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ABBREVIATIONS

ALARP	As Low As Reasonably Practicable
BAT	Best Available Techniques
CCTV	Closed Circuit Television
DSC	Dry Shielded Canister
DSP	Design Safety Principle
EPR	European Pressurised-water Reactor
HSM	Horizontal Storage Module
PCSR	Pre-Construction Safety Report
PSA	Probabilistic Safety Analysis
RAM	Radioactive Material
SDO	Safety Design Objective
SF	Spent Fuel
SFR	Safety Functional Requirement

REFERENCES

1. Interim storage facility for spent fuel assemblies coming from an EPR plant. ELI0800224 Issue A. EDF. November 2008.

2. Solid Radioactive Waste Strategy Report (SRWSR). NESH-G/2008/en/0123 Revision A. AREVA NP. November 2008.

0. EXECUTIVE SUMMARY

This report demonstrates that the risks over the lifetime of an interim storage facility for spent fuel are as low as reasonably practicable. It provides complementary information to PCSR, UKEPR-0002-115 Issue 00 Sub-chapter 11.5 – Interim storage facilities and disposability for UK EPR.

1. INTRODUCTION

1.1 ITEMS ADDRESSED IN THE REPORT

To demonstrate risks are as low as reasonably practicable this report addresses the following:

- Design principles and safety aims for the storage facility.
- A demonstration that the need for active safety management during longer-term storage has been minimised.
- Identification of the characteristics of the used fuel and equipment needed to maintain integrity and handling over the storage period. The identified characteristics are analysed to see how they will evolve over the storage period. Provisions for used fuel or equipment that fails to meet the required characteristics are described.
- Details of the provisions and functions for retrieval and inspection of used fuel, including details of the inspection regime.
- Details of the changes necessary to the retrieval and inspection regime as materials age and their characteristics change.
- Plans for the facilities, and their functions, needed to retrieve the used fuel and prepare them for onward processing or disposal.

1.2 THE SPENT FUEL INTERIM STORAGE FACILITY

The proposed storage facility for spent fuel (SF) will have a design life longer than the period of operational experience for any existing interim storage facilities for SF. In other respects the stores are conventional and present no particularly novel safety issues. It is therefore concluded that the key issues to be addressed at this stage are those relating to the adequate control of hazards and risks over the long term.

1.3 FUNCTION OF THE INSTALLATION

It is generally considered that an interim storage facility has three main functions. These are:

- Receiving and/or conditioning the fuel assemblies prior to storage;

- Interim storage of spent fuel;
- Retrieval of the spent fuel assemblies following interim storage. The overall objective of these operations is to prepare the assemblies for transfer or transport to the final repository. The facilities and equipment used for the reception and conditioning operations of the assemblies will be reused for the retrieval activities. If they are not available, similar facilities and equipment will be required.

Maintenance operations will also be carried out during the interim storage phase, in order to ensure that the assemblies can be retrieved.

All fuel assemblies from the EPR operating phase will be considered in the specification of the facilities considered in this document. Specifically, assemblies with cladding failure or those that have been repaired will both be considered in addition to normal, undamaged assemblies. Assemblies damaged during their transfer, during unloading or conditioning operations, during storage or retrieval will also be considered.

In summary, the activities considered in this document include all of the activities undertaken at the interim storage facility ranging from the reception of the transfer/ transport casks containing the assemblies at the facility, to the final export of fuel assemblies for further treatment or final disposal.

1.4 DESIGN ASSUMPTIONS

The storage building will be located at, or adjacent to, the EPR site. The assumption is that all the assemblies from the EPR unit from 60 years' operation will be stored, representing around 3400 assemblies (for one EPR unit). It is also assumed that the residual power of a single assembly when entering the interim storage facility will be approximately 1.4 kW since they will have spent 10 years in the reactor storage pool. The interim storage facility lifetime is assumed to be 100 years from receipt of the first assembly for storage.

1.5 APPLICABILITY OF THE ALARP PRINCIPLE

The ALARP Principle is applicable to all aspects of the design and operation of the storage facility. Its application should ensure that all hazards associated with normal operation of the facility and all risks associated with accidents occurring during its operation are restricted as low as reasonably practicable throughout its operational life and that, so far as is reasonably practicable, the disposability of the stored SF will not be compromised.

Similarly, from the viewpoint of environmental protection, the principle of employing Best Available Techniques (BAT) is applicable to all aspects of the facility's design and operation which might adversely impact on the environment or the future management of the fuel.

It is noted that both principles involve a similar cost benefit balance in that neither requires expenditure to be incurred that is 'grossly disproportionate' to the safety or environmental impact benefits accruing from the expenditure.

A commitment to the ALARP Principle as a fundamental requirement is provided in Chapter 3.1 (Section 3.1) of the PCSR and is codified in a Safety Design Objective, SDO-1, as follows:

'The radiation doses to workers and the general public from an EPR, under normal operating and postulated accident conditions, must be as low as reasonably practicable'

1.6 APPROACH TO COMPLIANCE WITH THE ALARP PRINCIPLE

The approach adopted to ensure ALARP will be to ensure that all aspects of the design and mode of operation of the storage facility comply fully and demonstrably with applicable modern standards of good practice.

A set of indicative design safety principles (DSPs) has been generated, compliance with which will contribute to compliance with the relevant modern standards. While the storage facility remains at a ‘concept’ stage, these DSPs are necessarily relatively generic in nature such that they would be applicable to any interim storage facility for radioactive materials.

Finally, the achievement of ALARP will be facilitated through the setting of targets for normal operations exposures and accident risks compliant with UK modern standards. Such targets have already been defined as Safety Design Objectives for the EPR in Section 3.1 of Chapter 3.1 of the PCSR (SDOs 2 to 7).

1.7 MAIN HAZARDS AND RISKS

1.7.1 Sources of Hazards and Risks

The primary source of radioactivity giving rise to hazards during normal operation and contributing to the risks from accidents is the spent fuel inventory itself. However, additional inventories of radioactivity may be present as corrosion product contamination on, or emanating from, fuel cladding surfaces and, potentially, from fission product activity released from the fuel during handling and storage.

The principal operations which may result in exposure of members of the workforce or of the public either under normal or abnormal conditions are as follows:

- Transfer of inventory to the store;
- Emplacement of inventory in the store;
- Storage of inventory;
- In-situ inspection and monitoring of inventory;
- Retrieval of inventory for inspection;
- Ex-situ inspection of inventory;
- Retrieval of inventory for final export;
- Preparation of inventory for final export;
- Maintenance of facilities and equipment.

1.7.2 Normal Operations Hazards

Members of the public may be exposed either to extremely low levels of direct radiation from the facility or radioactivity discharged under authorisation to the external environment in liquid or gaseous effluents. Members of the workforce may be exposed to direct radiation or to chronic levels of airborne contamination.

1.7.3 Accident Conditions

Under accident conditions, both groups might be exposed to the same types of hazards but with enhanced magnitude. Additionally, members of the workforce and, to a lesser extent, members of the public might be exposed to hazards from external radiation and dispersed radioactivity resulting from accidental criticality. The risks associated with these hazards would then be a function of the frequency of the fault sequences which cause their realisation.

At the concept stage, potential fault sequences cannot be precisely defined due to a lack of available detail regarding the engineered design and the demands made of the operators. However, a listing of potential internal and external hazards that might initiate fault sequences has been generated for the EPR via a process summarised in Section 1.2.3.5.1 of Chapter 3.1 of the PCSR. Those of primary relevance to ancillary facilities devoted to fuel storage are listed below.

1.7.3.1 Internal Hazards

These are defined as events originating within the facility boundary and having the potential to cause adverse conditions or damage within the facility. These are:

- Dropped loads or load collision;
- Fire;
- Loss of shielding;
- Internal flooding;
- Loss of electrical supplies.

It is noted that some more energetic internal hazards identified for the reactor itself are unlikely to be of significance for fuel storage facilities.

It is recognised that the risks associated with these hazards may vary over the plant lifetime. This may be due to variation in operational frequency (e.g. due to increases in inspection frequency), initiating fault frequency (e.g. due to ageing of handling equipment) or fault sequence consequence (e.g. due to degradation of fuel assembly impact withstand capability over time).

1.7.3.2 External Hazards

These are natural or man-made hazards originating externally to the plant but having the potential to adversely affect the safety of the plant. These are:

Natural Hazards:

- Seismic events;

- External flooding;
- Extreme Weather.

Man-made Hazards:

- Aircraft impacts;
- Other man-made hazards.

It is noted that this latter group of hazards are, to some extent, location specific.

It is again recognised that the risks associated with these hazards may vary over the lifetime of the facility due to potential deterioration with age of structures and systems.

1.8 FUEL STORAGE OPTIONS

The following four spent fuel storage technologies have been considered for the production of the PCSR:

1. A wet interim storage facility: fuel assemblies stored in a pool.
2. A dry interim storage facility: fuel assemblies stored in metallic casks.
3. A dry interim storage facility: fuel assemblies stored in vault type storage.
4. A dry interim storage facility: fuel assemblies stored in horizontal storage modules.

At this concept stage, these all remain potential design solutions. Throughout this report, therefore, the safety analysis addresses all potential interim storage options.

The various storage options are described in outlined in References [1] and [2].

2. SAFETY AIMS AND DESIGN SAFETY PRINCIPLES

2.1 INTRODUCTION

This section defines the high-level safety aims and objectives to be achieved by the storage facility design and mode of operation. It also identifies the Safety Functional Requirements (SFRs) and DSPs which will require to be satisfied to meet those aims and objectives over the long term.

2.2 SAFETY AIMS & OBJECTIVES

The primary safety aim is as follows:

'*To ensure, so far as is reasonably practicable, the protection of all potentially affected groups of people and the environment throughout the storage facility's life-cycle and facilitate future safe management of the wastes'*

A set of objectives underlying this aim is defined as follows:

- To restrict normal operations exposures on and off the site;
- To prevent accidents;
- To mitigate the consequences of accidents that do occur;
- To control the condition of stored fuel throughout the storage facility's life cycle.

2.3 SAFETY FUNCTIONAL REQUIREMENTS

Safety must be assured under normal operating and accident conditions. At the concept stage of design development, safety functional requirements can only be defined at a high level. However, from a knowledge of the processes to be undertaken and the hazards and risks to be controlled (see Section 1.7), the primary SFRs to be delivered are identified as follows:

- Normal Operations Functions:
    - Maintain containment of all radioactive materials (RAM);
    - Restrict exposure to external radiation;
    - Control discharges of RAM to the external environment;
    - Remove decay heat;
    - Maintain sub-critical conditions.

- Accident Conditions Functions:
    - Prevent loss of containment;
    - Prevent loss of shielding;
    - Prevent criticality;
    - Mitigate loss of containment;
    - Mitigate loss of shielding;
    - Mitigate criticality.

The design will deliver these SFRs to the degree that is reasonably practicable and thereby restrict doses and risks to ALARP levels.

2.4 DESIGN SAFETY PRINCIPLES

2.4.1 Introduction

This section details the set of DSPs that have been developed as the basis for design of the storage facility. Higher level, more fundamental design principles such as the requirement for the provision of defence in depth[1], adherence to the single failure criterion[2] and the classification of safety functions by safety significance provide the foundations of the Requesting Parties' safety approach to be implemented in all aspects of the EPR design. This approach is described in Chapter 3.1 of the PCSR.

It is noted that, in some cases, these high level principles have been interpreted in the PCSR for application to reactor operation and may require a degree of reinterpretation to clarify their applicability to spent fuel management operations. Nevertheless, the fundamental implications of the principles are clear and are equally relevant to spent fuel management.

Because of its 'concept' status, the design of the storage facility is not currently sufficiently detailed to permit the application of the most rigorous hazard identification techniques and the DSPs listed are therefore generally high level and applicable to the design of any modern interim storage facility. As the design is developed, the increase in available detail will permit more rigorous examination and the derivation of more plant-specific DSPs. Nevertheless, adherence to the DSPs in the development of the design will ensure compliance with modern standards of good practice for radioactive materials management and will contribute significantly to the delivery of compliance with the ALARP Principle throughout the facility's lifespan.

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[1] In the internationally accepted sense. See for example HSE SAPs06, IAEA Standard NS-R-1. and Chapter 3.1 of the PCSR

[2] In the internationally accepted sense. See for example HSE SAPs06 and IAEA Standard NS-G-1.2 and Chapter 3.1 of the PCSR

2.4.2 Optimisation

The design must be optimised both in relation to safety and environmental impact. Therefore, for all of the principles listed here, all required actions should employ the ‘best available techniques’ (BAT) as defined by the environment agencies and the principles should be complied with ‘so far as is reasonably practicable’, as defined by the HSE.

2.4.3 Design Safety Principles

The following DSPs for spent fuel interim storage have been defined based on UK regulatory guidance:

1. Spent fuel should be stored such that the need for active safety systems to ensure safety is minimised.

2. The primary means of confining all radioactive inventories within the facility should be passive sealed containment systems.

3. Containment of significant radioactive inventories within the facility should be afforded by multiple engineered barriers.

4. The primary means of protection against external radiation should be passive shielding.

5. The design should ensure that the spent fuel will be prevented at all times from mixing with other materials which may compromise subsequent safe and effective management or increase environmental impacts.

6. Spent fuel and its storage containers should be physically and chemically stable and compatible with handling, retrieval, transport, storage and the long-term management strategy for the spent fuel including disposal.

7. Any operational limits and conditions required for safe storage and the need for review and revision over the facility lifetime should be identified through the development of the safety case and should take account of relevant factors such as:

    a. Environmental conditions (e.g. temperature, pressure, humidity, and contaminants);

    b. External heat sink (where relevant);

    c. Water supply (where relevant);

    d. Electrical power supply (where relevant);

    e. Heat generation;

    f. Gas generation;

    g. Radiological and criticality hazards.

8. Monitoring, examination, inspection, and testing arrangements should be developed for the facility, equipment, stored spent fuel and storage containers that take account of any potential for ageing and degradation.

9. The need for monitoring to ensure safety should be minimised.

10. Monitoring, recording and alarm systems should be used to report significant deviations from normal operating conditions as an aid to maintaining plant control and detecting leakage.

11. All aspects of the facility design should take account of the anticipated storage duration (including ageing and degradation) to ensure that the facility continues to meet its safety function.

12. The safe working life of all equipment and systems which perform a safety function or whose failure could affect the delivery of a safety function should be defined early in the design process providing an adequate margin over the intended operational life.

13. The storage environment should avoid degradation that may render the spent fuel unsuitable for long-term management and/or disposal.

14. The storage facility should be designed and operated so that any individual fuel assembly can be inspected and retrieved within an appropriate period of time.

15. The design of the means of inspection of spent fuel, facilities and equipment should be such as to avoid the potential to compromise the integrity of the containment of the spent fuel.

16. Appropriate provisions should be available for dealing with spent fuel or its containers that shows signs of unacceptable degradation.

17. The design and operation of all facilities and processes should facilitate the control and accountancy of spent fuel at all times in the facility such that all waste is identified and an inventory established that should be reviewed and kept up to date.

18. Containers or packages used for the transfer or storage of spent fuel within the facility should be clearly and uniquely marked for identification.

