Cask Operation and Maintenance for Spent Fuel Storage

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1 INTRODUCTION

Steady arising of spent fuel from nuclear power production, against the current backdrop of delays in disposal and limited reprocessing, has entailed rising inventory of spent fuel to be stored for extended period of time possibly a hundred years or even beyond. At the end of 2003, about 178 000 t HM of spent fuel were stored in storage facilities around the world (the balance 86 000 t HM from global arising 264 000 t HM having been reprocessed). With an assumption that roughly one-third of the global inventory would be removed by reprocessing, about 8 000 tHM/year on average will need to be added annually to the global inventory.

The current trend toward extended storage is likely to continue in the foreseeable future [1]. In fact, interim storage is an essential platform for any option to be chosen later as an endpoint for spent fuel management. In view of such a circumstance, the most imminent service required for the spent fuel management worldwide is to provide adequate storage for the future spent fuel inventory arising either from the continued operation of nuclear power plants or from the removal of spent fuel in preparation for plant decommissioning. While the bulk of the global inventory of spent fuel are still stored in AR pools, dry storage has become a prominent alternative especially for newly built AFR facilities, with more than 17,000 t HM already stored in dry storage facilities worldwide. Storage in cask under inert conditions has become the preferred option, given the advantages including passive cooling features and modular mode of capacity increase. In terms of economics, dry storage is particularly propitious for long-term storage in that operational costs are minimized by the passive cooling features. The trend toward dry storage, especially in cask type, is likely to continue with an implication that and the supply will closely follow the increasing demand for storage by incremental additions of casks to the effect of minimizing cost penalty of the idle capacities typical of pool facilities.

A variety of storage systems have been developed to meet specific requirements of different reactor fuels and a large number of designs based on these generic technologies are now available for the spent fuel containers (horizontal, vertical etc) and storage facilities. Multi-purpose technologies (i.e. a single technology for storage, transportation and disposal) have also been studied. Recent concern on security measures for protection of spent fuel has prompted a consideration on the possibility of placing storage facility underground. The future evolution of requirements and technologies will bring important impacts on cask operation and maintenance for spent fuel storage.

2 SYSTEM DESIGN FOR CASK O&M

Operation and maintenance of casks are largely conditioned by the design of the system. When the systems are designed taking O&M into account, most difficulties and glitches can be avoided and costs can be better controlled. It is generally estimated that 90% of the costs originate from the design stage; it is therefore essential to study operation and maintenance right from the start.

2.1 System Design

It includes a variety of information and data, as applicable:

- Access from outside (roads, railroad tracks,... with maximum load and gauge)
- Configuration of all facilities considered: access, indoor routes, hatches, main and ancillary lifting equipment, allowable floor load.

- Suitability of cask materials, of consumables, and of processes for the plant and the environment
- Compatibility of components, durability of assembly over the lifetime of the cask; protection against chemical and electrochemical corrosion in operation, transport, storage. This would include grease, paint, and coating materials
- Reserve sources of power generation and fire protection systems as required

2.2 Operability Considerations

Great care should be devoted to assuring a smooth and safe operation. This includes but is not limited to: fail-safe systems including fool proofing shapes, etc., so that parts cannot be misused, switched, mis-assembled, lost, limiting moving parts, of active parts, of external power requirements, avoidance of small items that are difficult to handle with gloves, and can be dropped in the cask or in a pond and become inaccessible, easy removal of all sub-assemblies and parts. The system should be provided with ;

- Reasonable torques and weights
- Standard tooling, except if inadvertent tampering must be prevented
- Compatible materials against seizure
- Simple kinematics
- Sufficient "elbow room" and storage space in the considered premises

2.3 Maintainability Considerations

A maintainability study is essential at the design stage. It should be based on a FMECA study, and the return of experience gained from previous cask models. Design output documents should include a maintenance program, an instruction manual, a list of spare parts that should be kept available, and of parts that should travel with the cask. Any part or function that is determined as sensitive should be subject to maintenance. It should therefore be made controllable and interchangeable. Inspection methods should be listed. The facilities where the cask can be maintained and decontaminated should be determined at this stage: existence, possible modifications, specific tools or lifting gear... Spare parts should be selected from standard and, preferably, already owned sizes. Future availability should be considered; single-source and patented parts should be avoided. Long procurement time and shelf life should be taken into account for proper stock management. Shelf life shall be specified by the vendor, and should be compatible with the intended use of the cask (for instance no elastomer gaskets for long-term storage casks.

