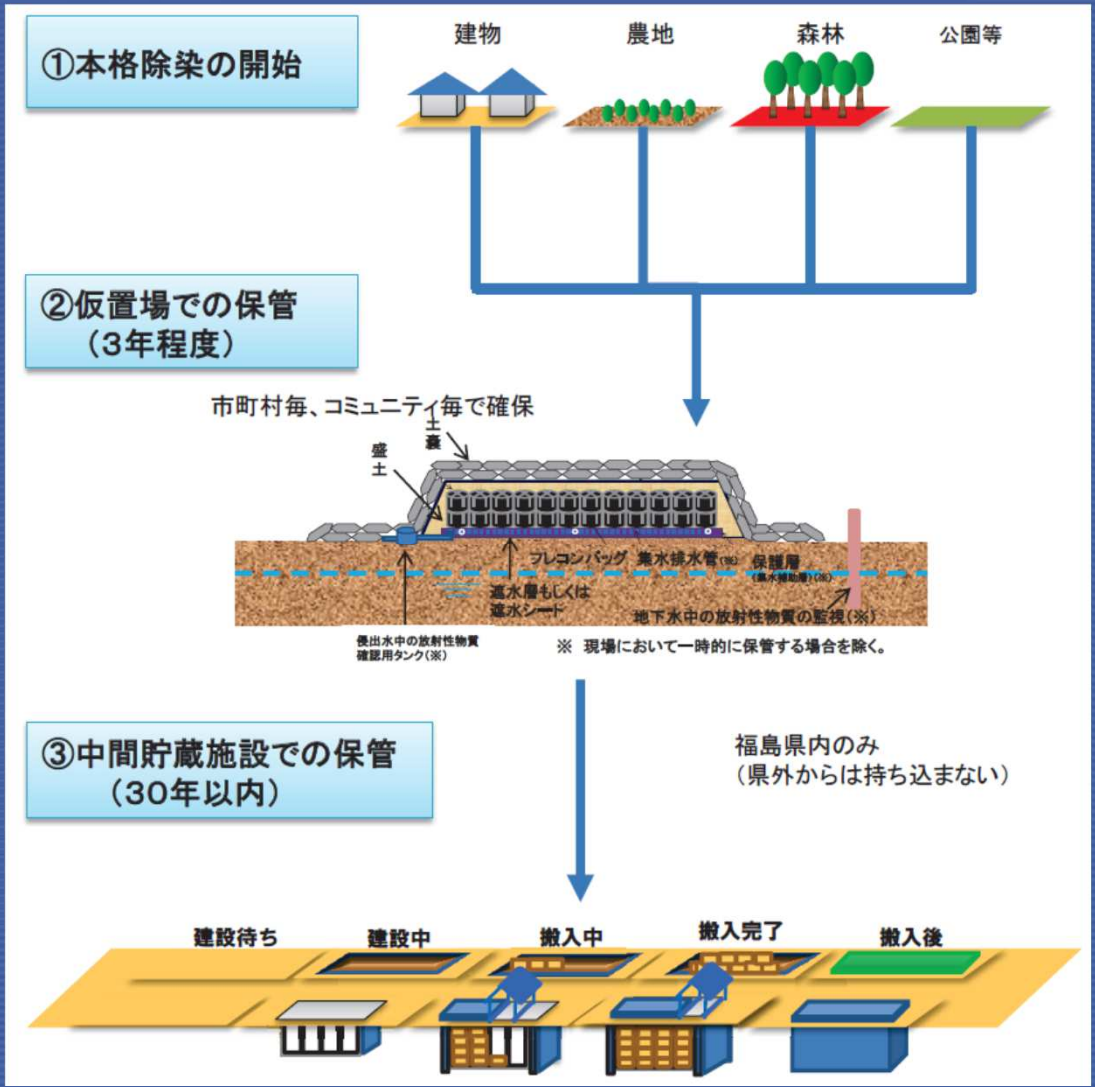
Road Map for Storage

- Phase 1



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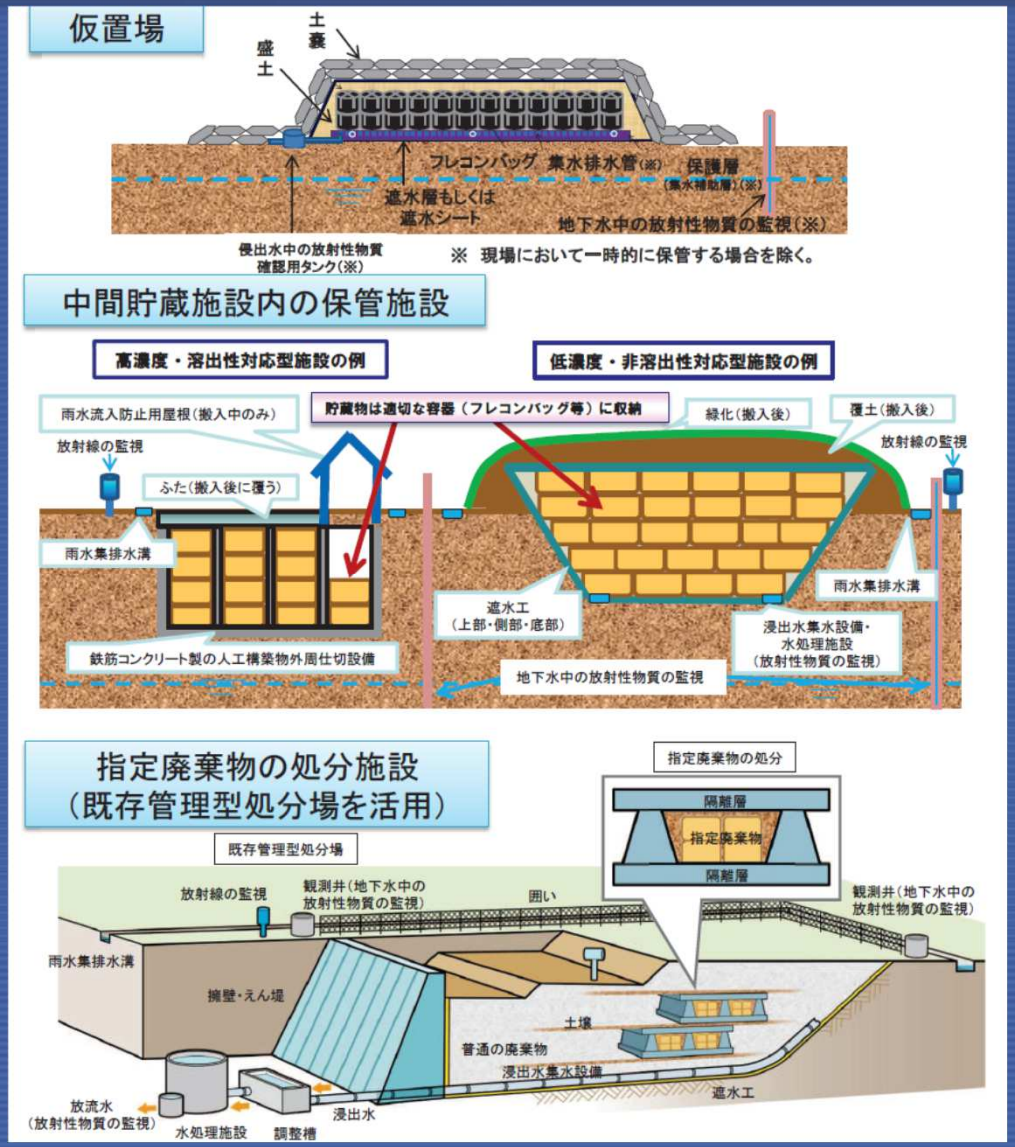
Road Map for Storage