19. Each spent fuel assembly should be characterised prior to storage in relation to its radioactive and fissile inventories, enrichment, burn up, cooling time, decay heat output and presence of contaminants to facilitate subsequent safe and effective management and suitability for processing for final disposal.

20. The design should afford suitable and sufficient design features, locations, equipment and arrangements to support spent fuel characterisation, segregation and other spent fuel management operations.

21. Where spent fuel is being packaged into a form that is intended to be suitable for final disposal, it should be sufficiently characterised to properly inform subsequent decisions about its suitability for disposal.

22. Acceptance criteria should be established for admitting spent fuel to the storage facility which should take account of requirements for storage, handling, and retrieval and the overall long-term management strategy, including disposal.

23. Arrangements should be made and implemented (which may include examination, testing and auditing) to ensure that incoming spent fuel meets the acceptance

criteria. Arrangements should also be established for the safe management of any incoming spent fuel that fails to meet the acceptance criteria.

24. Information should be recorded for all stored spent fuel, which may be required for its future safe management.

25. The design and operation of plant and equipment dealing with spent fuel should be such as to facilitate the termination of a criticality incident.

26. The design should adopt a double contingency approach such that criticality cannot occur unless at least two unlikely, independent concurrent changes in the conditions originally specified as essential to criticality safety have occurred.

27. The facility design and mode of operation should be such that secondary waste generation and discharges to the environment are minimised.

2.5 SAFETY CRITERIA

A system of normal operations dose and accident risk criteria have been developed for EPR that are compatible with UK legislation and regulatory expectation. These are presented in Section 3 of Chapter 3.1 of the PCSR.

3. PRELIMINARY ASSESSMENT OF RISKS & HAZARDS

3.1 INTRODUCTION

This section demonstrates that risks will be controlled to levels that are ALARP throughout the facility's operational life. It describes the means by which the design and its anticipated mode of operation will deliver the SFRs identified in Section 2.3.

Additionally, it outlines the means by which internal and external hazards will be controlled by design, identifies the classes of accident which are likely to be bounding in terms of radiological consequence and those classes of accident which are likely to dominate the residual risk associated with the plant's operation.

3.2 NORMAL OPERATIONS SAFETY FUNCTIONAL REQUIREMENTS

3.2.1 Maintenance of Containment of Radioactive Materials

The main inventories of radioactive material whose uncontrolled dispersal must be prevented by design are the following:

- Activity deriving from the irradiation of the fuel located within the fuel cladding;
- Deposited activated corrosion product contamination on the fuel cladding surfaces;
- Activation products within the materials from which the cladding and fuel assembly structure are fabricated;
- Potentially contaminated pool water;
- Accumulations of activity on components of pond water purification systems.

To ensure continuing adequate containment of all radioactive materials (RAM) present within the facility, the storage structures, systems and components will be designed, fabricated and constructed in accordance with applicable standards of good engineering practice.

Containment of radioactive materials will be provided through the combination of:

- A first system including multiple passive static barriers provided as close as possible to the radioactive inventory and dynamic containment with dedicated extract ventilation for process equipment or hot cells. This system will prevent the transfer of activity to the building internal atmosphere;
- A second system provided in case of unavailability of the first, comprised of the building envelope and building space extract ventilation as dynamic containment to prevent the transfer of activity from the building interior to the external environment.

In this context, dynamic containment refers to the provision of a containment compartment served by a dedicated extract ventilation system that creates a depression within the compartment and ensures that air movement is from areas of lower to greater contamination hazard.

On receipt of fuel for storage, the first static barrier is the fuel cladding itself. The second barrier is the transport cask, complemented by the building containment structure during fuel loading/unloading loading operations.

Once in storage, the following static containment barriers are afforded:

- In the case of the dry storage concept, the first static barrier is provided by the fuel cladding itself (or a sealed canister in the case where there is reason to suspect cladding failure anywhere within the assembly). A second barrier is then provided by a sealed canister for the vault storage and horizontal storage options and the storage cask body for the cask storage option;
- In the case of a wet storage concept, the fuel cladding again represents the first static barrier. The second barrier is either the water contained within stainless steel tanks that form the storage pool during storage or the building structure during remote handling operations requiring assemblies to be lifted out of the water. Dedicated, corrosion proof secondary containment is also provided for the pipework and vessels of active liquid and gas circuits together with adequate bunding.

These barriers are in place during the whole process of fuel reception, unloading, emplacement and storage.

Monitoring and sampling will be carried out to detect any reduction in the effectiveness of the primary containment. In the case of wet storage, this will include monitoring of pool water activity concentration and airborne activity in the pool hall and continuous monitoring of pool water level. In the case of dry storage, sampling of vault and storage well atmospheres will be performed on a regular basis and the air from the storage wells cooling system continuously monitored prior to stack discharge.

3.2.2 Normal Operation Doses

3.2.2.1 Operator Doses

The total effective dose delivered to any worker will be the sum of the effective dose from external radiation and any committed effective dose delivered via exposure to any chronic airborne contamination hazard within the operational area.

At all times, other than during cask transfer, fuel assemblies will be handled behind bulk concrete or water shielding. Shielding thicknesses will be optimised during the design process to ensure that worker doses from sources behind shielding will be maintained ALARP and within design objectives consistent with UK industry best practice. Dose uptake from this source should be very low.

It is not always practicable to design transfer casks to surface dose rate levels comparable to those for permanent shielding. Given that exposure to cask surface dose rates is generally transitory, ‘acceptable’ dose rates are often higher than for permanent enclosures. Annual doses from this source may therefore be higher. However, this will depend on the time spent in the vicinity of casks, the number of cask movements per annum and the manning regime.

Under normal operating conditions, there should be no release of activity either to pool water (wet storage) or cooling air (dry storage) from stored assemblies. For wet storage, any assemblies with leaking pins will be placed in containment ‘bottles’ prior to transfer to the pool. The pool clean-up systems will remove any contamination spreading to the pool water thereby preventing its re-suspension to the pool hall atmosphere. For dry storage, assemblies and cooling air are always separated by at least a sealed storage canister and, depending on the option adopted, by a sealed well or sealed storage cask. There is therefore little chance of fuel activity spreading to manned areas. Further protection is provided, under all options, by space extract ventilation of all operating areas.

It follows from the above that possible sources of airborne contamination are limited and chronic airborne contamination levels will be very low.

Further protection will be afforded by real time airborne activity monitoring and confirmatory sampling regimes.

It is considered that intakes of activity via inhalation are unlikely to add significantly to the low effective doses delivered by external radiation.

3.2.2.2 Public Doses

The shielding of radiation sources within the facility will be designed to ensure that public doses from direct radiation will be negligible.

However, some radioactivity will be discharged to the external environment via aerial and liquid discharges. Under normal operations, these will be made in strict compliance with authorisations based on potential doses to critical individuals via the various possible environmental pathways. For this reason and because of the low anticipated airborne activity levels and HEPA filtration provision, public exposures from discharged material are expected to be very low.

3.2.3 Restriction of Radiation Exposure

The primary sources of penetrating radiation to be considered are as follows:

- Spent fuel assemblies;
- Spent fuel assemblies in transport casks;
- Spent fuel assemblies in storage casks or canisters;
- Storage pool water;
- Storage process wastes (liquid, gas, sludge/resins depending on process);
- Extract ventilation filters;
- Pool water filters.

For fuel, both gamma and neutron emissions must be considered. For contaminant inventories, only gamma dose rates are likely to be significant.

In compliance with DSP 4, the primary protection against external radiation exposure is provided by passive shielding. In relation to workers, the most important shielding provisions are as follows:

- Inherent shielding of the transport cask structure during shipping and internal transfers;
- Inherent shielding of the storage cask structure (where used for dry storage);
- Shielding provided by storage pool water and the pool structure (wet storage option);
- Bulk shielding of cell structures and design of docking stations (to avoid shine paths) during spent fuel handling;
- Concrete vault walls, roofs and plugs (dry storage).

These primary provisions are complemented by a zoning system based on the level of radiological hazard potentially present. By control of access to these designated areas to an extent proportionate to the hazard, unnecessary exposure of personnel is avoided and unavoidable exposure controlled. Zone classifications will range from those permitting free access to all personnel through those requiring the restriction of access to specified groups for limited periods to those permitting limited periods of entry only after source removal.

Further support to the dose restriction regime will be provided via radiation surveys.

In relation to public exposures, the protection afforded by shielding will be equally effective. However, for this group, access to the reactor site will be prevented and attenuation by distance will be an additional factor.

3.2.4 Restriction of Discharges

The nature of the effluents requiring disposal from the storage facility will be heavily dependent on the storage option adopted. In all cases however, discharges will only be made under formal authorisation and in compliance with the limits and conditions set down in the relevant authorisations.

No wastes will be created without prior justification, and the best available techniques will be employed to minimise those that are created. The design will employ BAT for the abatement of discharges of radioactivity to the environment and for the overall strategy for disposal of all wastes generated at the facility.

Aerial discharges via the ventilation systems will be generated under both storage options. In both cases, solid wastes are anticipated from the filtration of these discharges.

Under normal operating conditions, discharges may contain beta and beta-gamma activity associated either with particulates or long lived fission gases (e.g. Kr-85). Monitoring for these species will be carried out prior to the discharge stack, to confirm the continuing effectiveness of containment and abatement provisions.

However, in the wet storage case, additional wastes are anticipated from the treatment of the storage pool water. Both solid and liquid wastes may be generated. However, no liquid wastes will be released directly to the environment from the storage facility under any option. Any solid or liquid wastes will be transferred to dedicated treatment and assay facilities. The waste treatment requirements are similar to those of the EPR unit itself and could, therefore, possibly use its dedicated treatment facility during the 60 years of reactor operational life and possibly beyond.

3.2.5 Decay Heat Removal

It is necessary to provide adequate provision for the removal of decay heat from spent fuel for the following reasons:

- To ensure cladding integrity by maintaining its temperature within an acceptable range;
- To maintain the safety functional capability of structures and equipment whose rate of degradation may be accelerated by excessive temperatures;
- To maintain a working environment conducive to high operator reliability;
- To maintain spent fuel in a condition suitable for retrieval.

In all cases, decay heat removal systems will be designed to have reliability commensurate with their importance to safety.

Heat removal calculations will be performed for normal, off-normal and accident conditions to evaluate temperatures and delay times to reach temperature limits.

Temperature limits will be set for fuel, transfer casks and containment structures which will be consistent with international standards and take account of previous operational experience on fuel handling plants and international experience gained over the facility’s operating life.

It is noted that the cladding’s susceptibility to some potential degradation mechanisms will be a function of the fuel’s cooling and burn-up history. The design assumption is that, based on the sizing of the reactor storage pool, fuel will spend 10 years in reactor pool storage prior to transfer to the interim storage facility.

3.2.5.1 Transport and Unloading

During receipt and unloading operations, the objectives of decay removal that must be delivered by the design are as follows:

- Maintain the integrity and leak tightness of fuel cladding;
- Maintain the integrity and heat removal efficiency of transport cask cooling fins;
- Restrict temperatures within unloading facilities.

Thermal calculations will be performed for any possible configurations (in normal and accidental conditions) as well as to determine grace times for intervention under fault conditions such as loss of ventilation or cask immobilisation. The design of process and equipment must then maintain:

- Safe thermal conditions for the spent fuel;
- Safe working conditions within the building;
- Efficient working conditions for equipment.

The primary operations to be considered are:

- Transfer cask reception and handling operations;
- Transfer cask preparation before fuel unloading and during docking;
- The unloading of fuel from casks.

Temperature limits are likely to be set for the following systems:

- Cask external surfaces;
- Fuel cladding during transport;
- Resins in cask cooling fins;
- Cask lid closing seals;
- Cell concrete walls.

3.2.5.2 Dry Storage

Under the dry storage options, heat removal from the stored fuel is by the convection-driven passage of air over the stored fuel canister.

Depending on the design option selected, heat removal will be promoted by:

- Filling of storage canisters or casks with a gas with good heat transfer properties;
- Design of vaults or horizontal storage modules to optimise air flows in the vicinity of the stored fuels;
- Design of storage casks or canisters to promote heat removal through selection of the heat conducting properties of fabrication materials and the container structure;
- Specific design features such as aluminum heat exchangers attached to the secondary containment shell;
- Selection of the appropriate number of assemblies per canister.

In addition to the importance of maintaining cladding integrity, a major consideration under this option is restricting the thermal load of concrete storage structures to restrict detrimental ageing phenomena.

3.2.5.3 Wet Storage

In addition to the maintenance of acceptable fuel cladding temperatures, the heat removal system must also help to maintain a stable level and favourable water chemistry for storage pools.

The design of the heat removal system will be based on established international standards of good practice and the extensive international experience accrued to date of long-term underwater storage of spent fuel.

The thermal energy within the pool must be transferred to some heat sink and this will require an efficient heat exchange system between the two. The design of the heat removal system will be the subject of optioneering studies and will be optimised during the design development process. The cooling system will require to be rated to cope with the maximum design thermal loading (that is, with the pool stocked to its maximum capacity for fuel assemblies of maximum permitted thermal power) and with any other systems which would normally remove heat (either by design or adventitiously), such as the building ventilation, unavailable but making allowance for unavoidable heat losses by conduction through the pool walls.

Limits will be set on pool water temperature for normal operation and for operation with partial loss of primary cooling. In the worst case, with total loss of cooling capability, intervention will be required to restore water levels diminished by evaporation to prevent the stored fuel becoming uncovered. However, it is noted that, due to the huge volume of water present, this eventuality is extremely remote. It is noted that additional protection will be afforded by an emergency water supply, low pool water level alarms and the capability to isolate leaks where these are from pipes.

The cooling water will maintain the temperature of the pool water at a low level (typically below 45°C during normal and abnormal operating conditions) in order to permit safe retrieval of the assemblies at the end of the storage period. In addition, it is noted that this temperature is also suitable for avoiding degradation of concrete structures over the long term.

3.3 ACCIDENT CONDITIONS SFRS

3.3.1 Loss of containment

The following are considered to be the most likely potential initiating events for fault sequences involving a breach of containment afforded for radioactive inventories:

- Degradation of fuel cladding through:
    - Age related mechanisms;
    - Chemically induced mechanisms;
    - Thermally induced mechanisms.
- Degradation of fuel assembly structure;
- Dropped loads and impact events;
- Leaks and pipe breaches;
- Fires;
- Flooding;
- Loss of power;
- External Events:
    - Natural hazards:

  - Man-made hazards.

The events with the greatest harm potential will be those which potentially involve the loss of containment of the fuel itself rather than of secondary contamination inventories. Of particular significance will be events with the potential to affect the inventory of multiple fuel pins or even multiple fuel assemblies.

The prevention of loss of containment accidents initiated by the above causes is discussed in Sections 3.3.4 to 3.3.6.

Mitigation of loss of containment events will be primarily afforded by the containment systems discussed in Section 3.2.1 and supporting monitoring provisions.

3.3.2 External Exposure

Fault sequences resulting in exposure to an unshielded fuel assembly or assemblies represent the worst case accidents in this class due to the intensity of the radiation sources involved. The primary penetrating radiation of interest is gamma radiation. However, neutron dose rates from fuel assemblies may also be significant.