2.4 Ancillary Systems, Infrastructure, and Modifications

Ancillary systems may have to be modified in order to accommodate new casks. Particular issues such as drying equipment, re-flooding equipment, ventilation, and radiological monitoring should be addressed, as modifications may be necessary. The corresponding instruction manuals, procedures and maintenance specifications should be prepared or revised accordingly. The weight of the cask and the free-drop height in shafts may require specific energy-absorbing structures or devices. The lifting capacity of cranes may have to be upgraded, as well as any overflow area such as parts of spent fuel pool bottom.

When a facility is modified, all new equipment shall be tested, instructions revised, and personnel trained accordingly.

2.5 Environment

Any installation designed to accommodate casks shall be subject to the applicable local siting regulations, depending of the total activity envisioned. Access to such installation shall be studied: road or railroad load and width, turning radiuses, slope, etc. Tilting areas should be considered, as well as adequate headroom including lifting beams, hooks, and cask height. Climatic conditions must be considered, specifically to check whether outdoor storage is acceptable over the foreseen storage period. Climatic and other environmental conditions (wind, temperature, visibility, daylight, etc.) shall be specified for operation and on-site transfer.

3 O&M PROCEDURES

3.1 Operation

As the procedure for operation of casks at various stages of spent fuel management are similar, the following information is equally applicable to all types of package.

- General conditions

Prior to the selection of any package to be operated in any facility the following key points should be considered to ensure all points highlighted during feasibility study are satisfied, and that handling procedures encompassed within the facility QA system are appropriate : plant operating licence considerations, power pant / receiving plant key limitations, compatibility with fuel assembly type, crane capacity and height limitations, ground (incl. pool / hot-cell) loading criteria, clearance through all handling routes, assessment of handling route (incl. any transfer), ancillary equipment requirements

- Operation

storage operation of the packages is done in accordance with site procedures which may be split into loading of spent fuel, preparation for transfer/shipment, transfer or shipment, preparation for storage

- Preparation for loading

Prior to the start of loading activities, confirmation is made that all the administrative and technical requirements of the regulatory and package license are complied with (e.g., fuel characteristics). This procedure will cover activities to ensure the safe operation of the package: Protection of critical surfaces from potential damages during loading (e.g. seals sitting surfaces) Protection of the package surfaces from contamination. Inspection and testing of all operational items of the package (ports, fuel holder, etc.) and of the ancillary equipment (tools, drainage/drying equipment).etc.

- Loading of the fuel assemblies

Loading of the fuel assemblies is done in accordance with plant specific procedures. Confirmation and verification of the fuel assembly identification and loading patterns is performed. Unloading and re-flooding procedures, and other emergency procedures are required (e.g. cask specific procedures may involve limitation on safety operations).

- Preparation for transfer/shipment

This procedure will cover activities to ensure compliance with the safety reports/license requirements and transport regulations for inter site moves or site specific regulation for intra-site moves. These procedures will cover : closure of the package, decontamination, draining/drying if applicable, leak testing of the package if applicable, radiation measurements, contamination controls, temperature measurements. For some of these procedures, a step-by-step approach may be required.

- Transfer/shipment

Transfers are carried out according to plant specific procedures agreed between the utility and its safety authority. Shipments are carried out under the IAEA and country specific rules for the transport of radioactive materials.

- Preparation for storage

This concerned primarily with dry storage of packages at designated facilities. Unloading procedures at reprocessing facilities or wet storage facilities are considered to be similar to loading procedures.