Phase 2.



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Storage - Remarks

- Storage in numerous dispersed locations as discussed above is envisaged as a temporary measure that has to be followed by relocation of the material in smaller number of interim storage sites. Therefore identification of sites for location of interim storage facilities is of high priority and this is recognized by the authorities in Japan. The national government continues to discuss this matter with the prefectural authorities to find an agreeable solution and it is hoped that these efforts will be fruitful.
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- It needs to be noted that technical approach would be to locate temporary storages for combustible material at the reasonable distance from the treatment facilities, to locate treatable soil close to soil washing facilities and to locate storage facilities for waste that needs to be disposed without any further processing close to locations of existing or purposely designed new disposal facilities.
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Storage - Remarks

- The design of interim storage facilities should take into consideration the key functional requirements, namely, to provide safe retrieval from storage pending transfer to a final disposal facility, to ensure water ingress and egress control, to provide an environment such that the waste packages do not degrade during the period of storage and are safe to retrieve and transfer to the final repository, to prevent inadvertent or malicious entry to the store, etc. Safety includes the operators who will access the store for operational duties and the public.
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- Provision of purpose built industrial buildings for dedicated storage of waste packages represents the most common storage solution. In its simplest form the storage building is simply a shell erected on a reinforced concrete slab, with vehicle access doors for a fork lift truck to bring waste packages into the building and personnel doors (a normal entry and possibly one or more emergency exits depending on the size of the building). The building design can be tailored to the particular environmental conditions to give a design life of 25 years or more. The building can be sized to hold the total volume of waste that is expected. Alternatively, a modular design that can be expanded in the future to provide additional storage volume can be provided

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Clean-up disposal scenarios

1. Contaminated material is collected from 1 km2 and concentrated in large piles or natural depressions close to the point of the highest contamination
2. Limited number of larger disposal sites
3. Centralized disposal

Usually mixture of these concepts is used in practice

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Disposal of large volumes of contaminated material from remediation

- Two important functions
  - Limit the dispersion of radionuclides via water and air pathways
  - Isolate the waste from the environment and humans

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Selection of disposal facility design

- Basic factors:
  - The nature and quantity of waste
  - Site characteristics and engineered features
  - Requirements for support services, operational monitoring and institutional control, including post-operational monitoring

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Disposal facility design options

- Natural depressions
- Excavated trenches
- Surface mounds
- Existing excavations
- Mined caverns or cavities
- Concrete vaults

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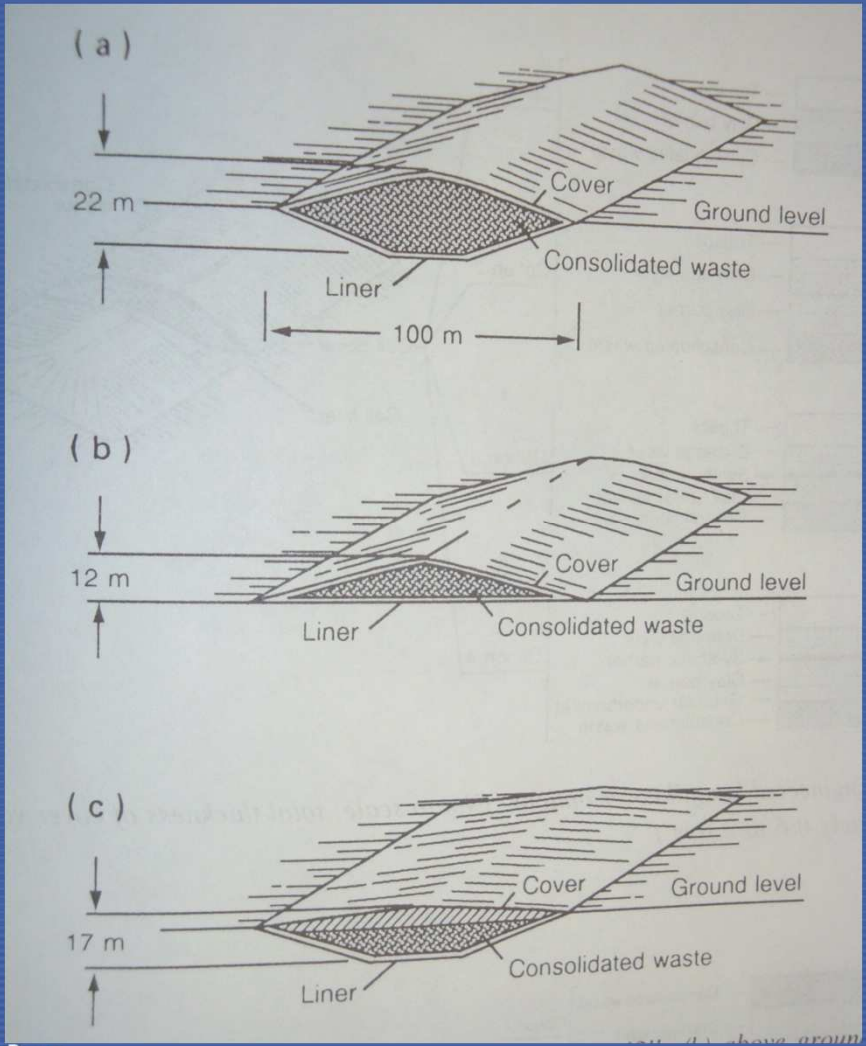
Types of engineered landfill