Accidental disclosure of fuel assemblies from shielding is an unlikely event given that, under all design options, the fuel is surrounded by bulk shielding at all times. This is afforded either by the concrete structure of fuel handling cells (all options), fuel storage modules, storage casks or vaults (dry storage), or the pool structures and water (wet option). However, unshielded exposure at close quarters to sources of this size may well result in individual doses above the thresholds for deterministic effects. It is therefore essential that such exposures are avoided.

Three classes of potential fault sequences are identified:

- Catastrophic damage to plant shielding structures;
- Catastrophic impact damage to transfer or storage cask structures;
- Inadvertent opening of shield doors or entry to fuel handling cells with inventory present.

Plant shield structures are comprised of monolithic concrete shielding. Only extremely energetic events could possibly cause sufficient damage to produce significant shine paths.

The only internal hazards which could lead to such a consequence on dry storage facilities are dropped load events involving casks or other similarly massive equipment items. These will be prevented by the controls identified against loss of containment scenarios in Section 3.3.5.2.

Under the wet storage option, the shielding of radiation from stored fuel is provided by the storage pool water. Other than seismic disturbance beyond the qualification of pool structures, it is conceivable that engineering or human failure could lead to the accidental draining of the pool. However, this water loss would be gradual and would be rapidly detected by pool water level monitors providing adequate grace times for the performance of remedial actions.

The only external hazards which could conceivably give rise to such a consequence are seismic disturbance (which could also be an initiator for dropped load) and aircraft crash. In the case of seismic disturbance, the event is prevented though design of all important structural components, including bulk shielding, to withstand the design basis earthquake without loss of safety functional capability. The degree of qualification required (i.e. the magnitude of the design basis event) will, as always, be proportionate to the potential consequences of failure.

In the case of wet storage, shielding is also provided by the pool water and the pool structure. Catastrophic loss of pool water will again be prevented by designing the pool structure to withstand the design basis seismic event. Should the design of the facility permit the movement of casks or similarly massive objects above the pool, then impact qualification of the pool structure against dropped loads will also be required.

The casks currently employed for storage and transfer of fuel assemblies are of extremely robust construction. Loss of shielding due to impact is, therefore, an extremely unlikely consequence. The only fault sequences which could conceivably produce severe impacts are those involving dropped loads or seismic disturbance. These are again prevented by the controls listed under prevention of loss of containment accidents including, for example, inherent safety features in lifting and transfer systems and qualification of structures. As for potential loss of containment scenarios, consequences will be limited by restriction of lift heights to within the qualification of the casks.

Where shielded cells are employed for fuel handling under any of the storage options, it is possible that access for maintenance may be required on occasion or shield doors may require to be opened for import and export of equipment. Under those circumstances, access and shield doors will be interlocked to prevent their being opened with fuel present in the cell. Given the potentially very high consequences of such events, interlock systems will require to have very high reliability. This is likely to require multiple diverse channels of protection within the interlock systems.

3.3.3 Criticality

Given the very large inventory of discrete masses of fissile material present in the storage facility under any of the design options, it will be essential to control its disposition such that a critical assembly cannot be created accidentally.

In theory, fault sequences ending with the production of a critical assembly could be initiated by:

- Human failures;
- Failures of the fissile material accountancy system;
- Incorrect data for comparison with acceptance criteria;
- Disruption of stored fuel storage arrays.

The first three of these are unlikely to generate a critical assembly since all options require the stored fuel to be in fixed locations either within the pool, dry storage modules, vault wells or casks. The geometry of these will be based on robust and conservative criticality assessments such that it is extremely unlikely that even an error in locating assemblies with particularly high fissile inventories would generate a critical assembly.

Nevertheless, strict accountancy and acceptance conditions will be in place, and systems will be designed to take account of human factors to maximise operator reliability.

In dry storage facilities of any type, the only conceivable cause of a change in geometry of the stored fuel would be a seismic event causing structural damage to the facility. Such an event could also, theoretically, cause a rearrangement of fuel within the storage pool of a wet storage facility. However, as with all other structures important to safety, these structures will be designed to be robust against the design basis earthquake.

The control philosophy for criticality will have the following basis:

- *Primary control through employment of safe geometries:*
  The design of spent fuels handling areas and storage areas will incorporate engineered features to ensure that favourable geometries and spacings will be maintained at all times during handling and storage conditions. It will also take into account accident conditions such as seismic events or toppling of the pool storage racks;

- *Safety margins:*
  Margins of safety will be employed for relevant nuclear criticality parameters (separation distance, mass of fissile material, enrichment etc) that are commensurate with the uncertainties in the data and methods of both fuel characterisation and criticality hazard assessment analyses. These will be carried forward into the acceptance conditions for fuel for storage;

- *Double contingency criteria:*
  At least two unlikely, independent and concurrent or sequential changes must occur in the conditions identified as being essential to nuclear criticality safety before a nuclear criticality accident is possible (DSP 26). Criticality evaluations will specifically consider potential scenarios to ensure that the double contingency criteria would be achieved;

- *Monitoring:*
  Criticality Incident Detection & Alarm Systems (CIDAS) will be provided in areas where spent fuel is handled or temporarily stored prior to interim storage (i.e. buffer storage) where analysis predicts that the potential frequency of accidental criticality incidents is above established criteria.

3.3.4 Loss of Cooling System (Heat Removal)

Since the dry storage options depend on the natural circulation of air for removal of decay heat, this is not a concern for those options.

Under certain accident conditions, it is conceivable that loss of water from a storage pool might occur. It is noted that the water inventory in the pool is such that there will be a significant grace time for topping up water levels. It is anticipated that preventative and mitigating design features including level alarms and leak detection will be provided and that these will be similar to those on the EPR fuel pool whose design takes account of many years of international operating experience. However, sudden catastrophic loss of water from the storage pool could lead to the uncovering and consequent overheating of stored fuel assemblies with significant releases of radioactivity due to cladding failure.

Such an event would require the transfer of very considerable amounts of energy to the pool structure. The only credible initiator for sudden, catastrophic structural failure of the pool structure is a seismic event. There will be no requirement or opportunity to carry loads above the pool of sufficient mass to cause major breaches of the integrity of the pool. Other failure mechanisms such as degradation would be gradual and would inevitably be detected in time to take remedial action. Protection against seismic disturbance will be provided through the design of the pool structures which will be qualified against the design basis seismic event.

3.3.5 Internal Hazards

3.3.5.1 Loss of Power Supply

Potentially loss of electrical power could give rise to several classes of fault sequence resulting in loss of containment of fuel. These include dropped or impacted loads or the shutdown of the pool water active cooling system (wet storage).

However, provision will be made in the design so that, in the event of a loss of the primary source of electric power to instruments, control, service and operating systems, power will be available in sufficient amounts to allow safe storage conditions to be maintained and to permit continued functioning of all systems related to the essential safety functions of the facility. Reliable and timely emergency power will be provided in the design. The nature and operational duration of these back-up supplies will be determined through optimisation procedures implemented in the development of the detailed design.

The design of fuel handling equipment will be such as to ensure that loss of power results in failure to safety and the maintenance of the capability to return loads to a safe state.

In such cases, the main risk would be the shutdown of the pool's active cooling system. However, the very large heat capacity of the pool water would afford a significant grace time for remedial action even in the unlikely event of failure of redundant power supplies.

3.3.5.2 Dropped Loads

Load handling of spent fuel (whether of bare or contained assemblies) inevitably has an associated risk of loads being dropped or impacted. Such events could produce the following radiological consequences:

- Accidental criticality;
- Dispersal of fuel radioactive inventory due to cladding damage;
- External radiation exposure of site workers.

Prevention

Such fault sequences will be prevented by:

- The design of high reliability lifting and handling equipment with intrinsic safety systems to terminate runaway load fault sequences safely;
- The design of equipment and structures to withstand seismic disturbance to a degree proportionate to the potential consequences of their failure;
- The inclusion in the design of mechanical locking systems and physical stops, anti-derailing and anti-lifting devices on cranes, trolleys, etc.;
- The production and implementation of specific operating procedures to limit the lift heights for loads in general and fuel assemblies in the unloading cell in particular.

Fuel handling systems will be designed to ensure adequate safety under normal, off-normal and accident conditions and will be designed to established international standards for nuclear load lifting and transfer equipment. Specifically, in addition to being designed to minimise the likelihood of dropped or runaway loads and impacts, they will be designed to:

- Be able to return the load to a safe and stable state under any foreseeable operational conditions;
- Retrieve dropped fuel assemblies;
- Be replaced or refurbished should their useful operational life be less than the anticipated, very extended facility operational life (see Section 5.6).

Mitigation

All areas where direct handling of fuel assemblies is performed are classified as potentially contaminated and thus designed to limit the radiological impact of handling accidents through dynamic containment.

For those operations involving fuel in storage canisters or storage casks (dry storage), the impact resistance and containment afforded by the containers will also serve to mitigate consequences. Where containers have been qualified against impact events of a specified magnitude, the design will prevent impacts of greater magnitude by design, for example, by the restriction of potential drop heights and impact energies.

Impact qualification of floors potentially impacted by dropped loads will prevent inventories of fuel in compartments below floor level being affected by the accident.

Finally, mitigation will be afforded by multi-layer containment as previously described in Section 3.2.1.

3.3.5.3 Internal Fire

Fires may result in release of activity from fuel either by direct thermal effects or indirectly by damaging equipment and systems whose effective operation is necessary for safety or preventing operators from performing safety-related tasks effectively.

The facility will be designed to:

- Prevent fire ignition;
- Provide fire detection and suppression systems;
- Prevent fire spread;
- Prevent radioactive material spreading in case of fire.

Prevention

The general principle applied for fire prevention will be to restrict, as far as possible, the presence of ignition sources in areas where there are significant fire loadings, and strictly to limit fire loadings in areas with an unavoidably high density of potential ignition sources. This principle will be particularly strictly applied in areas where fuel is handled or stored.

The primary contributor to fire loadings in many areas is likely to be electrical cabling which, itself, will present potential ignition sources. However, it is intended that the design will specify non-combustible electrical cabling.

Mitigation

Items important to safety and safety related items will be protected by systems designed to ensure early detection. For fuel handling cells, it is envisaged that detection heads will be located in extract ventilation ducts. Areas with high fire loadings will be equipped with automatic fire detection and suppression systems – due regard being paid to criticality control considerations.

Fire spread, particularly to areas where fuel inventory may be located, will be prevented by the division of the facility into fire compartments segregated by non-combustible structures.

In order to prevent radioactivity being released from the facility, the design will afford physical protection to the HEPA filtration installations. As part of these arrangements, the ventilation network is to be designed so that even in case of fire, the final stage of filtration retains its capability.

3.3.5.4 Degradation Mechanisms

Prevention

Fuel assembly degradation may be brought about by a coincidence of unfavourable conditions over time. More detailed consideration is given to these mechanisms in Section 5. The primary means of prevention will include the following:

- Original specification of cladding and assembly structural materials;
- Definition of acceptance criteria for fuel transferred to the storage facility;
- Control of cladding temperature by decay heat removal systems (see Section 5.3.1;
- Control of pool water chemistry (wet storage);
- Control of canister or cask cooling air quality (dry storage).

Unless those systems controlling the storage environment were to become unavailable for a very extended period, it is unlikely that multiple pin failures would occur.

Mitigation

Mitigation of the consequences of such events will primarily be achieved by the multi-layered passive and dynamic containment provisions and supporting monitoring arrangements described in Section 3.2.1.

Protection of workers would additionally be provided by space extract ventilation systems in occupied areas and monitoring for airborne contamination.

Discharges to the environment would be restricted by the provision of HEPA filtration prior to discharge.

In the wet storage option, pool clean-up systems would also serve to mitigate consequences.

3.3.5.5 Internal Flooding

The risks associated with flooding due to internal hazards must be considered separately for wet and dry storage options.

Dry Storage

Flooding of the storage facility compartments could be caused by the failure of piping, tanks and other types of leakage or by the operation of the fire suppression system. In theory, loss of containment of fuel could occur through direct action of the water on storage canisters or indirectly through damage to fuel lifting or handling systems and their associated systems causing dropped or impacted loads.

Systems and components of the storage facility with the potential to cause flooding will be designed and located so as not to jeopardise the operation of systems important to safety, thereby preventing the initiation of fault sequences with the potential to cause loss of containment. In vault areas, water piping runs will be located so as to avoid any risks of water ingress to the storage canister locations. In any case, the only mechanism for loss of containment of these sealed containers would be corrosion which would require the undetected presence of moisture over extended periods of time.

Wet Storage

The volume of water present within the facility would be much greater than for dry storage. Two main sources of flood water are present on such facilities:

- The very large water volume retained in the storage pool;
- The cooling water network.

The fault is addressed by the adequate sizing of the storage pool and all liquid containing equipment. The water is contained by a stainless steel lining and surrounding concrete structures. Pool water level alarms will be provided to give early warning of potential overflow.

Leakage of the pool would require the failure of the pool stainless steel liner. This will be subjected to a 100% radiographic examination at the time of manufacture, while possible pool leakage is continuously controlled through a network of drainage pipes incorporated into the pool structural framework. These pipes will then be routed to collecting channels leading to the facility leak monitoring cabinet where any leaks will be detected.

Cooling water and purification pipework systems will run outside the pool itself. Breaches in these systems that could potentially initiate internal flooding will be protected against by double containment of pipes, isolation capability and appropriate bunding.

The main concern is that flooding could disable safety related systems. These will be protected by locating them appropriately to provide segregation of redundant components.

3.3.6 External Hazards

These are natural events or events linked to human activities originating from outside of the facility, but which may have a detrimental effect on the facility’s safety.

External hazards have already been discussed in relation to the initiation of fault sequences that could result in one or more of accidental criticality, loss of fuel containment and external radiation exposure.

The general approach to design for protection against external hazards is described here.

3.3.6.1 Natural Hazards

The most potentially significant of this group of hazards are as follows:

- Seismic events;
- Extreme weather conditions:
  - Wind;
  - Rain;
  - Snow;
  - Temperature;
  - Lightning.
- Flooding (other than due to extreme weather):
  - River flooding;
  - Tidal surges;
  - Tsunami.

These events will not only be considered on an individual basis but, where it is possible, their simultaneous or sequential occurrence will also be taken into account.

To a significant extent, the frequency/magnitude relationship for each of these hazards will be site specific. However, for the purposes of design development, a design basis event will be determined for each hazard type. This will have a conservatively assessed predicted frequency of being exceeded in magnitude of less than 1 E-4 y^{-1}.

Protection against this group of events will be through design of all systems, structures and components whose failure could lead to unacceptable radiological consequences to withstand the challenges defined by the design basis event by an appropriate margin of safety, taking account of any identified potential cliff-edge effects.

Where failure of structures, systems or components could only result in low radiological consequences, a design basis event of lower magnitude (higher frequency) may be defined.

For some hazards, particularly seismic disturbance, a range of sophisticated approaches may be required to determine the hazard load. For these analyses it will be ensured that the methods adopted are appropriate and conservative and their results will be subject to sensitivity analysis.