3.2 Maintenance

Maintenance specifications take into account regulatory, owner, and user requirements. Maintenance requirements typically focus on the transportation aspects of spent fuel, not the storage. General maintenance requirements would apply to handling equipment and facilities (ie, crane, transfer facility). Examples of typical maintenance activities may include:

- Transport

As specified in license conditions such as visual inspection of all components including body, impact limiters, trunnions, finned area, top of basket, an inspection of all threads with go-no go gauges, dimensional and dye-penetrant inspection of trunnions, check of trunnion screws, check of free passage of a gauge in fuel compartments, and replacement of all gaskets, check on neutron absorber in the basket walls, and check of shielding and thermal efficiency when the cask is loaded with fuel.

- Storage

Visual inspections of all components, repair of external paint, calibration checks (and replacement, if needed, of over-pressure monitoring systems), check and repair of trunnions and bolts, corrective maintenance as required

Any modification or repair to a package must be controlled. This could involve re-analysis of the package safety reports. Development of repair or modification procedures would be in accordance with a QA system. The modification or repair would be recorded in the package history.

3.3 Data and Records Management

All records should be maintained in accordance with the applicable quality assurance requirements. Inspection frequency shall be determined based on industry and operational experience. Environmental factors should be considered.

4. INDUSTRIAL EXPERIENCES

4.1 Short List of Lessons

- Contamination control

  Contamination has proved to be a nagging problem in cask operation, as was witnessed at several consignments in Europe in 1998 [2]. A large amount of industrial experience has been accumulated for transportation, with lessons applicable to operations associated with spent fuel storage. Counter-measures recommended for storage include: the use of plastic and metal skirts, duplication of contamination measurements, use of easily cleaned or removed materials, special paints, spraying with clean water before placing in the pool.

  Some designs are prone to trapping contamination, especially when used submerged. Precautions such as installing a skirt around the body will significantly reduce contamination. Circulating demineralised water under the skirt will cool the loaded cask and avoid any pool water ingress. Skirts are usually made of stainless steel or plastic.

- Hydrogen control

  Hydrogen may be created as a result of radiolysis or chemical reactions. Recombiners and/or getters should be used to preclude any risk of ignition or blast. Time under water in the pool should be limited accordingly.

- Welding of canisters

  Welding material and equipment should be checked before welding operations begin. Use of automated welding machines has become an industry practice for seal welding of the canisters. Adequacy of critical welds shall be verified as specified in the design specifications and drawings. Specific UT or NDE requirements may be called for.

As the welding of the canister opening with the cover, together with subsequent operations, is the crucial operation for interim as well as long term AFR storage, active developments have been pursued in the related industry. Highly automated welding systems for spent fuel canister welding are available in the market. Some technical problems associated with welding of canister closure in storage casks were reported in the US by USNRC inspection and appropriate corrective measures were taken [3].

- Sealing and sealant experiences

  Coatings (both internal and external) should be specified and selected for the following characteristics: durability, decontaminability, emission and absorption, ability to undergo touch-up and repairs on the loaded (warm) cask.

  Bolted trunnions have a gap around their base, where water may flow. These gaps are filled with silicone. The heads of the screws are also covered by silicone. In order to protect contamination of the silicone gaskets, and provide additional protection against seepage of contaminated water, adhesive tape and metallic covers with seals are frequently used (over the silicone) before immersion. Drying and leak testing procedures may be beneficial.

  For bolted casks, seal surfaces are a critical part for leak-tightness. Special precautions should be taken to protect those surfaces, such as plastic rings covering the seal surfaces. Any threads should also be protected or plugged. Adequate protection from environmental exposure is essential.

4.2 Further Wisdoms from Experiences

- Pre-installation check

  Before they are installed or closed, all components including seal areas and spare parts, shall be inspected, at least visually, in order to make sure that they are in perfect condition and fit for installation. For gaskets, damage and scratches, remaining shelf life shall be particularly inspected. For spare parts, inspection should take place in a no-radiation zone and adequate numbers of spare parts should be verified.

  It is recommended to have universal connecting tools that will fit all types of casks. Utilities should specify their requirements to the vendors. Consideration should be given to leak testing regimes and standard procedures should be developed for leak testing.

- Handling damage

  Protection should be mounted on the closing and/or leak tightness surfaces of the cask during handling and maintenance operations (avoiding scratches on sensitive surfaces). Procedures should request the verification of any handling tools before use. Procedures should also avoid handling of small tools or devices in the vicinity of the open cask (limitation of tools drop in the cask).