Conventional landfill

Above ground landfill

Shallow entombed landfill

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Engineered features

- Barriers to prevent intrusion of humans, animals, plants
  - E.g. Greater depth of earth cover and concrete
- Barriers to prevent ingress of groundwater, surface water or precipitations
  - E.g. Clay covers, synthetic impermeable barriers
- Barriers or mechanisms to prevent egress of radionuclides from the facility
  - E.g. Impermeable clay or man-made barriers

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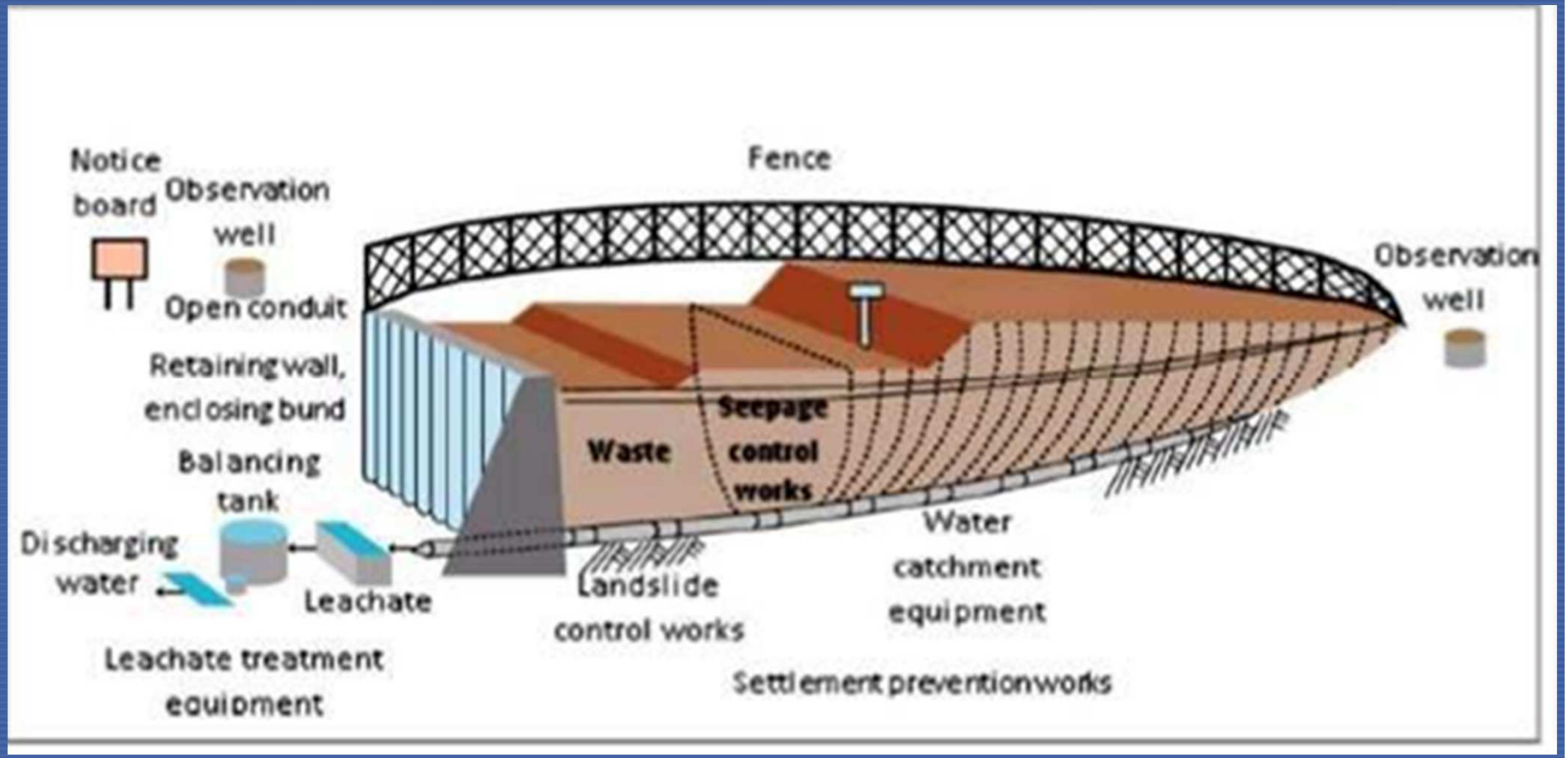
Engineered landfill options (controlled)



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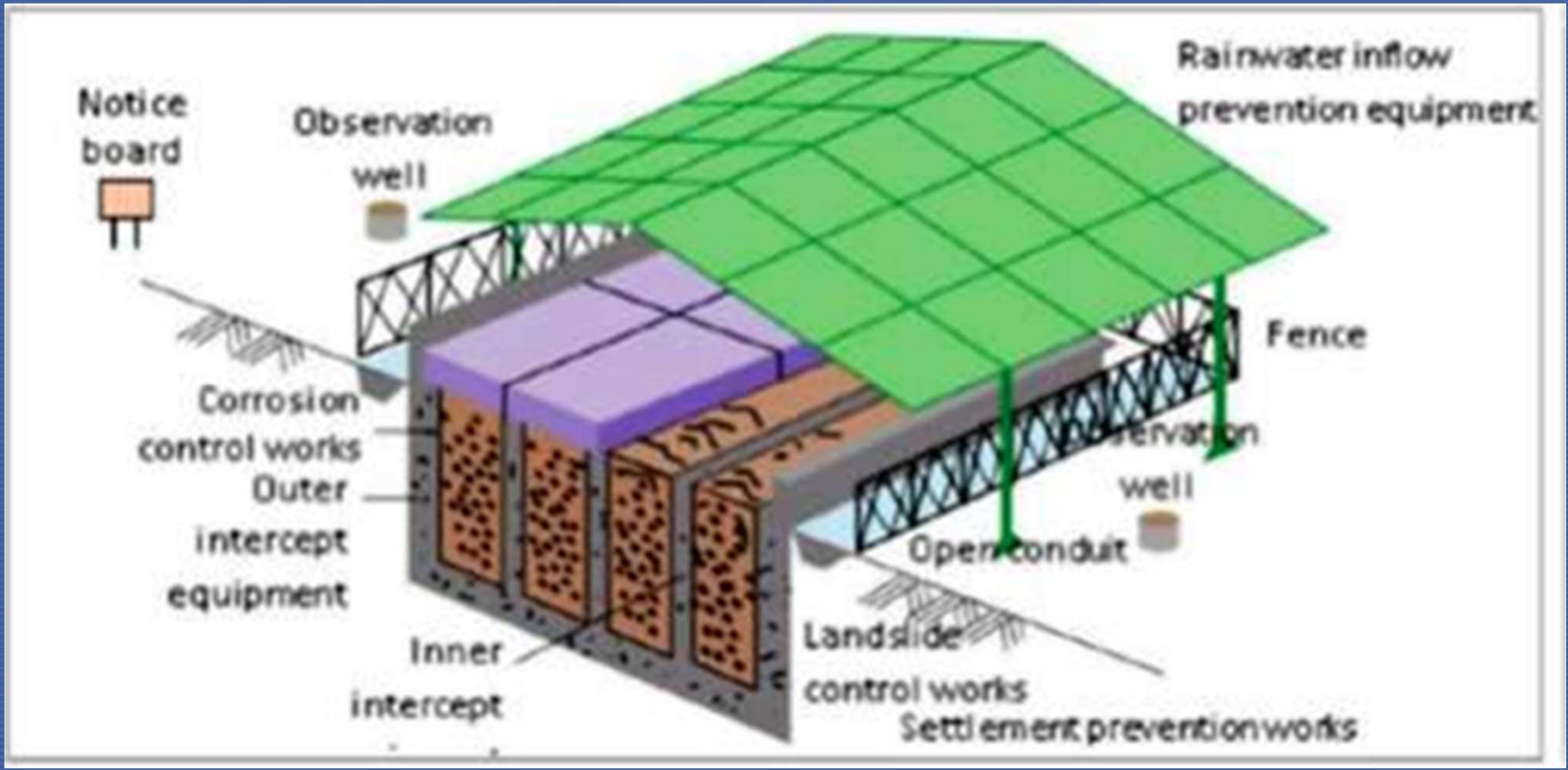
Engineered landfill options (strictly controlled)