For flooding from external sources, particular attention will be paid in the design to the potential combination of natural phenomena. For example, in the case of flooding from the sea, extreme wind not only affects wave heights but can also elevate sea levels further through storm surge. Storm surge can be additive or subtractive, and must be combined with the highest and lowest predicted tides and with barometric effects.

It may be reasonable for the operational response to recognise some warning of extreme flooding, provided the necessary response measures can be initiated with sufficient margin.

In addition to external barrier defences such as sea walls, systems important to safety may be protected by their location at horizons within the facility above the maximum predicted flood level for the design basis event.

It is also noted that future climatic changes are likely to have an impact on the frequency/magnitude relationship for some external hazards over the anticipated very long facility operational life. These are likely to include extreme temperatures, wind and flooding. In this respect, the design process will take into account the latest available predictions from reliable sources over the facility projected lifetime including the decommissioning phase. Such potential variations in the frequency/magnitude relationship for external hazards will require to be addressed in the periodic revalidation of the safety case required under Nuclear Site Licence Condition 15.

In the case of hazards, such as lightning, which are not amenable to the definition of a design basis event, protection will be assured by designing to appropriate codes and standards.

3.3.6.2 Man-made Hazards

These are again likely to be site specific in some cases in relation to frequency and magnitude. Some sites may pose specific man-made hazards that others do not.

Such external hazards may include:

- Aircraft impact (all classes of aircraft);
- External explosions;
- Missile generation;
- Hazardous gases (toxic, flammable or corrosive).

Aircraft Impacts

For aircraft impact accidents, the mechanical challenge to structures will depend principally on the mass, rigidity, velocity and engine location of the specific aircraft assumed to impact directly, or skid onto, the structure of the facility, and also the angle of incidence of the impact.

A further thermal challenge to structures systems and components will be posed in some scenarios by an intense aviation fuel fire. This will be more significant for the heavier classes of aircraft because of the quantity of fuel carried.

The total impact frequency for all aircraft classes will be assessed on the basis of an effective "target area" for the facility, taking account of the dimensions of the facility and adjacent buildings and structures, a representative range of angles of impact, and the aircraft impact frequency per unit area for the geographical area of the UK around the site. It may also be appropriate to take account of any ‘no-fly zone’ around the site.

Clearly both the target area and aircraft impact frequency will be highly site-specific due to the location of the nearest airfields, flight paths and military training zones, as well as the disposition of buildings on the site.

Should the total aircraft impact frequency be assessed to be below than 1 E-7 y^{-1}, this external hazard may be excluded from further consideration. However, if the assessed frequency is above this figure but below the design basis frequency threshold (1 E-5y^{-1}) the potential consequences of the combined impact, thermal and explosive challenge to structures, systems and components will be investigated and reasonably practicable means of minimising these by design considered.

It is extremely unlikely that the frequency will exceed the design basis event threshold and therefore, it is likely that the analysis will be restricted to probabilistic safety analysis (PSA) with the assessed risk from aircraft impacts included within the facility risk. It is noted that the possible effects on safety related equipment from a nearby (rather than direct) impact may need consideration.

Other Man-made Hazards

Man-made hazards may arise, for example, from either the conveyance of hazardous materials on adjacent transport routes (pipeline, rail, road and sea) or adjacent permanent facilities, such as quarries. Since the nuclear licensed site also houses the reactor and may house additional nuclear plants, potential hazards arising from these which could affect the fuel storage facility will also be considered and designed against where appropriate.

Typical hazards, which may arise from industrial plants, may be from stored gas, fuel, explosives, pressure vessels or turbine disintegration. All potential sources of external missiles and explosion overpressures will be taken into account. However, the majority of such hazards will be site specific and a comprehensive safety analysis will not be possible until the site is identified.

3.3.6.3 Key Structures and Systems

The most safety significant systems and structures in the storage facility which will require to be qualified against external events are, for wet storage:

- Pool structure;
- Pool water cooling systems;
- Pool Hall building structure;

and, for dry storage:

- Storage vault;
- Storage wells;
- Horizontal storage modules;
- Storage casks.

For all options, fuel lifting and transfer systems and fuel handling cells will also be required to be designed to permit the necessary qualification.

In regard to aircraft impacts, whose low frequency is likely to take them out of the design basis, the effects of mechanical challenge to the above systems will also be considered and minimised where reasonably practicable. However, for dry storage options the consideration of the effects of ingress of burning aviation fuel into storage wells or horizontal storage modules and means of its prevention will also require to be considered.

3.4 SUMMARY ANALYSIS

3.4.1 Introduction

This section provides a high level discussion of the main radiological hazards and risks associated with the operation of a storage facility for spent fuel.

At this concept stage, a lack of engineering design detail and information regarding the demands placed on operators precludes the performance of detailed frequency assessment for PSA and the classification of faults as design basis faults.

However, it is possible to preliminarily identify classes of accidents which are likely to have the greatest harm potential and hence to require inclusion within the design basis and those likely to provide the dominant contributions to the residual risk from the facility.

3.4.2 Bounding Accidents

This section identifies the classes of accident which could potentially deliver the greatest radiological consequences to members of the workforce and members of the public. Where these potential consequences would be unacceptable, in relation to national legal limits on dose, the facility will require to be designed to be robust against the challenge posed by the accident to the extent that the realisation of the consequences is prevented or that they are reduced to acceptable levels. The consequences of interest are those that would be realised in the event of failure of all active safety systems and those passive systems that could be adversely affected by the accident. The accidents with the greatest harm potential will generally be those affecting multiple fuel assemblies.

Because the interim storage facility remains a concept at this stage and design detail is not yet available, it is not currently possible to precisely define the initiating events and fault sequences that might affect the facility.

However, it is clear that severe seismic disturbance could, theoretically, lead to the loss of containment of fuel through impacts from failing structures, disruption of storage arrays and the loss of heat removal capability. This could be accompanied by loss of shielding due to loss of pool water, disruption of bulk concrete shielding or failure of cask shielding and possibly by criticality due to a reconfiguration of the fuel assemblies. Further, such an event could affect all of the areas that will have particularly large inventories of fuel.

Dropped loads may also, in cases such as the dropping of a fuel cask (applicable to all concept options), theoretically have the potential to produce loss of fuel containment and shielding and accidental criticality due to disruption of fuel within the cask and damage to the cask.

Dropping of massive loads onto structures containing significant fuel inventories could also potentially result in loss of fuel containment (through direct impact and disruption of heat removal systems), loss of shielding and criticality.

Dropping of individual fuel assemblies or storage containers containing a number of assemblies could also result in loss of containment of fuel. However, in this case, the only possible accident locations are within containment structures or under water with very significant mitigation being afforded in either case.

In relation to workers, particularly severe consequences could be produced should access to shielded containments occur with fuel inventory present.

3.4.3 Summary of Preliminary Risk Assessment

The bounding accidents discussed in the preceding section all have potentially serious consequences. However, due to this harm potential, these classes of potential accidents will be specifically protected against by the inclusion in the design of defence in depth in terms of passive and active safety measures and proportionate qualification of structures and equipment. These measures will also protect against accidents with less severe potential consequences.

Fault sequence frequencies will be controlled by elimination of potential initiating events or by reducing their frequencies by design and by the provision of high integrity safety systems to terminate fault sequences before the realisation of consequences. Additionally, systems will be provided to mitigate radiological consequences should these preventative systems fail.

The primary means of controlling risks from accidents were discussed in Section 3.3. The control of risks associated with accidents initiated by external hazards is discussed in Section 3.3.6.

The primary means of control of risks from accidents initiated by internal hazards are discussed in Section 3.3.5.

The control of risks from accidents initiated by failures within and/or protected against by engineered systems, will primarily be controlled through the approach to maintenance, refurbishment and replacement as described in Section 5.6, which takes due account of the anticipated, very long operational life of the facility. This will be complemented by fuel inspection regimes as described in Section 6 and, of particular importance in relation to the final phase of operation of the facility, the preparation strategy for the final export operations described in Section 7.5.

The risks associated with accidents initiated by human failures will be controlled through design by ensuring all safety-related systems are robust against operator error during operation or maintenance, through adherence to appropriate modern standards of good practice for ergonomics, and through design of tasks and procedures to optimise human reliability. The dependence on operator intervention to maintain or reinstate safe conditions will be minimised. Over the long term, a workforce adequate in terms of number, quality and experience will be maintained at all times.

3.4.4 Facility Lifetime Risk Profile

The facility risk can be expected to vary over the operational lifetime of the plant as the nature and intensity of operations and the facility inventory varies.

Three main operational phases are anticipated:

- Fuel Receipt;
- Fuel Storage;

- Fuel Export.

During the receipt phase, there will be a relatively high frequency of fuel handling operations for the receipt and emplacement of fuel in storage. The stored inventory will rise from zero to full capacity. Some operations to retrieve fuel for inspection may be required.

During the storage phase, there will be a relatively very low frequency of fuel handling operations other than any retrieval operations for inspection of fuel. The store will be filled to capacity.

During the export phase, there will again be a high frequency of fuel handling operations for retrieval for export and, if required, some retrieval operations for inspection of fuel. Over this phase the stored inventory will gradually reduce from full capacity to zero.

The risk associated with stored waste will be approximately proportional to the inventory stored. Due to the low level of active operations, much of the risk will be associated with accidents initiated by external hazards or failures of systems required to maintain a safe storage environment. Provided degradation of the fuel and essential systems such as heat removal systems is prevented, the risk per unit inventory stored should remain approximately constant throughout the plant’s operational life. Thus the risk associated with stored fuel will be expected to rise gradually over the receipt phase, remain constant over the storage phase and diminish gradually during the export phase.

The risk associated with fuel handling will be a function of the frequency of fuel handling operations (i.e. for receipt, ex-situ inspection or final export). Since retrieval operations essentially require the reverse procedure to emplacement operations the risks per operation should be similar. The risk associated with fuel handling should, therefore remain roughly constant during the receipt phase, reduce to very low levels during the storage phase, when the only contribution will be from retrieval for inspection and possible remediation, and then remain constant again during the export phase given a reasonably uniform export rate. The absolute value of fuel handling risk for the export phase will depend on the rate of export achieved, which in turn will depend on the handling capacity of the facilities for further treatment or final disposal.

The overall facility risk can therefore be expected to rise gradually during the receipt phase, remain constant over the storage phase and gradually diminish over the export phase.

It is emphasised that if permitted to, the effects of degradation of the fuel itself, of the handling equipment, of structures and other safety-related equipment would cause a gradual, underlying rise in both storage and fuel handling risks. However, this will be effectively prevented by the implementation of the strategies for maintenance, refurbishment and replacement, inspection of fuel, equipment and structures and the preparation for commencement of the export phase.

4. MINIMISATION OF ACTIVE SAFETY MANAGEMENT OVER THE LIFESPAN OF THE FACILITY

4.1 INTRODUCTION

This section describes how the dependence on active safety systems during longer term storage is minimised.

4.1.1 Key DSPs

Of the DSPs defined in Section 2.4.3 the most relevant to the restriction of dependence on active safety measures are DSPs 1 and 2:

1. *‘Spent Fuel should be stored such that the need for active safety systems to ensure safety is minimised’.*

2. *‘The primary means of confining all radioactive inventories within the facility should be passive sealed containment systems’.*

A number of other DSPs also have relevance to the achievement of safety by predominantly passive means. These DSPs are:

3. *Containment by multiple barriers;*

4. *Passive shielding;*

5. *Prevention of mixing with other materials;*

6. *Container stability over time;*

9. *Minimisation of monitoring to ensure safety;*

22. *Definition of acceptance criteria;*

26. *Double contingency approach to criticality control;*

27. *Minimisation of secondary waste.*

4.1.2 Definition of Passive Systems

A passive system may be defined as having the following characteristics:

- Requires no services or input signal of any kind (electrical, pneumatic, fuel etc.) to fulfil its defined safety function;

- Is not required to provide any kind of output (e.g. Electrical signal, changing magnetic field, mechanical movement, light or sound);

- Does not require any operator involvement to fulfil its safety function.

These requirements effectively define all forms of monitoring as ‘active’. The third requirement conforms to the fundamental principle that reliance on operator intervention to ensure safety should be minimised. This leads to the need to optimise the design in relation to the need for operator intervention to either maintain or reinstate safe conditions on the plant i.e. to minimise their involvement in the delivery of primary, normal operations SFRs or secondary, accident conditions SFRs.

It is noted that in some aspects of nuclear plant design, active systems such as ventilation are afforded as part of the means of maintaining safe conditions but that their failure need not necessarily immediately produce unsafe conditions since the design may still be capable of delivering the safety function passively. In such cases, the primary defence is the design characteristic which delivers the SFR passively and the active system is a secondary contributor to the defence in depth arrangements. Similarly, in some cases, the active systems required complement a passive system in delivering the SFR to the performance level specified in the design. Following failure of the active system, the passive system continues to deliver the safety function but possibly with diminished performance. This diminished performance may or may not be sufficient to maintain safe conditions.

4.1.3 Design Approach

Under the design approach that will be adopted, the main routes to minimisation of dependence on active safety management are:

- Adoption of a primarily deterministic approach to the achievement of safety;
- Reliance on passive means and natural processes to deliver primary safety functions;
- Optimisation of the design with respect to operator involvement for the maintenance or reinstatement of safe conditions;
- Optimising the required frequency of periodical inspections and maintenance through robust design, definition of acceptance criteria, provision of adequate pre-storage characterisation facilities;
- Optimisation of the requirement for management of secondary wastes.

4.1.4 Monitoring

DSPs 8 and 9 present an apparent paradox. DSP 8 demands the provision of monitoring while DSP 9 appears to require the minimisation of monitoring. However, it is clear from earlier discussion that monitoring is a secondary defence and does not directly ensure safety by the preservation of normal operating conditions. Rather, monitoring represents good practice and constitutes part of the defence in depth arrangements. The essence of DSP 9 is that monitoring should not be a primary means of control. That is, it should not be essential to monitor operational parameters as a first line defence against the creation of accident conditions.

4.2 PRINCIPAL MEANS OF ENSURING SAFETY

4.2.1 Containment of Radioactive Material

4.2.1.1 Dry Storage

Under this option reliance is placed on primary and secondary passive containments to maintain safe conditions during storage. Primary containment of the fuel inventory is afforded in all cases by the fuel cladding. In the case of vault storage and horizontal module storage, secondary, passive containment is provided by the sealed metal storage canister. In the case of storage casks, the secondary passive containment is provided by the cask itself.

It is noted that the fuel cladding represents the first containment barrier for radioactivity in the fuel. It does not present a barrier to crud contamination on the outer surfaces of the cladding. In the case of vault storage, additional static containment is afforded by the storage well. For horizontal and cask storage options additional containment is afforded by the storage building structure. Thus two levels of containment are also always available for these contamination inventories.

In all cases, the primary SFR is delivered by passive means with a degree of redundancy.

4.2.1.2 Wet Storage

In the case of wet storage, the primary containment will be afforded passively by the fuel cladding for intact assemblies and by protective bottles such as those currently used in existing pool storage facilities, for those known to contain some pin cladding failures. A degree of secondary containment will also be afforded passively by the pool water.

Containment would be afforded by the pool hall structure should either the first barrier be ineffective or during handling operations requiring the fuel to be removed from the water. This containment would be dynamic i.e. dependent on air extraction to maintain depression. The ventilation design will be optimised during the design development process.