  The personnel should be trained for using the handling devices. The cask surfaces have to protected during cask handling as: protective plastic plates mounted on area where moving devices are handled, protective rubber liner under the cask during rail way transport.

- Interaction between components and with the environment

  Corrosion-sensitive materials should be protected against external influences, including against neighbouring components and plant equipment and fluids. Protective covers should be used whenever possible. Screens over inlet and outlet vents can be used.

- Storage conditions of casks not in use

Any cask should be protected from weather conditions whenever possible. It is best to keep it indoors when it is not in use. Tarpaulins are not advised as they usually cause condensation that may induce corrosion. Special provisions such as inert gas filling may be specified in operating instructions. Adequate precautions shall be taken to remove any device or gas before using the cask again.

- Hazardous materials and situations

All precautions in occupational safety remain applicable: protection against fall, heat, pressure, and oxygen deprivation, as well as harmful chemicals such as asbestos and lead. When incidents or accidents may give rise to such exposure, the instruction manuals should warn against it and provide the necessary safety precautions.

- User groups and training for skills

  User groups are always beneficial as it is in the interest of safety and economics to share feed back experience. Utilities and cask vendors might want to set up such groups to exchange operational and maintenance experiences.

  Staff training is essential and should include full scale, all-inclusive "cold" (ie. without radioactive materials) tests. Procedures are to be validated, and possibly revised and retested, as a result of the tests. Such training should be regularly repeated, as a minimum whenever equipment or procedures are modified. Operation experience will improve both time and resource needs. First loading demands will be higher than those of future loadings. Skill level will improve with on-the-job experience.

- Feedback reporting

  Periodical review should be performed on operational events, incidents, defects found during maintenance, and rate of replacements of parts. Reports should be raised and forwarded as applicable and/or requested to clients, competent authorities, and cask design engineers for new designs and possibly retrofit. Feedback studies may be used as support for modifying the maintenance frequencies. Information made available by the different competent authorities should be analysed on a systematic basis.

5. DOSE REDUCTION TO OPERATORS

Traditional techniques have been widely used to reduce the dose rate are, among others : reduce time in the area of the loaded cask, optimise the distance, use temporary shielding equipment etc. It is also very important to plan the work in such way to minimize operational time at the loaded cask. Therefore a quality plan or a step-by-step sequence plan is necessary. This plan should be reviewed from time to time, at minimum after the first cask loading's or unloading's, to optimise the procedure and the organization of the work to be done. After a campaign (several loadings or unloadings) a report on lessons learned should be prepared, to capture the experience which have been made. Although the position of the fuel elements into the cask could be non-specific, it is a good practise to load the hottest fuel in the centre of the basket and the coolest at the outside, to reduce the dose rate. That aspect has to be included in the loading plan.

Dry runs to improve actual time to perform task are necessary, as well as tool staging and equipment location and design to facilitate the users. When lifting gear travels with the cask, the receiving facility should check whether any inspection is requested, including regulatory tests. It is also necessary to prevent spurious movement of the conveyances when tilting the cask.

5.1 Radiation Shielding and Monitoring,

To reduce the dose rate and the affect on people outside of the storage site, different techniques are used. The placing of spent fuel casks inside protective building, for instance, is a common practice to reduce radiation dose due to skyshine effects. It is very helpful and efficient to have a plan to position the casks in a pattern that takes account the ALARA concept.

Additional temporary shielding can be designed and utilized, such as polyethylene sheets against streaming from designated spots and against general radiation from the cask.

Radiation levels in storage areas shall be monitored, recorded and any changes shall be analysed.

5.2 Remote Operations and Maintenance

After loading the cask with fuel, several preparation works could be done as a remote control technique e.g. vacuum drying, leak testing (partly), bolting/unbolting the lids etc. Following this matter, it is possible to reduce the number of people in the area of the loaded cask. In case of storage the fuel in metal canisters (within concrete modules,) automatically welding machines are used, to minimize the personal dose rate. Further automatic systems for e.g. ultra sonic inspection or remote visual inspection by using cameras, are available.