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Engineered Disposal Options (VLLW & LLW)

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Factors affecting final choice for disposal

- Short and long term safety – public, workers, environment
- Availability of suitable disposal sites
- Availability of equipment, to construct and operate
- Time required to characterize site and construct facility
- Long term predictability
- Institutional control after closure
- Consequence of failure
- Land area
- Cost
- Public acceptance

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Suggestions for low level contaminated material from remediation

- Clearance levels should be established
- Likely clean material should be collected treated, stored and disposed in similar fashion as Municipal Solid waste (MSW)
- Existing infrastructure for MSW should be considered for utilization
- Higher activity material should be treated as nuclear waste and processed, stored and disposed appropriately

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Findings and Recommendations from Mission Team

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Findings and Recommendations from Mission Team

- Very large quantities of contaminated material running into millions of m3 are estimated to be generated from clean-up operations.
- It can be easily concluded that relative comparison of volumes of generated “radioactive waste “from nuclear power plants and volumes of “contaminated material” from post-accident remediation is meaningless since the difference amounts to several orders of magnitude, even if one tries to compare it with all VLLW and LLW from the life cycle of the existing NPPs in Japan. It is then also possible to conclude that pathways for management of these “materials” should have different considerations and end-points.
- It is necessary to establish criteria to make distinction between material that can be cleared (unconditional and conditional) and material that will qualify as radioactive waste;
- The segregation of the material based on activity at the point of collection from clean-up is the only way that can help in simplification of determination of further steps required to manage the volume of collected material. Such effort may also contribute to better understanding for decision on establishment of criteria for unconditional clearance, conditional clearance, or classification as VLLW and LLW.

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Findings and Recommendations from Mission Team

- National strategy for dealing with disaster and clean-up waste is established and it is sound. The main technical challenges in waste management strategy implementation and consequently in the implementation and success of clean-up campaigns are:
  - existence of infrastructure that is required for management of such very large volumes of generated material (including collection, segregation at the source by the activity;
  - establishment of numerous temporary storages, transportation, capacities available for treatment for volume reduction and capacities of municipal landfills for disposal of unconditionally or conditionally cleared material);
  - determination of site locations for interim storages for such volumes and the time frame for storage;
  - establishment of designated final disposal locations for different types of wastes.

- The National Strategy rightly includes the use of existing municipal waste treatment and landfill facilities to the extent possible. It can be concluded that existing infrastructure for municipal solid and industrial waste exists and it would be able to handle contaminated material to the significant extent, especially if the following criteria are established to assist in management of post-tsunami and post-accident situation:

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Findings and Recommendations from Mission Team

- The limits established for disposal of incinerator ash are fully aligned with established limits in the other IAEA member states
- Development of volume reduction technologies for contaminated soil should be pursued for industrial deployment, since availability of interim storages or disposal sites for soil because of total volumes could be considered as the most critical to successful implementation of clean-up campaign;
- Model demonstration tests have successfully established feasibility of deploying a number of decontamination, treatment and storage options under field conditions. However, all collected material was equally placed as bulk in temporary storages, which actually may add to the volume that needs to be further managed.;
- Interim storage facilities should be established at the earliest to allow consolidation of temporarily stored waste from numerous clean-up locations. The design of interim storage facilities should take into consideration the key functional requirements, namely, to provide safe retrieval from storage pending transfer to a final disposal facility;

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Findings and Recommendations from Mission Team

- The lessons learned from clean-up campaigns after Chernobyl accident points out to risk of having many sub-surface temporary storage facilities;
- The capacity of existing infrastructure including human resources to collect, characterize, handle, transport, treat, condition and store contaminated material should be assessed and augmented as necessary;
- Establishment of new disposal facilities for contaminated material from clean-up should be pursued either as fully dispersed or for 1-10km2 of clean-up area, or by limited number of disposal sites or fully centralized;.
- Establishment of new near surface facilities for final disposal of material considered as radioactive waste that needs to be stabilized and properly packaged should be pursued. One of the most important technical criteria for new disposal sites is closeness to the point of highest contamination, because of transportation and lesser risk of cross contamination.