4.2.2 Protection against External Radiation

4.2.2.1 Dry Storage

The primary protection against penetrating radiations (gamma and neutron) will be afforded by bulk shielding. For storage in canisters, the primary shielding will be provided by the concrete structures of the vault or horizontal storage modules. For cask storage, the primary protection will be afforded by the cask’s integral shielding.

Thus, safety during storage is assured, under normal operating conditions, by passive means.

In all cases, for those operations requiring fuel handling outwith shielded containment, shielding will be afforded by the cask structure against both neutron and gamma radiations.

For fuel handling cells, the primary protection is again afforded by passive shielding in all cases. However, where entry to cells is required for maintenance, primary protection will be afforded by interlocks which will necessarily be active systems. However, these will be designed to fail to a safe condition wherein the protection reverts to that provided by the bulk shielding.

4.2.2.2 Wet Storage

The primary shielding of stored fuel is provided by the pool water which is effective against neutrons as well as gamma rays. Shielding is also provided by the concrete pool structure surrounding the pool liner. Both systems are fully passive.

Fuel handling facilities and operations will be similar to those for dry storage and shielding will again be provided passively and the comments on interlocked access control also apply for this storage option.

4.2.3 Decay Heat Removal

The SFR for efficient removal of decay heat from the fuel is essentially to ensure that the primary containment afforded by the cladding is not undermined.

Cladding failure temperature thresholds occur at many hundreds of degrees Celsius. Heat removal is necessary to maintain cladding temperatures below those at which failure mechanisms might be expected to occur by a significant margin of safety. It is also required to minimise chronic degradation of fuel cladding.

4.2.3.1 Dry Storage

Under the dry storage options, removal of heat would be by passive natural convection. Heat removal efficiency may also be enhanced by the inclusion in the design of passive heat removal features of the design of the storage canisters, storage wells and/or storage casks (resin filled fins). The design will also enhance passive heat removal through the choice of containment materials on the basis of their thermal conductivity and the heat transfer properties of gases used to pad canisters and casks.

In some cases, forced ventilation will form part of the design. However, this would normally be to supplement naturally generated air flows and the design should ensure that the heat removal SFR could be achieved by passive means only.

In all cases, even should the primary heat removal mechanism fail, an extended period of time would be required for fuel cladding to reach temperatures at which failure mechanisms are likely to occur. This grace time will be sufficient to permit operator intervention to restore heat removal through active safety management procedures.

4.2.3.2 Wet Storage

Under this option, the primary means of heat removal from the fuel is passive conduction through the cladding and convection via the pool water, whose massive volume provides a very large heat capacity. While fully immersed in water, it is extremely unlikely that even localised areas of cladding would ever reach failure mechanism temperature thresholds.

However, for such facilities, heat transfer from the water will generally be performed by an active cooling system involving movement of water by pumps. Failure of this active system, which will include levels of redundancy, would lead to a progressive increase in pool water temperature and, theoretically, eventual evaporation of sufficient water to uncover the fuel.

However, due to the enormous volume of water present above the fuel assemblies (typically 4 metres deep), this process would take such a long time that operator intervention to implement active safety management strategies such as replacing lost pool water, and re-establishing pool water cooling is certain.

It is also noted that some heat removal will be obtained adventitiously by the extraction of the pool hall atmosphere and through conduction through the pool structure.

4.2.4 Control of Environmental Discharges

The primary means of preventing discharges to the atmosphere are passive since they are the containment barriers discussed in Section 3.2.1.

Aerial discharges are anticipated to be very small under normal operating conditions for both dry and wet storage options. These will be abated through the provision of HEPA filtration upstream of the discharge point. Although HEPA filters deliver their safety function in a passive fashion, it is necessary for the potentially contaminated air to be drawn or driven through the filter installations by ventilation. However, as discussed in Section 4.2.1.2, the ventilation flows may be driven by passive processes and forced extraction will not necessarily form part of the design.

For wet storage, liquid effluent discharges will be abated to some degree by passive filtration. However, chemical treatment such as ion exchange will also be necessary. While this is essentially a passive process, it is acknowledged that significant operator involvement will be required in the pre-discharge treatment process.

Nevertheless, it must be noted that the consequences of failure of the abatement arrangements described above would not result in public exposures of the order possible should failure to deliver the containment or heat removal SFRs discussed above occur.

4.2.5 Control of Criticality Hazards

Safe, normal operating conditions in relation to criticality hazards will be primarily maintained through maintenance of safe geometries by design of storage facilities to afford adequate separation of fissile inventories. Given compliance with the conditions assumed in the criticality hazard assessment and with the conditions of acceptance relating to inventory of fissile species and enrichment, this is a passive means of control.

Mitigation of events involving failure to deliver this SFR, would be provided by passive shielding in the first instance but reliance would also be placed on active monitoring and alarm systems to stimulate evacuation.

Should any accidental criticality event release significant quantities of fission products and actinide activity, protection would again be afforded by the passive containment systems discussed earlier.

4.2.6 Internal Hazards

Internal hazards which could remove the safety functional capability of safety important systems include dropped and impacted loads and fires.

These could directly affect fuel integrity in some cases or render unavailable systems (including engineered or operational systems) necessary for the maintenance or reinstatement of safe conditions.

4.2.6.1 Fire Hazard

In relation to fire, as discussed earlier, the primary protection is preventative i.e. the control through design of fire loadings and ignition sources. However, the approach to protecting fuel inventory from direct thermal challenge will employ the passive means of dividing the plant into fire compartments by means of non-combustible barriers. This same approach will be employed for the protection of systems required for the maintenance of other aspects of plant safety. This design approach depends entirely on passive means of protection.

4.2.6.2 Load Impact Hazards

In relation to dropped and impacted loads, these could, in the worst case, lead to direct impact on the primary storage locations for fuel i.e. vault wells and horizontal storage modules for dry storage options and the fuel storage pool for wet storage, leading to consequences of a similar nature to those of seismic disturbances.

Whilst it is unlikely to be practicable to render lifting and transfer systems safe by completely passive means, an important contribution to safety will be made by passive systems such as:

- Qualification of lifting equipment against internal and external hazards;
- Qualifications of potentially impacted structures (floors);
- Physical stops on travel;
- Passive load attachment systems;
- Provision of multiple load paths;
- Engineered restraints on lift heights;
- Physical constraint of load travel paths.

Other important systems, while not purely passive, will rely on fail-safe technology such as emergency brakes and ‘dead mans handles’.

However, given a failure to prevent uncontrolled load descent or lateral travel, protection will again, where appropriate, be afforded through qualification of potentially impacted structures and systems such as dry storage arrays and the fuel pool.

4.2.7 External Hazards

4.2.7.1 Natural Hazards

Seismic events and, to a lesser extent, other potentially disruptive natural phenomena, potentially represent the greatest challenge to the integrity of the stored fuel inventory. Catastrophic structural failures would have the potential, under all options, to remove the containment barriers afforded for the fuel inventory while simultaneously causing severe damage to the fuel itself.

Additionally, such events could potentially remove the heat removal capability afforded by the design.

In the dry storage options, this would occur by disruption of the routes for convective airflow and damage to storage wells or horizontal dry storage modules, storage canisters and casks and their engineered features for promoting heat removal.

In the wet storage option, breach of the storage pool would remove the primary heat removal agent and potentially cause the fuel to become uncovered. Even should the pool retain integrity, the active heat removal systems may be disabled.

In both wet and dry storage cases, loss of heat removal capability would likely be accompanied by mechanical impact damage to fuel integrity and rearrangement of the fuel storage geometry such that criticality protection might be undermined. Again, in both cases, the scenarios may be exacerbated by the loss of integrity of the containment buildings and HEPA filtration installations which form the final barrier against release to the environment.

For both options, sufficiently severe events could also diminish the effectiveness of bulk shielding leading to extremely high external radiation hazards within the facility and beyond.

Because of the very considerable harm potential of these scenarios, they will be addressed by the design such that the plant is deterministically safe by significant margins.

All structures, systems and components whose failure could cause or prevent the termination or mitigation of such fault sequences will be designed to withstand the challenge of the relevant design basis events and retain their safety functionality in a purely passive manner through their inherent robustness to mechanical challenge.

4.2.7.2 Man-Made Hazards

The approach to protection against man-made external hazards mirrors that for natural events in that design basis events will be defined and structures, systems and components qualified against the challenge posed by such events or protected by structures which are themselves qualified. That is, the design process will adopt a deterministic approach relying primarily on passive protection.

4.3 OPTIMISATION OF INSPECTION AND MAINTENANCE REGIMES

4.3.1 Introduction

Inspection and maintenance are, by their nature, active safety management systems.

The design approach will be to avoid complexity in handling, storage, inspection and monitoring processes so that very little need for intrusive surveillance and maintenance is required.

Reducing the need for periodical inspections and maintenance (preventive and/or curative) will mainly be achieved by:

- Setting of acceptance criteria for items for storage (in terms of cladding integrity, cooling time, and restriction of corrosion product contamination of fuel surfaces);
- Pre-storage characterisation of items for storage to confirm compliance with acceptance criteria;
- Selection of appropriate process options;

- Avoidance of novel, untried processes and equipment;
- Appropriate equipment design (simple, reliable and robust);
- The anticipation of ageing mechanisms, and their prevention through coolant chemistry control and condition and effective heat removal.

Each of the above will call heavily on the considerable body of international experience accumulated for similar facilities. Over the extended storage period, each of the above will be reviewed in the light of operational experience accumulated on the facility and internationally to ensure that the best available technology available at the time is employed and that any alternative options that are reasonably practicable are adopted. The periodicity of inspections will also be kept under review to ensure that it remains appropriate over the longer term.

4.3.2 Process & Equipment Selection

Irrespective of whether active or passive processes are adopted, the choice of a specific process option can assist in restricting the need for safety related surveillance and maintenance. In relation to selection of equipment, simple, reliable and robust systems of established provenance and compliant with international standards of good engineering practice will be selected. In this way, the operational life of systems,, and hence the requirement for intervention for maintenance and replacement, will be optimised.

4.3.3 Ageing Phenomena

The understanding and anticipation of ageing phenomena (see Section 5.1) potentially affecting both stored inventory and safety related equipment will permit the optimisation of procedures, personnel training and monitoring and inspection regimes in relation to the prevention or control of degradation mechanisms with a potentially detrimental affect on safety.

4.4 OPTIMISATION OF WASTE MANAGEMENT REQUIREMENTS

Restricting the need for management of secondary wastes will have a direct, positive impact on the restriction of the need for active safety management, since less processing and surveillance will be required.

In the case of underwater storage this can be achieved by the use of closed circuit, recirculatory systems for pool water and pool cooling water to limit the volume of effluent arisings.

Dry storage facilities do not produce significant amounts of process wastes under normal operating conditions. However, the provision of recirculatory coolant systems would restrict the volume of aerial discharges.

It is noted that any secondary wastes will have much lower activity concentration than the stored fuel. The restricted harm potential of fault sequences involving such materials means that the restriction of active safety management requirements, while still desirable, is of less importance to the safety of the facility as a whole than is the case for the management of the stored fuel inventory.

4.5 OPTIMISATION OF MANNING REQUIREMENTS

The optimisation of the requirement for active safety management will reduce the number of operational staff required, reducing the collective dose accrued and limiting reliance on operator intervention to ensure safety.

Furthermore, only a very gradual variation in parameters related to safety such as concrete temperatures and corrosion mechanisms is anticipated. This is supported by the accumulated international experience of operating similar facilities. This again indicates that the need for operational surveillance will not be burdensome under normal operating conditions.

Under abnormal conditions, as discussed in Section 4.2.3.2, the heat capacity of storage pools and dry storage structures will ensure a grace time of many hours after loss of heat removal capability before conditions requiring operator intervention to ensure safety are established.

It is likely, for all storage options, that the management of all active systems will be centralised in a control room, thereby limiting the number of staff required to carry out operations on the facility. In addition, the number of staff required for monitoring operations on the facility (maintenance staff, auxiliary operators, etc) will be kept as low as reasonably practicable while still fulfilling safety requirements.

Overall, the spent fuel storage facility will have very limited dependency on active safety management systems involving operator action to ensure safety.

5. MAINTENANCE OF INTEGRITY DURING STORAGE

5.1 INTRODUCTION

This section describes those characteristics of the fuel and equipment whose integrity must be maintained over the storage period, addresses their evolution over that period and details the provisions that will be made for fuel or equipment that fails to meet the required characteristics.

Key DSPs to be addressed by the design are:

DSP 6:	*Compatibility of stored fuel and containers with long-term management;*
DSP 10:	*Monitoring, recording and alarms to report deviations from normal conditions;*
DSP 11:	*Accounting for age-related degradation in the design;*
DSP 12:	*Definition of safe working life in relation to intended operating life;*
DSP 13:	*Avoidance of degradation to permit long-term management;*
DSP 16:	*Provisions for fuel showing unacceptable degradation.*

The design will take into account the potential occurrence of age-related degradation mechanisms which may affect the integrity of the cladding forming the primary containment of the fuel or any other containment barrier, structure or system whose integrity will be important to maintaining the fuel integrity, under normal and abnormal conditions, over the extended storage period. Safety must be guaranteed during passive storage and any fuel handling operations required for retrieval for inspection or final disposal.

Considerable experience has been accumulated internationally, which will permit confident prediction of materials behaviour over time and which can therefore be fed into the development of characterisation, storage, inspection and monitoring regimes.

Of primary concern is the maintenance of an effective primary containment barrier to retain radioactivity during normal operations and to contribute to the containment of activity under accident conditions.

Failure to maintain this integrity may result in the release of gaseous radioactive species such as H-3, and the longer-lived nuclides of xenon and krypton, solid fission products such as nuclides of ruthenium, iodine and strontium or even fuel particulate generated through contact of the UO_2 fuel matrix with air or water.

Safe retrieval during and after the storage period will depend not only on the cladding integrity but also on the structural integrity of the fuel assembly as a whole and the condition of the handling equipment employed.

5.2 POTENTIAL FUEL DAMAGE MECHANISMS

The condition of the fuel cladding and much of its behaviour during transfer and storage will be determined by its irradiation history within the reactor. Some of these factors are listed below:

- Thermal exchanges with the primary coolant;
- Thermal expansion between pellets and cladding;

- Fission gas release and helium gas production from alpha decay;
- Cladding creep due the pressure difference between primary coolant and cladding internal pressure. The original internal pressure will be determined during manufacture but will alter over time due to the gas production mechanisms identified above;
- Mechanical stress between pellets and cladding due to the repetitive irradiation cycles;
- Corrosion product activity (crud) from primary coolant depositing on fuel cladding surfaces.

From experience, it is considered that the most important causes of cladding failure during fuel packaging and storage processes are:

- Cladding creep due to pin pressurisation and elevated temperature from residual decay heat';
- Clad Failure by fretting;
- Delayed hydride cracking;
- Corrosion:
    - U_3O_8 formation in defective pins causing fuel pellet swelling which together with cladding creep can result in cladding breach. This is particularly true of high burn- up fuels;
    - Exposure of cladding to corrosive fission product species such as nuclides of iodine. The corrosion risk is enhanced by high temperatures;
    - Uniform oxidation of the cladding due to direct contact with high temperature coolant in the reactor. The material properties of the M5 cladding employed in the EPR design render it less susceptible to this potential problem.