Several industrial experiences in remote-controlled unloading of casks are made, for instance at the Tihange nuclear power plant (2 & 3 units), and at several reprocessing plants (UP3, Thorp, Mayak).

5.3 Site Geography

There are different storage concept's ie., earthen berms may be used as shielding, as well as increased distance to the site boundary.

6. FUTURE ISSUES

6.1 Spent Fuel Characteristics and Cask/Canister Design

- Trend to High Burnup (HBU) and Mixed Oxide (MOX) Fuel Use

The fuel burnup in nuclear industry has continued to show upward trend, mainly driven by economics consideration in the competitive market. Fuel failures are a concern both from reactor operation and fuel storage point of view. However, fuel failure rates are diminishing. The main failure causes at present day are debris and grid to rod fretting. These failure mechanisms are not strongly dependent on burnup, hence the strive for higher burnup has not lead to increased number of fuel failures.

Although this trend to higher burnup is foreseen to be constrained at a certain level by regulatory notches or other balancing factors, and despite the fact that overall rate of accumulation of spent fuel assemblies should decline because of extended reactor residence time of HBU fuel, the preparation for storing spent fuel of higher burnup has become an active issue in a growing number of countries because of the higher heat and radioactivity content.

In a similar token, the increasing amount of MOX fuel used in LWRs, as observed in Europe, will result in growing inventory of spent MOX fuel with still higher content of heat and radioactivity than high burnup UOX fuel.

The current methods employed to handle the more hostile characteristics of HBU fuel and MOX fuel are either to keep them for longer period to decay in cooling pool, or in some inevitable cases requiring to be placed in restrictive storage conditions such as casks, combinatorial loading with lower burnup or longer cooled spent fuel, or even partial filling of the available spaces at the cost of underrating the cask usage. Emerging technologies could evolve over this period to enable buffer storage in dry systems, e.g., casks with forced cooling.

Application of burnup credit that can make significant improvement in the problem of underrating spent fuel management facilities for criticality safety which which is generally regulated by licensing conservatism based on fresh fuel. Enhancements in burnup credit applications are making progress in some countries.

- Trend to larger cask

Both operation and maintenance will be impacted by the size of casks. Cask designers will augment size and weight in order to pack more fuel in a cask, mainly driven by consideration of cost-effectiveness.

For operation and maintenance, this will limit the margins for lifting equipment and ground load, and reduce the clearance to walls and working areas; also, it will require larger transfer and transport means. On the maintenance side, larger sizes make sense as it means fewer casks, and because maintenance is more in proportion to the number of parts, such as threadings, than to accessible area and obviously than to weight.

- Multi-purpose Systems

The increasing use of casks for dual purposes on one hand and ramifications of diverse storage casks with canisters on the other have also raised an issue of longer term consideration for the optimisation of the overall operation by use of a uniform container design which would be compatible with diverse package designs. A well known example is the USDOE initiative to develop MPC (Multi-Purpose Canister) which was supposed to provide a standardization as required for compatibility of interface between different stages of the spent fuel management [4]. Even if the implementation of this proposal came to face up a baffle, due to the absence of definition of disposal containers, several vendors have come up with MPC designs for possible applications in the market.

6.2 Issues of Long-term Storage

- Safety and security of spent fuel

As for prolonged storage, there is confidence in coping with the long term storage requirements without major technical issues. Such confidence has been built on the extensive industrial experience gained in spent fuel storage, and especially on the recent development of dry storage systems which are beneficial for long term storage in that spent fuel is kept in an inert sealed atmosphere [5, 6].

More recently these issues are compounded with security and physical protection questions for which underground options are attracting interest.

- Retrievability

Consideration needs to be given to receipt and fuel retrieval if casks are sent for repackaging at a final repository. Regulators have expressed interest into the issue of fuel integrity following extended interim storage periods, in particular the integrity of the cladding or the structural integrity of the fuel assembly itself, particularly if the basket conditions may cause fuel to stick during its retrieval and removal from the cask.

REFERENCES (full documents downloadable from http://www.iaea.org/OurWork/ST/NE/NEFW/index.html)

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