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Lessons Learned

Chernobyl

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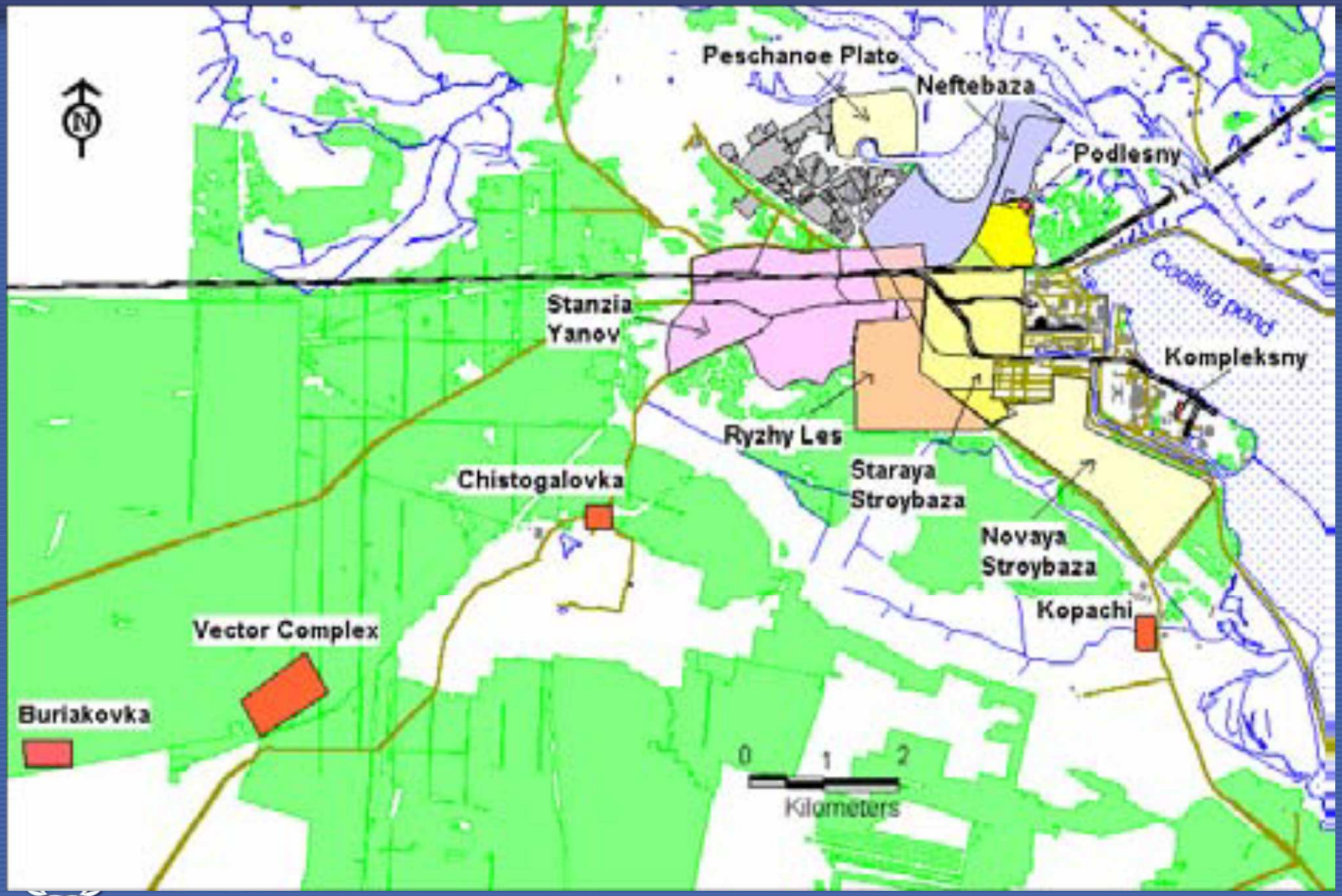
Temporary radioactive waste disposal facilities in the territory of the Chernobyl Exclusion Zone



CHERNOBYL: CLASSIFICATION OF RADIOACTIVE WASTE WITH UNKNOWN SPECIFIC ACTIVITY

- Using the dose rate at 0.1 m distance (μGy/h)
  - Low activity 1–100
  - Intermediate activity 100–10 000
  - High activity >10 000

- Categorization:
  a) Radioactive waste from the shelter and the nuclear power plant site that will be created by construction of infrastructure and the NSC;
  b) Accident generated transuranic waste that has been mixed with radioactive waste from operations at Chernobyl nuclear power plant units 1, 2 and 3;
  c) Radioactive waste in temporary radioactive waste facilities located throughout the CEZ;
  d) Radioactive waste in existing radioactive waste disposal facilities.

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Mixing of accident related waste with operational radioactive waste

This waste amounts to about 2500 m3, with a total radioactivity of about 131 TBq and is stored unconditioned. Once filled, the storage facility was backfilled with concrete grout and
covered with a concrete roof to reduce radiation levels and water infiltration.

Existing above ground storage facility for solid radioactive waste at the Chernobyl nuclear power plant site

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Temporary radioactive waste storage facilities

- The largest volumes of radioactive waste generated by unit 4 remediation activities are located in the CEZ. Sites for temporary storage of radioactive waste, of the trench and landfill type, were constructed shortly after the accident at distances of 0.5–15 km from the nuclear power plant site.
- They were created from 1986 to 1987 and intended for radioactive waste generated after the accident as a result of the clean-up of contaminated areas to avoid dust spread, reduce radiation levels and provide better working conditions at unit 4. These facilities were established without design documentation, engineered barriers or hydrogeological investigations.
- The total area of temporary radioactive waste facilities is about 8 km2, with the total volume of disposed radioactive waste estimated to be over 10x6 m3. The main inventories of activity are concentrated in the Stroibaza and Ryzhy Les temporary radioactive waste facilities along the western trace of the Chernobyl fallout. The specific activity of the radioactive waste in the temporary radioactive waste facility at Ryzhy Les is 105-106 Bq/kg of 90Sr and 137Cs and 103–104 Bq/kg of plutonium isotopes (total).

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Temporary radioactive waste storage facilities

- Most of the facilities are structured in the form of trenches 1.5–2.5 m deep in the local sandy soil.
- The radioactive material (soil, litter, wood and building debris) is overlain by a layer of alluvial sand 0.2–0.5 m thick. The majority of the temporary radioactive waste facilities consist of trenches in various types of geological setting, in which waste was stacked and covered with a layer of soil from the nearby environment.
- These facilities are very variable with regard to their potential for release, which depends on the total radioactivity stored, the waste form (in particular timber), the retention capacity of the substratum along migration pathways and the location of the sites in hydrogeological settings.