The spent fuel temperature and internal pressure are important factors in determining cladding degradation over time. For transfer, receipt and storage operations, the temperatures anticipated are a function of the following:

- Fuel type;
- Fuel irradiation history (burn-up);
- Cooling time in the reactor storage pool.

Therefore, the definition of appropriate acceptance criteria, in respect of pre-storage cooling time, will help control the cladding degradation potential

In relation to the structural strength of the fuel, international operating experience has revealed that the fuel assembly skeleton, as well as the fuel itself, can become embrittled during reactor operation due to chemical effects on its Zircaloy 4 components i.e. guide tubes and grids in addition to the cladding itself. This is clearly of importance for fuel handling operations during receipt, emplacement and retrieval but also for the extended storage period.

5.3 FUEL INTEGRITY DURING STORAGE

The frequency of cladding failures increases when the fuel and its cladding are subjected to high temperatures and when the chemistry of the medium surrounding the fuel is such as to promote cladding corrosion.

The primary consideration in maintaining fuel integrity in the long term is the maintenance of a storage environment conducive to the preservation of fuel containment through the provision of effective heat removal and conditioning of the storage medium.

5.3.1 Wet Interim Storage

Wet interim storage (see Reference [2]) has been employed over many years as buffer storage for reprocessing plant and for long-term interim storage.

As discussed earlier, water is the cooling medium in wet storage and has the additional role of providing bulk shielding.

In such facilities, spent fuel integrity is maintained over the long term by:

- Maintaining pool water temperatures at levels which promote spent fuel heat dissipation and prevent, or at least reduce the rate of degradation mechanisms;
- Maintaining the water chemistry characteristics to prevent or reduce cladding degradation mechanisms through control of phenomena such as:
    h. H_2 ‘pick-up’;
    i. H_2 redistribution;
    j. Water induced corrosion;
    k. Mechanical load.

The key systems in the design of wet storage facilities in relation to maintenance of fuel integrity are then:

- Storage pool water cooling system;
- Storage pool water purification system.

In relation to heat removal, temperature limits will be set for systems which could either be the subject of temperature enhanced degradation mechanisms or which play a role in the heat removal process.

These will include:

- The fuel cladding itself;
- The pool water;
- The pool structure.

These will be based on knowledge accumulated regarding the properties and behaviour of relevant materials garnered from international experience. These limits will then determine the heat removal capacity required of the pool water-cooling system and will be fed into its design.

These limits, since they have safety significance, will be periodically reviewed and revised as necessary based on operational experience and inspection and monitoring feedback, particularly that relating to cladding condition. This will be necessary for the periodic safety reviews required under the Nuclear Site Licence to ensure the continuing validity of the safety case.

As mentioned above, the assemblies are stored at low temperature (typically below 45°C), which limits or even prevents the occurrence of temperature dependent phenomena. As such, no changes in the spent fuel pins’ characteristics are expected over the interim storage period, since the chemistry of the pool water will be carefully managed and optimum operating conditions maintained. This has been confirmed by over 30 years of international operating experience.

In addition, for defective spent fuel, the formation of a swelling oxide such as U_3O_8 is very unlikely to occur over the storage lifetime of 100 years. As such, the tearing of the cladding and subsequent release of solid radioactive material is not likely to occur.

Embrittlement of the Zy4 skeleton may occur due to irradiation and oxidation-hydruration of the materials. However, it has been shown that the corrosion of the zirconium alloys in water at low temperature is minor. Operating experience has provided evidence that galvanic corrosion can be discounted.

In addition, mechanical tests have been carried out on Zy4 skeleton components from highly irradiated assemblies. The results of these studies have indicated that safe handling of the assemblies will be possible under normal operating conditions at the end of the interim storage period. However, embrittlement of the Zy4 skeleton may reduce the assemblies' impact resistance under accident conditions. The handling procedures will take this into account.

The risks from handling accidents are minimised as the assemblies are placed in storage racks in the conditioning cell. The use of the racks minimises the number of handling activities required and protects the assemblies from potential impacts that may damage them during handling activities between the conditioning cell and the storage pool.

5.3.2 Dry Interim Storage

There is less accumulated international experience of dry storage facilities. The options described here (and in more detail in References [1] and [2]) are based on existing designs. However, the options considered for the EPR storage facility will not necessarily be restricted to these options should additional options become available (provided the fundamental technologies employed by these options are proven).

The three potential options considered here are as follows:

- Dry storage in a metallic cask;
- Dry shielded canisters in horizontal storage modules;
- Dry storage in a vault.

For dry storage, the most important risk of rod cladding failure is presented by rupture through creep mechanisms. Creep speed is influenced by both temperature and internal pressure levels. As with wet storage, the maximum acceptable temperature depends on fuel type and initial cooling history.

Under dry storage conditions, spent fuel integrity is maintained by:

- Maintaining spent fuel cooling through a passive ventilation system;
- Providing an inert atmosphere (with good heat transfer properties) in the spent fuel storage containers;
- Providing heat removal enhancement features in the design of storage containers and/or storage locations.

The detailed design of these features will be based on conservative assessments of decay heat power and heat removal efficiency. The values of key parameters assumed in these analyses will be employed in the setting of acceptance criteria for interim storage and in determining pre-storage fuel characterisation regimes.

It is noted that characterisation of the fuel intended for storage will be essential to obtain base-line data against which the results of inspection and monitoring can be compared over time to aid early detection of degradation.

5.3.2.1 Dry Storage in Specialised Casks

Experience to date has shown that spent fuel assemblies can be safely stored in metal casks of existing design which can also be used for fuel transfer. Both containment and heat removal can be adequately performed by the cask itself. Key features of the cask design are listed below:

- The cask cavity is backfilled with helium (a gas with a high heat conduction coefficient (10 times that of nitrogen)) - under atmospheric pressure during the loading procedure at the reactor site. The fuel rod cladding temperature will thus always be kept below the maximum allowed temperature in both transport and storage configurations;
- The cask is provided with an aluminium storage basket to house and separate fuel assemblies during transport and storage. The basket structure, with its aluminium and steel plates, affords conduction pathways to the inner surface of the cask cavity;
- Aluminium heat exchangers are pinned on the outer surface of the secondary containment shell to conduct decay heat to the outer surface of the cask (additional ones can be provided to account for higher heat dissipation requirements);
- The inter-lid space is pressurised with helium (and continuously monitored), which ensures that no gas can flow from the inner cavity to the atmosphere.

5.3.2.2 Horizontal Modular Dry Storage

Systems of this type have been in use for 20 years. Such systems provide passive heat removal independent of any other facility structures or components.

This technology involves:

- A sealed Dry Shielded Canister (DSC) confining the fuel assemblies in a helium atmosphere;
- A Horizontal Storage Module (HSM) fabricated from concrete.

Radioactive material containment is provided by the fuel cladding as the primary containment barrier and the DSC as the secondary containment barrier.

The HSMs are monolithic concrete structures and provide radiation shielding (but not containment) and physical protection for the stored fuel. The massive structure of the modules facilitates their qualification against even severe natural external hazards. The HSM has internal air flow passages to permit natural convection cooling for removal of decay heat from the fuel.

5.3.2.3 Dry Storage Vault

The storage of spent fuel in a dry vault involves the sealing of spent fuel in canisters and the placement of those canisters in sealed storage wells set into a reinforced concrete slab. The sealed canisters and the closed wells constitute the two containment barriers preventing fuel degradation and radioactive material release to the environment.

The facility is designed to maintain spent fuel integrity by maintaining storage temperatures within the prescribed limits under all expected combinations of radioactive decay heating and ambient temperature. During storage and transport, spent fuel cooling is achieved entirely by passive conductive and convective processes, aided by design features such as:

- Heat conducting design of canister (cupro-aluminium partitions with honeycombed structure ensure the heat dissipation to the shell of the fuel assemblies canister);
- Selection of a gas with good heat transfer properties for backfilling canisters;
- Vault design with air channels to provide natural convection in all conditions.

5.4 DEGRADATION OF OTHER CONTAINMENT STRUCTURES

5.4.1 Introduction

The design of all structures intended to provide containment under normal operating and accident conditions must take into account their intended operational life and potential degradation mechanisms that could limit their effectiveness over time.

The primary structures of concern will be fabricated from stainless steel and/or concrete.

5.4.2 Stainless Steel Containment Structures

The primary degradation mechanism of concern for steel structures is corrosion which could potentially lead to loss of integrity or reduction in impact resistance.

Stainless steel has excellent resistance to corrosion, mechanical impact and thermal effects, provided that it is not submitted to excessive loads or forces. In dry storage facilities its use is anticipated for the fabrication of the following containments:

- Inner and outer shells of the Dual Purpose Casks;
- DSCs for storage in the horizontal storage module;
- Leak-tight storage canisters and storage wells in the vault storage facility;
- Unloading cell liners.

and, under the wet storage option, for:

- Storage pool liner material;
- Unloading cell liners;
- Storage racks;
- Storage baskets;
- Bottles for storage of defective fuel.

Stainless steel is also used for containment gasket material, in preference to elastomeric materials, which exhibit less resistance to degradation due to high temperatures and radiation levels. This is the case in existing dual-purpose casks where both containment barriers (inner and outer shells) employ lids equipped with steel gaskets.

Stainless steel also possesses excellent impact resistance. This is essential for all containers in which fuel is transferred or stored to mitigate impact accidents due to dropping the container itself or dropping massive items onto the container. These containers will be designed and qualified to withstand a range of impacts without releasing any radioactive material. The limitations on this qualification will be fed into the plant design or, alternatively, the container may be designed to meet the most potentially severe mechanical challenge posed by the design of the facilities.

The need to retard or prevent degradation mechanisms in stainless steel systems used for containment during the storage phase will also be taken into account in determining the design objectives for coolant clean-up and heat removal systems for the storage facilities.

Steel liners for concrete structure such as the storage pool liner and liners for shielded cells will be amenable to remote visual inspection techniques and potentially more sophisticated techniques to monitor for evidence of corrosion mechanisms. In the case of the pool liner, which is of greater safety significance, systems will be in place to continually monitor for leakage of cooling water from the pool that would be indicative of penetrative failure.

Direct inspection of storage containers employed for dry storage would be less straightforward given that they are, in all options, surrounded by additional containment or shielding structures. For any rigorous direct inspection, these containers would require to be retrieved to shielded inspection facilities. Should such ex-situ inspection be required, its periodicity would require to be optimised employing ‘balance of risk’ decision-making processes such as those described in Section 6.3.1.

However, indirect monitoring of their integrity will be carried out by sampling the atmosphere between the storage containers and the next containment barrier for helium gas which would escape from the containers should their containment integrity degrade. In the case of storage in horizontal storage modules, the cooling air flow would require to be sampled given that the there is no additional barrier between the DSC and the cooling medium.

For vault storage it would be the storage well atmosphere that would be sampled. Mobile units have been employed elsewhere to permit in-situ sampling of well atmosphere. Additional monitoring of the integrity of the well itself would be carried out.

For cask storage, the atmosphere between the secondary containment shell and the cask's body would be sampled.

The frequency of such inspections would require to be optimised taking account of the risks associated with the inspection procedure and the risk associated with continued storage without inspection.

The systems listed above are of varying importance to safety. They will all be subjected to inspection and examination throughout the storage period. The periodicity of inspections will be determined primarily by their safety significance, but will also require to be optimised in relation to the risks associated with inspection procedures and other disbenefits of inspection (particularly for systems which are difficult to access or require their retrieval for ex-situ inspection).

Where their performance impacts on the continuing validity of the safety case, they will be among those safety structures, systems, and components addressed under the periodic safety reviews required by Nuclear Site Licence Condition 15.

5.4.3 Concrete Structures

Concrete structures contribute to containment and shielding of fuels under normal operating conditions for all of the storage options. The ability to fulfil these functions must be retained throughout the facility lifetime. In addition, as previously discussed, it is essential that they maintain their safety functional capability under mechanical challenge from major external and internal hazards and that this withstand capability is not diminished over the facility life-cycle by any age-related degradation mechanisms.

It is noted that in terms of safety function, the greatest concern will be those structures supporting safety related equipment such as fuel handling machinery and requiring to deliver seismic and impact withstand capability. Short of total collapse, degradation mechanisms are unlikely to significantly diminish the attenuating effect of concrete structures intended to provide radiation shielding or the effectiveness of concrete partitions defining fire compartments.

Considerable research material and experience is available to the designers in relation to the long-term behaviour of concrete used in civil structures in nuclear plants posing similar challenges to those anticipated for the proposed facility.

The major causes of ageing / degradation in concrete civil structures are known to be:

- Chemical reaction between concrete and certain substances such as chlorides and carbonates;
- Corrosion of steel reinforcement armatures;
- Excessive thermal loading;
- Irradiation by nuclear radiations;
- Weather conditions and ground movements.

In order to limit concrete degradation phenomena over time, the following will be specifically addressed at design:

- All outside concrete walls will be protected with painted coating;
- Steel armatures will be reinforced and their casings over-dimensioned;
- The concrete formulation will be selected to minimise porosity;
- Ventilation systems will be designed to limit the temperature of concrete structures (both in normal and accidental situations);
- The concrete structures performing a shielding function will be tested during inactive commissioning to reveal cavities.

Additionally, to ensure good long term performance, it will be necessary to avoid concrete cracking during the construction stage through the optimisation of concrete pouring and drying times. Rigorous quality assurance systems will be adhered to during design, procurement, construction and commissioning phases

All concrete structures of structural importance to any of the concept options will be amenable to direct or indirect examination and inspection. These include, shield walls to fuel handling cells, vault roofs and walls, horizontal storage modules and the fuel storage pool. It is noted that while the internal surfaces of the pool are not directly examinable, they are protected by a high integrity stainless steel liner.

All concrete structures will be the subject of a regime of periodic inspection and testing to ensure their continuing fitness for purpose throughout the facility’s operational life. The periodicity of inspection for a given structure will be commensurate with its importance to safety and be optimised as discussed above. As always, where their performance impacts on the continuing validity of the safety case, they will be among those safety structures systems, and components addressed under the periodic safety reviews required by Nuclear Site Licence Condition 15.

5.5 OTHER SAFETY RELATED SYSTEMS

Of those systems which may be important to safety but have not yet been discussed, the correct functioning of fuel handling equipment will be of central importance to the prevention of accidents with potential radiological consequences. These systems will operate within shielded enclosures provided for fuel receipt, export and storage and, in the case of wet storage, within the storage pool. For this equipment, the design and maintenance and inspection regimes must serve to minimise the frequency of dropped or impacted load accidents. The facility will afford suitable facilities for the inspection and maintenance of this equipment whose design will take due account of radiation and contamination hazards to the workforce.

Transport casks will be employed both for the receipt of fuel for storage and for the final export of the fuel for disposal or further treatment. These casks will contain multiple fuel assemblies and, theoretically at least, significant radiological consequences could result should they be subjected to severe impact challenge. While it is anticipated that, as transport containers, these casks will be qualified to withstand impact, the systems employed for their handling, such as cranes and tilting frames, will require to be of demonstrably high integrity.

The integrity of all of the above systems will be important to the facility safety case and will therefore be subject to the periodic review required under Nuclear Site Licence Condition 15. They will also be subjected to regular inspection in compliance with UK legislation for lifting equipment, where appropriate.

5.6 MAINTENANCE, REFURBISHMENT AND REPLACEMENT

The design philosophy for all aspects of the facility will take due account of the extended period for which the operation of the facility is anticipated and ensure an adequate margin is maintained between the operational life and the safe working life of all safety related structure, systems and components (DSP 12).

5.6.1 Civil Engineering Systems

The civil engineering structures and engineered equipment making up the interim storage facility will be robust and durable due to, in particular:

- Specification of the quality of the materials and the building arrangements used for the main shell and metal-fabricated structures;
- Design of elements of the facility fabric and equipment to be inspectable and, if required, to be refurbished or replaced under the maintenance regime.

No periodical replacement is planned for the main shell and the main metal structures of the facility. Feedback from international operating experience has shown that degradation of civil-engineered structures does not present a significant issue for even the oldest nuclear facilities. Additionally, a fundamental design parameter applicable to all aspects of the civil-engineering design of the facility is a 100 year operational life.

5.6.2 Other Systems

Periodical replacement of electrical and electromechanical equipment will be considered. The frequency of these replacement operations is yet to be defined, but will be defined and optimised during the design studies for the facility. In particular, the frequency of replacement will take into account parameters relating to the nature of operations and the anticipated operational load on the equipment.

It is noted that many systems, such as fuel handling systems, will be subject to a heavier operational load (frequent operation) during receipt and emplacement and final retrieval phases than during the storage period phase (to a degree determined by the frequency of retrieval for inspection or conditioning).

The regime for equipment replacement will take into account the long operational life anticipated for the facility. In particular, it will involve:

- Definition of periodical monitoring programmes for the components, systems and structures likely to be affected by wear and tear (such as civil-engineering items and finishings, structural or mechanical elements, surface protections, etc);
- Carrying out replacement studies for components, or complete items of equipment likely to be affected by wear and tear;

- Studying the possibility, during the operating phase of the facility, of substituting specific components in order to protect against their obsolescence;

- Storage of spares and ensuring that they are appropriately conditioned for long-term storage.

5.7 DAMAGED FUEL

5.7.1 Introduction

Certain of the design challenges posed by the need for extended storage of spent fuel are exacerbated when the fuel exhibits damage sustained either in the reactor, during initial storage in the reactor pool or during transfer to the storage facility.

In this context, a fuel assembly is considered to be ‘damaged’ if at least one fuel rod has identified cladding defects greater than hairline cracks or pinhole penetrations. It is essential that the extent of cladding loss or crack dimensions are not great enough to permit egress of a fuel pellet through the opening.

Of particular safety significance are the requirements to:

- Maintain the spent fuel in a criticality-safe configuration at all times;

- Control the containment barriers throughout the storage period.

Clearly it would be economically advantageous to have a single facility that could handle and store fuel with pre-existing damage as well as undamaged fuel, thereby avoiding the situation where fuel must be stored at source for an extended period due to the lack of a route for disposal or treatment. However, if the proposed facility is to store damaged fuel, this must not in any way undermine the safety arguments for the facility.

Considerable experience has been accumulated in respect of the conditioning and processing damaged fuel assemblies. This will be utilised in developing the design such that it can safely handle and store damaged fuel.

5.7.2 Detection of Damaged Fuel

It is clearly important that damaged fuel is detected at the earliest possible opportunity to enable arrangements to be made for its safe transfer and processing for storage.

In the reactor, early detection of failed fuel will be by regular sampling of the primary coolant. The primary species of use in identifying pin failures are gaseous radioactive species including nuclides of krypton, xenon and iodine. These techniques will be transferable to pool storage of fuel assemblies. Given that it is not envisaged that damaged pins will be replaced or repaired, fail results will result in the whole assembly being treated as defective and conditioned accordingly (see Section 5.7.3).

Sections 6.3.2.1 and Appendix 1 provide details of established techniques for detection of failed assemblies commonly employed in power reactors. Section 6.3.2 also identifies further opportunities for detection by inspection of failed assemblies at other points in the fuel’s processing history at the interim storage facility.

For the wet storage option, significant cladding failure of assemblies stored in the pool will be betrayed by the accumulation of activity in elements of the pool water purification system such as filters and ion exchange resins. Regular sampling of the pool water will also serve to identify any abnormal release of fission product activity potentially due to cladding failure.

For dry storage options wherein the fuel is stored in sealed containers, monitoring and sampling of the coolant medium are unlikely to identify cladding failures due to the high integrity of the secondary containment afforded to the fuel. However, it is noted that, in these cases, storage containers are filled with inert gas and progressive deterioration of the cladding materials is less likely given adequate heat removal provision.

5.7.3 Options for Long-Term Interim Storage of Damaged Fuel

If one or several elements of a spent fuel assembly is detected to be damaged prior to loading into the transport cask for transfer to the interim facility, the assembly will be placed in a dedicated ‘bottle’ prior to shipment to the interim storage facility.

The bottle is a container designed to prevent the spreading of radioactive material in the transport cask cavity. It would be provided with lifting features compatible with the handling equipment at the receipt facilities.

It is not currently envisaged that defective assemblies will be repaired (either by the removal or replacement of defective pins) on receipt at the interim storage facility or during the interim storage period. Rather, the approach adopted will be to manage the problem employing methods already tried and tested on existing facilities.

For wet storage, the most likely solution is that damaged assemblies (either received damaged or degraded during storage) will be transferred to steel bottles and returned to pool storage. These containers will not be sealed so that they will permit the through-flow of pool cooling water. They will be fitted with valves and filters for retention of particulate fission products while permitting the circulation of liquids and gases.

This system has the advantage of permitting effective decay heat removal from the fuel while minimising the release of activity to the pool and its associated cooling and purification systems.

Experience to date of dry interim storage of damaged fuel is less extensive. In respect of release of activity, at least, the problem of storing defective fuel may be considered to be of lesser safety significance for dry storage given that, for all dry storage options, fuel assemblies are contained in robust, sealed steel containers providing secondary containment throughout their interim storage and are not in direct contact with the cooling medium.

Fuel known to be defective on receipt may be transferred to specially designed, high integrity sealed containers. Alternatively, the standard sealed interim storage containers may be considered to provide adequate containment particularly when supported by further containment barriers such as the sealed storage wells in the vault storage option. A third option would be to combine these options; that is to overpack damaged fuel before employing modified versions of the standard containers for storage.

6. RETRIEVAL AND INSPECTION OF SPENT FUEL

6.1 INTRODUCTION

This section of the report describes the provisions and functions necessary for the retrieval and inspection of used fuel and potential inspection regimes. It also considers changes to the retrieval and inspection regimes as materials age and their characteristics change.

Details of the various storage concept options are presented in References [1] and [2].

6.2 OVERVIEW

6.2.1 Design Safety Principles

The primary DSP to be addressed in relation to retrieval of fuel is DSP 14:

'The storage facility should be designed and operated so that any individual fuel assembly can be inspected and retrieved within an appropriate period of time'.

The primary DSP to be addressed in relation to inspection of stored fuel is DSP 8:

'Monitoring, examination, inspection, and testing arrangements should be developed for the facility, equipment, stored spent fuel and storage containers that take account of any potential for ageing and degradation'

Two classes of inspection are envisaged. Firstly, the design will ensure that effective and safe means of in-situ inspection of the fuel in its storage location will be afforded. Secondly, ex-situ means of inspection will be provided for fuel assemblies retrieved from their storage location either because in-situ inspection or indirect monitoring results indicate that their integrity has become suspect or because it is required to comply with the inspection regime devised to meet regulatory expectation.

In compliance with DSP 15, the means of in-situ inspection will be designed to be non-intrusive, minimising the potential for damage to the fuel and its secondary containment (and therefore minimising operator risk). Similarly the equipment for retrieval of fuel for ex-situ inspection, if required, will be designed to avoid damage to the fuel to be retrieved.

To ensure that the fuel remains retrievable so that, if required, it may be removed to specialised facilities for inspection, the design and mode of operation will ensure that:

- Account is taken of potential age-related degradation effects which might diminish the assemblies' structural strength or primary containment (cladding) integrity (DSP 6);

- The fuel and any containers employed (e.g. dry shielded containers (DSCs)) will be designed to be compatible with their storage environment taking account of the longevity required of them and hence suitable for handling and to ensure that the fuel will be effectively separated from any materials which might affect its integrity over the long-term (DSPs 5, 11,12, 13);

- Monitoring of the storage environment will be carried out to ensure early detection of failed fuel at a stage when safe retrieval of failed assemblies remains possible (DSP 8);

- Procedures and equipment are always available for the safe retrieval of fuel whose containment or structural integrity is suspect (DSP 16).

The first of these will be particularly important in the more challenging storage environment of the wet storage facility. However, a great deal of experience is available regarding the properties of both fuel fabrication materials and their performance over extended periods in dry and wet environments. Compliance will be fundamentally guaranteed by the original specifications for the EPR fuel and storage containers. This will be supported by rigorous quality procedures at all stages of design, procurement and manufacture.

In addition, the first and second requirement will require not only knowledge of potential degradation mechanisms (described elsewhere in this report) but also a detailed knowledge of the storage environment to which the individual assemblies have been exposed over the storage period. This will require the continuous monitoring or regular sampling of the properties of the storage medium and the secure recording of the resulting data (see Section 7 and DSPs 8, 17 and 18).

6.2.2 Retrievability

In relation to the final issue listed above in Section 6.2.1, there are several potential reasons why a particular assembly might not be retrievable by normal means i.e. employing the same equipment and the reverse procedures employed for its original emplacement. For example, should an assembly have lost cladding integrity, its movement without special precautions could lead to the release of radioactive material, potential exposure of both workers and the public and contamination of the storage environment and other facilities and equipment involved in fuel handling. Should the structural integrity of a fuel assembly be in question, to lift and transfer it in the normal way might result in its structural collapse, damage to the fuel cladding and the same radiological consequences. This would clearly apply to the wet storage option but also to dry storage options where individual assemblies from a storage container require inspection. Contingencies for dealing with suspect fuel are discussed elsewhere. In complying with DSPs 11 and 12, attention must also be paid to the condition of the equipment required for retrieval. It will be equally important to ensure that lifting and handling equipment remains capable of transferring the retrieved fuel with a degree of reliability that remains adequate for the restriction of the frequency and hence of the risk from dropped load events. This again will be primarily ensured by the original specification for the equipment but also by the implementation of a maintenance regime compliant with the approach described in Section 7. However, where significant deterioration in structural strength of either fuel assemblies or their storage containers is suspected, particularly in relation to lifting attachments, it may be necessary to employ specialised equipment for retrieval to give additional support and possibly containment to the retrieved item.

6.2.3 Monitoring

Monitoring will not necessarily identify specific assemblies as being suspect in relation to their primary containment (cladding). However, its results will be employed to trigger closer inspection of individual assemblies to identify those that are suspect and may require retrieval for either further more detailed inspection or for remediation to render them suitable for continuing storage. It is noted that monitoring will not generally provide any indication of progressive degradation of the structural skeleton of the stored assemblies.

6.2.4 Characterisation

For inspection, either in-situ or ex-situ, to be fully effective, benchmark data obtained prior to storage will be required regarding the condition, properties and history of each assembly. Means of obtaining these data will be required for compliance with DSP 19. These data must be suitable for informing decisions on retrieval for final disposal (DSP 21) and will also facilitate decision-making regarding the need for retrieval for inspection and suitability for retrieval employing standard equipment. Suitable facilities will be afforded by the design to permit the necessary characterisation to be performed (DSP 20). These data will be required for comparison with acceptance conditions prior to acceptance of the assembly for interim storage. This will be obtained from records of the assemblies' history in the reactor and also from inspections carried out prior to or during its storage in the reactor storage pool. These data will require to be securely recorded and readily retrievable employing systems meeting the requirements set out in Section 7.4.

6.2.5 Accountancy & Records

A key requirement in enabling the retrieval of specific assemblies for inspection will be the ability to determine quickly the precise location of any particular assembly and to confirm its identity once located. This will be enabled by the maintenance of records of location completed at the time of initial emplacement and updated during the storage period to reflect any change of location and by the marking of assemblies and any storage containers employed with unique identifiers (DSP 18).

6.2.6 Storage in Containers

Retrieval from wet storage of individual assemblies will be relatively straightforward in the sense that no movements of other assemblies should be required in able to access the assembly of interest. However, for assemblies stored in groups within sealed dry storage containers or failed fuel stored in specialised containers, the container will first have to be retrieved to a suitable facility where individual assemblies can be withdrawn for inspection.

6.3 INSPECTION AND MONITORING REGIME

6.3.1 Optimisation of the Regime

Provided the risks from the regime adopted are shown to be below a pre-defined limit on tolerability, acceptability will depend on the demonstration that the inspection regime has been optimised such that the perceived benefits of inspection are not outweighed by the disbenefits (particularly the radiological and conventional risks) associated with following that strategy. The balancing of risks associated with alternative inspection regimes will be an integral part of the process to ensure compliance with the ALARP Principle throughout the facility's life.

The primary potential radiological disbenefits relevant to the choice of option will be:

- Normal operations doses to workers and the public:
    - Background doses from stored assemblies;
    - Doses from fuel transfer operations;
    - Doses from inspection and possible remediation operations;

- Accident risks to workers and the public:
    - Accidents during fuel transfer operations;
    - Accidents involving stored packages;
        - During in-situ inspection procedures;
        - During retrieval of assemblies for inspection ex-situ.
    - Accidents during ex-situ inspection operations and possible remediation operations.

In relation to accidents, the primary concern will be with the potential for dropping or impacting assemblies during retrieval or inspection.

The decision-making process is likely to be based on the relative assessed magnitude of these potential contributors to risk (noting that for normal operation, radiological risk is proportional to dose). These will each be proportional to the frequency of inspection operations. It is this frequency that will require to be optimised to optimise the risks associated with inspection. This will include consideration of the balance of risks and benefits of in-situ inspection and retrieval for ex-situ inspection.

At this time it would be difficult to assess an absolute value for risk associated with the retrieval of a single assembly or storage container of assemblies. However, it should be possible to estimate the magnitude of the accident and normal operations risks associated with retrieval relative to the risk of emplacement of a single assembly.

6.3.2 The Key Elements of the Regime

6.3.2.1 In Reactor Inspection

The first stage of the inspection regime takes place while the assembly is still in the reactor, when techniques for the detection of damaged spent fuel are employed in situ. This also provides input to the necessary characterisation procedure that must precede interim storage.

A number of proven techniques are available. These include:

- Fuel sipping;
- Ultrasound inspection.

The sipping technique involves the drawing of gas samples from each assembly tested. The presence of fission product gases in these samples is evidence of failed rods within the assembly.

The ultrasound technique depends on the ultrasound scanning signal being attenuated by any water in the fuel pin that would have entered via imperfections in the cladding.

Further details of established techniques are provided in Appendix 1.