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The consequence of temporary storages

- There are also many other temporary radioactive waste facilities, estimated to comprise about 800 trench facilities each with waste disposal volumes in the range of 8 × 10x2 to 2 × 10x6 m3.
- **Only 50 % of the inventories of these facilities are known after 25 years of accident. The facilities are not under regulatory control.**
- Estimates made for a few sites show that their radioactive contents can be high (10–1000 TBq), sometimes of an order of magnitude comparable with the total radioactivity present in soil in the CEZ (about 7000 TBq)

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Radioactive waste disposal facilities

- The main radioactive waste disposal facilities for accident waste are the Buriakovka, Podlesny and Kompleksny sites, which are under regulatory control. These three near surface disposal sites were established after the accident to dispose of radioactive waste from remediation actions carried out during the first year following the accident.
- These sites were chosen and designed for the disposal of higher level accident waste than the radioactive waste located in the temporary radioactive waste facilities

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Radioactive waste disposal facilities

- The Podlesny vault type disposal facility was commissioned in December 1986 and closed in 1988. The facility was designed for the disposal of high level waste with a dose rate 10 cm from the surface in the range of 0.05–2.5 Gy/h. Material with dose rates above this was also disposed of in the facility. The total radioactive waste volume of 11000 m3 of building material, metal debris, sand, soil, concrete and wood was placed in two vaults.
- The disposal facility was covered with concrete at its closure. In 1990 the estimated total radioactivity of the disposed waste was 2600 TBq. In 2002 a re-evaluation of the facility status showed reasons to believe that the total activity of waste disposed at this site may be higher than initially estimated, and a need for a re-estimation of the current inventory was identified. Due to the uncertainties in the inventory, it is assumed that various types of waste were disposed of, including FCM.

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Radioactive waste disposal facilities

- The Kompleksny vault type facility was based on reconstructed facilities of the unfinished units 5 and 6 at the Chernobyl nuclear power plant site.
- Kompleksny was in operation from October 1986 until 1988 and was designed for low and intermediate level waste corresponding to dose rates up to 0.01 Gy/h at 10 cm from the surface of the waste container. More than 26 200 m3 of solid waste with a total activity of 4 × 1014 Bq was disposed of in 18 000 containers and later covered with sand and clay.
- This waste is mainly sand, concrete, metal, construction material and bricks. Due to the high level of groundwater at different periods of the year, the facility is flooded 0.5–0.7 m above its bottom. Significant uncertainties exist associated with the radionuclide inventory because of the lack of data about the radioactive waste disposed of at the site.

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Radioactive waste disposal facilities

- Buriakovka, built in 1987, is the only disposal facility currently in operation in the CEZ. It comprises 30 trenches covered with a 1 m clay layer and is located on 23.8 ha.
- Up to 652 800 m3 of radioactive waste has been disposed of. After in situ compaction, this was reduced to 530 000 m3, with a total radioactivity of 2.5 × 1015 Bq of solid short lived low and intermediate level waste.
- It consists of metal, soil, sand, concrete and wood contaminated with 90Sr, 137Cs, 134Cs, 238,239,240Pu, 154,155Eu and 241Am. Radioactive waste with dose rates at 10 cm from the surface in the range of 0.003–10 mGy/h was accepted in this facility.

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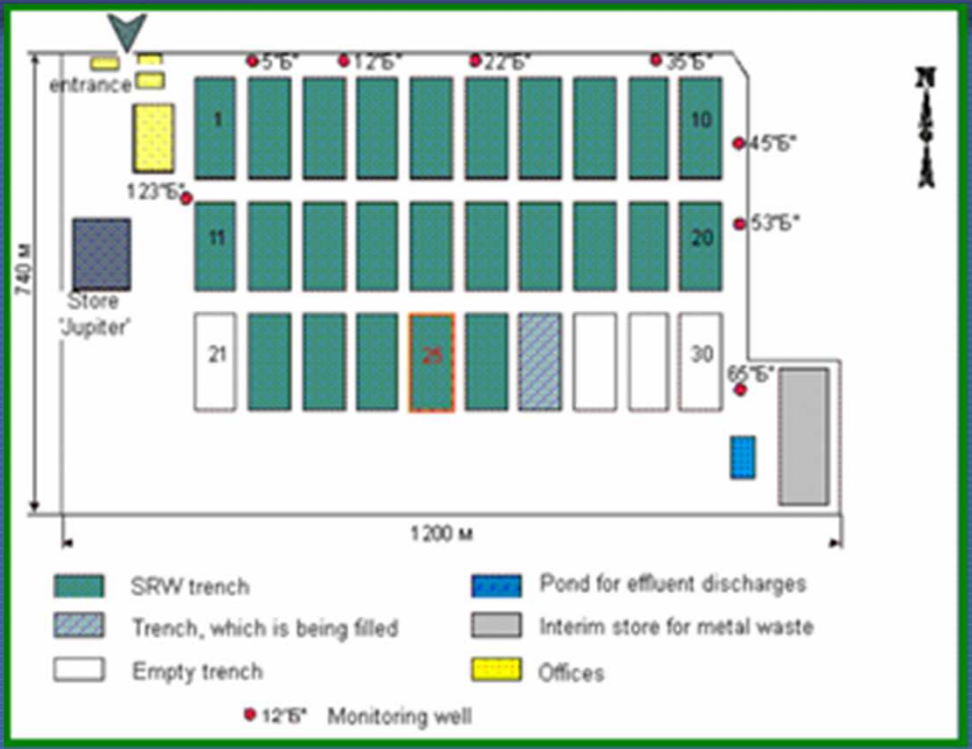
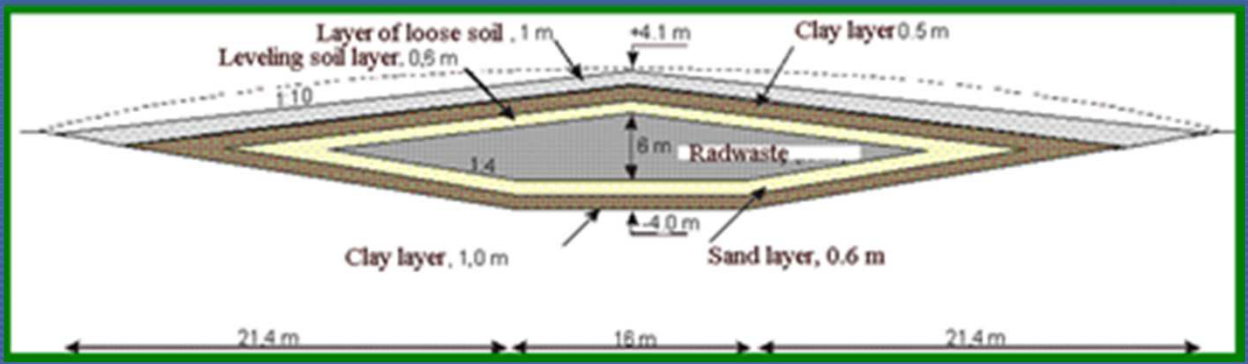
Buriakovka





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Radioactive waste disposal facilities

At present, a new near surface facility, the Vektor complex, for low and intermediate level radioactive waste processing, storage and disposal, is under development. The first phase is commissioned and licensed. This complex will include:

- An engineering facility for the processing of all types of solid radioactive waste (capacity of 3500 m3/a);
- A disposal facility for short lived solid radioactive waste (55 000 m3 total capacity);
- A storage facility for long lived solid radioactive material;
- A storage facility for FCM;
- Intermediate storage for high level conditioned radioactive waste to be prepared for final disposal at the deep geological disposal facility.

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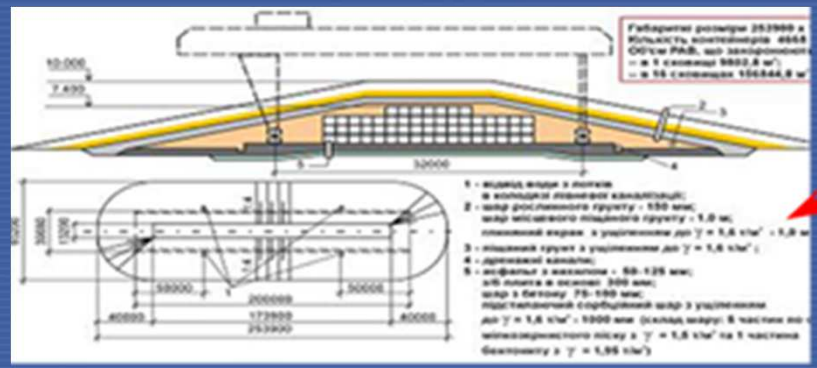
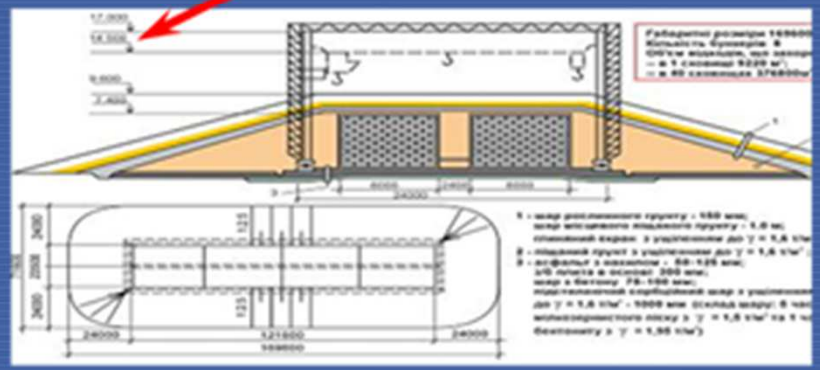
Vektor



Type I - for container disposal of short-lived waste

Type II - for disposal of short-lived waste In bulk form



Quantity:
- Type I = 16 storages
- Type II = 40 storages

Waste:
- SL-LILW – disposal
- HLW, LL-LILW – storage

Volume = 540,000 m³

Activity = ?

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Issues and areas of improvement

- Radioactive waste management programme for the exclusion zone and the Chernobyl nuclear power plant- strategy exists
- Development of Waste acceptance criteria
- Long term safety assessment of existing radioactive waste storage sites
- Potential recovery of temporary waste storage facilities located in the Chernobyl exclusion zone
  - Retrievability of waste and disposal in the short term in order to minimize environmental consequences and improve the safety of workers
  - Possible temporary storage of waste under institutional control in accordance with
  - radiation protection requirements with a view to future disposal;
  - Investigation of facilities that need to be studied in order to decide on adequate intervention measures;.

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FUTURE OF THE CHERNOBYL EXCLUSION ZONE

- Construction and operation of the NSC and relevant engineering infrastructure;
- De-fuelling, decommissioning and dismantling of units 1, 2 and 3 of the Chernobyl nuclear power plant and shelter;
- Construction of facilities for the processing and management of radioactive waste, in particular a deep geological repository for high activity and long lived radioactive material;
- Development of nature reserves in the area that remains closed to habitation;
- Maintenance of environmental monitoring and research activities.

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Actions

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Messages from DG IAEA

- The IAEA will continue to provide every possible assistance to Japan as it restores control over the Fukushima Daiichi plant and tackles the challenging work of decontamination and remediation. Continuing full transparency on Japan's part will also be important.
- The draft Action Plan, which builds on the Ministerial Declaration, represents a significant step forward in strengthening nuclear safety.
- In the aftermath of Fukushima Daiichi, the most important thing is to ensure transparency, build confidence, and meet the high expectations of the public.
- Firm and sustained commitment from all Member States is needed for the full implementation of the Action Plan to restore public confidence in nuclear power.

Action Plan

- Strengthening nuclear safety in light of the accident is addressed through a number of measures proposed in the Action Plan including 12 main actions, each with corresponding sub-actions, focusing on:
  - safety assessments in the light of the accident at TEPCO's Fukushima Daiichi Nuclear Power Station;
  - IAEA peer reviews;
  - emergency preparedness and response;
  - national regulatory bodies;
  - operating organizations;
  - IAEA Safety Standards;
  - international legal framework;
  - Member States planning to embark on a nuclear power programme;
  - capacity building;
  - protection of people and the environment from ionizing radiation;
  - communication and information dissemination; and
  - research and development.

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Action 10- Protection of people and the environment from ionizing radiation

- Ensure the on-going protection of people and the environment from ionizing radiation following a nuclear emergency:
  - Member States, the IAEA Secretariat and other relevant stakeholders to facilitate the use of available information, expertise and techniques for monitoring, decontamination and remediation both on and off nuclear sites and the IAEA Secretariat to consider strategies and programmes to improve knowledge and strengthen capabilities in these areas.
  - **Member States, the IAEA Secretariat and other relevant stakeholders to facilitate the use of available information, expertise and techniques regarding the removal of damaged nuclear fuel and the management and disposal of radioactive waste resulting from a nuclear emergency.**
  - Member States, the IAEA Secretariat and other relevant stakeholders to share information regarding the assessment of radiation doses and any associated impacts on people and the environment.

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Action 10- Protection of people and the environment from ionizing radiation

- 10.1 Member States, the IAEA Secretariat and other relevant stakeholders to facilitate the use of available information, expertise and techniques for monitoring, decontamination and remediation both on and off nuclear sites and the IAEA Secretariat to consider strategies and programmes to improve knowledge and strengthen capabilities in these areas
- 10.2 Member States, the IAEA Secretariat and other relevant stakeholders to facilitate the use of available information, expertise and techniques regarding the removal of damaged nuclear fuel and the management and disposal of radioactive waste resulting from a nuclear emergency.
- 10.3 Member States, the IAEA Secretariat and other relevant stakeholders to share information regarding the assessment of radiation doses and any associated impacts on people and the environment

Post Accident: Support of short-term strategies

- Assessment of criteria for counter measures related to clean-up environmental impacts, effectiveness, occupational dose, waste management of contaminated materials and etc.
- Mapping, characterizing and analysing radioactive contamination off and on-site
- Methods and technologies for decontamination and remediation on-site and off-site areas
- Strategies for life cycle management of waste generated during the accident and by remediation measures.
- Temporary measures for collection and confinement of large volumes of contaminated liquid and solid materials (including soil)

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Post Accident: Support of long-term strategies

- Assistance in formulation of strategies for life cycle management of waste by remediation measures and decommissioning of NPPs including:
  - Assessment of waste inventory, time-line and dynamic of waste generation for different end-use options (e.g. will the site be re-used for NPPs, used as industrial site or remediated to brown field?)
  - Development of criteria for selection of optimal possible technical scenarios for different life cycle options
  - Assessment of technical feasibility, safety, environmental impacts and cost of implementation of life cycle options including on-site and off-site disposal

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Post Accident: Technical support to on-site management of waste

- Solid and Liquid Waste (Processing and Storage)
  - Assessment of the existing processing facilities and storage capacities for possible utilization
  - Assistance in selection of mobile/modular systems to treat liquid waste at the source of generation (e.g. from cooling at individual reactor units)
  - Expert advice on methods, technologies and experiences in treatment and conditioning of large volumes of solid and wet solid radioactive wastes including problematic constituents
  - Assessment of options for confinement and storage of large volumes of contaminated liquid and solid materials (including soil)

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Post Accident: Technical support to decommissioning, site remediation and disposal

- Assistance in planning, costing and selection of options for decommissioning Selection of options for on-site and off-site disposal of accumulated radioactive waste and spent fuel
- Expert advice for remediation measures:
  - Practices and Lessons Learned from Clean-up/Decontamination of Large Areas
  - Management of Waste from Clean-up/Decontamination of Large Areas (Post accident)
  - State of the Art of decontamination technologies
  - Remediation of sites with dispersed contamination
  - Guide on Decontamination of Rural Settlements in the Late Period After Contamination with Long-Lived Radionuclides
  - A Software Tool for Decision Support on the Remediation of Rural Areas

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Post Accident: Review of Spent Fuel Recovery Strategy

- Review the strategy for recovery from the post accident (in a case of melting) situation to advise on possible alterations or extensions to the strategy
- The review focusing on
  - Supporting the assessment of the irretrievability of melted fuel and deformed assemblies
  - Identification of strategies and options for conditioning (processing) and packaging for storage or disposal
  - Development of the requirements for damaged fuel storage, including conditioning and monitoring requirements

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IAEA: Technical Publications (1/2)

Many technical and safety related publications were prepared from 87-92 to address post accident measures related to Chernobyl type accident. The following list is not inclusive:

- Revised Guidance on the Principles for Establishing Intervention Levels for the Protection of the Public in the Event of A Nuclear Accident or Radiological Emergency, **IAEA TECDOC 473**
- Clean-up of Large Areas Contaminated as A Result of A Nuclear Accident, **Technical Reports Series 300**
- Recovery Operations in the Event of A Nuclear Accident or Radiological Emergency, **Proceedings Series - IAEA**
- Environmental Contamination Following A Major Nuclear Accident, **Proceedings Series - IAEA**

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IAEA: Technical Publications (2/2)

- Disposal of Waste from the Clean-up of Large Areas Contaminated as A Result of A Nuclear Accident, **Technical Reports Series 330**
- Planning for Clean-up of Large Areas Contaminated as A Result of A Nuclear Accident , **Technical Reports Series 327**
- Management of Severely Damaged Nuclear Fuel and Related Waste, **Technical Reports Series 321**
- Derived Intervention Levels for Application in Controlling Radiation Doses to the Public in the Event of A Nuclear Accident or Radiological Emergency: Principles, Procedures and Data, **IAEA Safety Series 81**

Some of these document will be revised and updated to reflect accident at Fukushima Daiichi

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IAEA: Technical Cooperation Projects (1/2)

- IAEA provides on-going technical support to mitigate consequences of Chernobyl accident related to waste management, decommissioning and environmental remediation on site and on affected territories. The list of technical cooperation projects is not exhaustive:
- Decommissioning and RWM:
  - UKR 3002 Decommissioning of Units 1, 2 and 3 of Chernobyl Nuclear Power Plant and Assistance with the Shelter
  - UKR 4010 Management of Radioactive Material from the "Shelter" at Chernobyl NPP
  - UKR4011 Support for Decommissioning of Chernobyl NPP
  - UKR9017 Strengthening the State Nuclear Regulatory Committee for Safety Assessment Methodologies
  - UKR9026 Comprehensive Safety Assessment of Radioactive Waste in Ukraine (Classification, Characterization, Environmental Assessment)
  - UKR3003 Chernobyl NPP Units Decommissioning and Radioactive Waste Management at the Site Including Shelter

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IAEA: Technical Cooperation Projects (2/2)

Environmental Monitoring and Remediation:

- UKR9005 Chernobyl Post-Accident Environmental Monitoring
- UKR9006 Radiation and Nuclear Safety Regulatory Capability
- UKR9007 Reduction of Radionuclides in Human Food and Environment
- UKR9010 Environmental Impact for the Chernobyl NPP Unit 4
- RER/3/004 Radiological Support for the Rehabilitation of the Areas Affected by the Chernobyl Nuclear Power Plant Accident (2007)
- RER/9/074 Long-Term Countermeasure Strategies and Monitoring of Human Exposure in Rural Areas Affected by the Chernobyl Accident (2003)
- RER/9/059 Reducing External Exposure Doses in Contaminated Villages (1999)
- RER/5/004 Edible Oil from Rapeseed Grown on Contaminated Land

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Major Achievements in supporting facilities after accidents

RWM & Decommissioning:

- pilot plant for treatment and conditioning of problematic liquid wastes (containing TRUs and organic matters);
- software for remote access and dose estimation in high fields;
- robotic equipment for management of solid wastes and decontamination;
- soil treatment and decontamination;
- decommissioning planning and execution;
- remediation measures related to Cooling Pond;
- strengthening requirements for waste forms and packages to meet waste acceptance criteria of disposal facilities for solid and solidified waste
- strengthening safety assessment capabilities

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