6.3.2.2 Reactor Storage Pool

While assemblies are stored in the reactor fuel storage pool, their visual inspection by camera will be possible. Gas sipping and ultrasound inspection techniques may also be used at this stage. This may be carried out on a regular scheduled basis for all stored assemblies or be triggered by abnormal activity monitoring results. The exact approach adopted will be based on extensive experience of storage of PWR assemblies under water and will take account of expectations expressed by the nuclear regulator. As always, the regime will be optimised as described in Section 6.3.1.

Monitoring results will betray any cladding failure of assemblies stored in the pool. Monitoring will include:

- Analysis of pool water samples;
- Monitoring of activity levels in pool clean up systems;
- Monitoring of airborne activity in the pool hall.

6.3.2.3 Receipt at the Interim Storage Facility

The first opportunity for inspection of assemblies for interim storage forms part of the receipt procedures at the interim storage facility. As part of the receipt arrangements, the transport container inner atmosphere will be checked for the presence of inert gas radionuclides which would betray any damage to fuel occurring during transport or pre-existing damage which had gone undetected by earlier monitoring and inspection. This step will be carried out for all options, noting that for some options, the transfer container will also be the storage container.

For options which require the removal of the assemblies from the transfer container on receipt, following removal of the assembly in the unloading cell, an opportunity is presented for remote visual inspection of the assembly using CCTV.

The standard unloading procedure for received fuel involves the immersion of each assembly in the cooling and rinsing pit of the unloading cell. Failed pin cladding will result in a release of activity to the pit cooling loop. Any such indication would be checked by analysis of a water sample.

6.3.2.4 Fuel Monitoring and Inspection during Interim Storage

Wet Storage

Periodic sampling and analysis of pool water will be carried out both at the pool itself and at the ion exchanger outlet. Gas sipping and ultrasound inspection techniques may be employed in-situ if required. Should failure of a specific assembly be identified, retrieval of the assembly may be accomplished by the reverse of the emplacement process described in Reference [1]. This will permit visual inspection of the assembly to characterise the cladding failure either in-situ or in the unloading cell or other suitable shielded containment cell.

Dry Storage in Vault

For this storage option, two leak tight barriers (the storage canister and storage well) are in place which will prevent the leakage of any activity released through cladding failures to the cooling air stream. Direct visual inspection in-situ is therefore not possible and, although monitoring of air in the cooling system will be carried out, it is unlikely to identify cladding failures as a result of the intervening barriers.

Should direct inspection of any particular fuel assembly be required, the storage canister would require to be removed from its storage well and returned to the unloading cell by the reverse of the emplacement procedure where the canister would require to be opened and assemblies could be removed one at a time for checking. While this retrieval/inspection process is clearly feasible, it is unlikely that its frequent performance would be favoured by the risk balance/optimisation procedure described earlier.

Dry Storage in Casks

Casks again store multiple assemblies and present several barriers to the release of activity from failed fuel. In-situ inspection is therefore ruled out for the same reasons as vault storage. Retrieval for inspection of individual assemblies would require the removal of both outer and inner containment lids and the withdrawal of individual assemblies for inspection using for example, gas sampling, visual inspection or ultrasound techniques in a purpose designed shielded facility. While such inspections have been successfully carried out for research purposes, it is again unlikely that their frequent performance would be favoured by the risk balance/optimisation procedure described earlier particularly as the results of research on fuel stored in this way for 15 years did not reveal any significant cladding degradation or activity leakage.

Dry Storage in Horizontal Modules

The dry shielded containers employed for interim storage in horizontal concrete modules are again designed to hold multiple assemblies in high integrity containment. Retrieval of individual assemblies would therefore involve the retrieval of the DSC, cutting it open and removing and inspecting assemblies individually using similar methods to other dry storage options previously discussed. As before, the balance of risks between retrieval for inspection and continuing storage is unlikely to favour frequent performance of the former.

6.3.3 Implications of Storage Duration for the Inspection Regime

Due to the very extended period for which fuel assemblies will require to be stored prior to final export from the interim storage facility, the fuel assembly inspection regime will require to be reviewed over time to ensure that the risks from storage and those associated with final export will remain ALARP.

Factors requiring to be taken into account in the optimisation of the regime may alter over time. Clearly, in theory, if there are age-related degradation mechanisms which may affect the stored fuel or the equipment employed for its inspection or handling, the significance of these would be expected to increase over time. However, that is not to say that they will necessarily become significant in the absolute sense. The implication for the risk-balancing decision-making process is that, firstly, more frequent retrievals for ex-situ examination might be necessary if there is a real expectation of material changes in the fuel integrity. Such increased fuel failure probability would also increase the risks associated with continuing storage (i.e. non-retrieval) including those associated with in-situ inspection. However, given that the structural integrity of assemblies and the equipment employed to retrieve them may also have degraded over time, an increase in the probability of dropped loads per retrieval operation may also be anticipated.

Clearly there are a number of competing factors to be considered in developing an inspection strategy for the longer term and these can only be meaningfully compared on the basis of robust research data and continuing operational experience.

The research data available to date, relating specifically to fuel and the body of experience accumulated by storage pool operators, indicate that cladding degradation under the storage concepts being considered is unlikely to be a major issue over storage periods of several decades. Indeed, IAEA-initiated research programmes focusing on the durability of zirconium alloys employed for cladding have concluded that these are highly resistant to degradation in wet storage and may prove satisfactory over periods of at least 50 years and potentially of 100 years or more. It is noted that water storage is likely to pose a more aggressive challenge to fuel integrity than dry storage.

Nevertheless, extrapolation of the available data to the 100 year storage period anticipated between first assembly emplacement and last assembly export would carry significant uncertainties. However, these should reduce over time as experience is gained particularly from the results of inspection of non-radioactive ‘dummy’ samples and any assemblies that are retrieved under the initial inspection regime.

In relation to steel storage containers, the primary concern will be the behaviour over time of items fabricated from stainless steel. Significant degradation over time could not only give direct access for the cooling medium to the fuel but could also increase the likelihood of a dropped load during their transfer. However, the degradation resistant properties of this material are well known and documented and this potential issue will be primarily addressed by specifying appropriate steels and including significant margins of safety in container wall dimensions.

Other safety related items whose failure rate will dictate accident frequency and risk are fuel handling systems. However, again, these items will be fabricated from stainless steels. Further, these items of equipment will be accessible for maintenance, refurbishment and even, if necessary, replacement. There is no reason to suppose, therefore, that risks associated with their failure will significantly increase over the storage period provided an appropriate preventative maintenance strategy (such as that described in Section 7) is adopted.

It is concluded that the ALARP Principle can only be satisfied in relation to the risks from the operation of the facility by adopting a flexible inspection regime which is optimised on the basis of feedback from operational experience and continuing research programmes.

It is also noted that the UK licensing regime (specifically Licence Condition 15) requires a periodic review of safety to be undertaken with a normal review period ten years. These reviews will provide opportunities to revalidate the safety case for storage based on accumulated results of monitoring and of experience accumulated nationally and internationally. The review will also determine whether more intrusive inspection is required to revalidate the safety case.

6.4 SPENT FUEL RETRIEVAL PROCEDURES

6.4.1 Introduction

Whether or not ex-situ inspection of stored fuel is required, retrieval of the stored fuel will eventually be necessary for export for further treatment or final disposal.

Other than the storage arrangements themselves, the most safety important design features of the interim storage facility will be those which provide for the spent fuel to be safely received, handled, and retrieved since their failure will potentially generate very significant radiological consequences and contribute substantially to the plant risk.

Similarly, the processes and operating procedures will themselves require to be designed to minimise the potential for accidents, particularly those associated with human failures.

6.4.2 Retrieval from Pool Storage

The retrieval procedures for fuel assemblies are basically the reverse of the procedures described in Reference [1] for the emplacement of assemblies in the pool. In outline the transfer from pool to transport container is achieved as follows:

1. The storage basket containing the fuel assembly for retrieval is identified.
2. The basket is moved using the pool mast crane to the reception position at the end of the transfer channel connecting the pool to the unloading cell.
3. The basket is transferred to a steel-fabricated transfer device with a lateral door.
4. The transfer device then moves the basket and assembly through the transfer channel to the unload cell.
5. The unloading cell handling crane is then employed to remove the assembly from the basket.
6. A transport container is docked with the unloading cell.
7. The transport container lid is removed by means of the in-cell jib crane.
8. The retrieved assembly is transferred to the transport container cavity with the unloading cell handling crane.

The same procedure will be employed for assemblies which have been overpacked and stored in bottles in the pool due to previously identified cladding failures. The above procedure may be referred to as ‘dry loading’. This is presented as an example of possible retrieval procedures for the wet storage option. Other possibilities which are under consideration include direct loading of fuel to casks in the pool (see Reference [1])

6.4.3 Retrieval from Dry Vault Storage

Under the option of dry storage in a vault, assemblies are stored in a sealed steel canister within a sealed storage well.

The step-wise retrieval procedure is as follows:

1. The canister is removed from its storage well, placed in the shielded transfer machine and transferred to the unloading cell.
2. The canister is opened according to existing and proven cutting procedures (see Section 7); it is anticipated that an area will be provided in the fuel assemblies unloading cell, near the unloading station and in front of the work station, to accommodate purpose-designed canister opening and dismantling tools.
3. The fuel assemblies are picked up one by one and placed inside the cell buffer storage area.
4. A transport container is docked under the cell and filled with fuel assemblies for onward processing or disposal.
5. Once emptied, the canister is dismantled using purpose-designed tools.

6. The components of the dismantled canister are placed in a basket, loaded in a canister which is welded closed and emplaced in a dedicated well in the vault.

It is noted that, once removed from the canister in the unloading cell, individual assemblies may be examined as before prior to loading into the transport container. It is further noted that the cell will be designed to afford sufficient flexibility to permit reloading of assemblies into canisters designed to meet disposal facility acceptance criteria.

6.4.4 Dry Storage in Casks

Because the closure arrangements for the casks employed for these options are not welded closed (they are bolted), no cutting of the containers will be required.

Dry storage casks will be designed to mate directly with unloading facilities should the removal of assemblies be required. However, these casks will be dual purpose and are expected to be suitable for off-site transfer and hence assembly removal for repackaging may not be necessary. If repackaging is necessary, the procedure followed is expected to mirror that described in 6.4.3 for retrieval from vault storage without the canister cutting steps.

6.4.5 Dry Storage in Modular Storage Systems

For modular horizontal storage, the DSCs are designed to be directly discharged from the horizontal storage module tubes into transport casks. Again, if appropriately qualified, these casks may be employed for transport to facilities for final disposal or further conditioning. If repackaging is necessary, the procedure followed is expected to mirror that described in 6.4.3 for retrieval from vault storage.

As with cask storage the systems are sufficiently flexible to permit the unloading of assemblies into the unloading cell for inspection or repackaging if required.

6.4.6 Potential Implications of Material Ageing

The design intent is that the same design of equipment and procedures will be used throughout the operational life of the facility.

Clearly, if operational experience or technological developments over time identify safer or more efficient means of performing retrieval, these may be adopted provided they meet the modern standards of the day and any modifications successfully negotiate due process for safety justification.

However, the other potential driver toward modification of the retrieval process over time would be if confidence in the integrity of certain systems had been eroded over time through adverse operational experience or the result of condition monitoring and inspection. The main systems concerned are:

- Fuel lifting, handling and transfer systems;
- Fuel assembly skeleton structures;
- Fuel cladding;
- Pool storage baskets;

- Pool storage racks;
- Dry storage canisters;
- Dry storage casks.

Fuel handling systems will be subject to preventative maintenance and refurbishment throughout their service period and may even be replaced should this become necessary. Pool storage baskets should also be amenable to refurbishment or replacement although this would in itself require retrieval of assemblies from the pool.

However, the fuel assemblies themselves clearly cannot be replaced, and it is not intended to replace the various steel storage containers or storage casks during the storage period.

The key factors for these systems in relation to safe retrieval are structural strength, and the condition of lifting features in addition to the fundamental issue of cladding condition.

In the case of casks, inspection in situ will be relatively straightforward, and any evidence of early degradation readily identified in time for the cask to be handled safely for transfer to a facility in which its contents could be transferred to a replacement cask. Thus, there is confidence that, for this option, the original procedures and equipment of the original design may be safely employed throughout the storage period.

However, for steel storage containers, detailed examination requires their retrieval. It is reasonable to suppose that, in the early years of the storage period, there will be sufficient confidence in the integrity of the containers to permit their retrieval by the original procedure and equipment for inspection. However, as the period of storage increases, the potential for degradation will also, in theory, increase and this confidence may be diminished or at least become more difficult to substantiate. Further, it is unlikely that the inspection regime adopted will demand the retrieval for inspection of every canister since this is unlikely to be favoured by risk-balance considerations. It will therefore be necessary to extrapolate the inspection results of those canisters that are inspected to those that are not.

At some point in the later years of storage, a lack of certainty in relation to the structural condition of each canister (particularly its lifting features) may require consideration to be given to the modification of the procedures and equipment to be employed for retrieval in order to maintain risks from the process ALARP. Consideration may have to be given, for example, to developing alternative grabs for handling machines and lifting arrangements that afford greater support, and possibly additional containment, to canisters during lifting and transfer operations.

A similar argument will apply to pool-stored assemblies. However, the wet storage option does not employ canisters (except for suspect or failed fuel) and as a consequence, individual assemblies may be inspected more readily. This should delay the point when a decision has to be made on the equipment and procedures to be employed for retrieval. In the case of pool-storage, because the assemblies are not over-packed, the condition of cladding will be relevant to decisions relating to suitability for retrieval as well as the condition of the lifting features and structural skeleton. As before, lifting arrangements providing greater support and some containment may have to be considered.

It is not possible to predict at this time when decisions on the continuing suitability of retrieval methods will require to be made, if at all. Neither is it possible to predict with confidence what modifications to the process and equipment may be required in any detail. However, these decisions will be taken on the basis of experience gained through operation of the facility and similar facilities operated elsewhere together with feedback from relevant research programmes.

These matters will require to be kept under review and be addressed in the periodic reviews of safety required by the site licence to ensure that the safety case for retrieval remains robust throughout the facility’s operational life.

7. PLANS FOR FINAL FUEL RETRIEVAL

7.1 INTRODUCTION

This section of the report addresses plans for the facilities, and their functions, needed to retrieve the spent fuel assemblies and prepare them for onward processing or disposal.

7.2 KEY DSPS

The DSPs of particular importance in relation to final export of spent fuel from the facility are DSPs 13 and 16.

DSP 13 '*The storage environment should avoid degradation that may render the spent fuel unsuitable for long-term management and/or disposal'.*

DSP 16 '*Appropriate provisions should be available for dealing with spent fuel or its containers that shows signs of unacceptable degradation'.*

Meeting these DSPs by design will ensure that it will be possible to retrieve all stored fuel assemblies in a condition suitable for the intended operations to prepare them for disposal.

Additional DSPs whose purpose is to ensure that stored wastes are maintained in an undegraded condition have been discussed in earlier sections.

Further issues of importance relating to the final retrieval and processing for disposal are the need for accurate records of the fuel assemblies' initial condition on receipt and the results of inspections during interim storage to give sufficient confidence that retrieval and preparation for disposal can be safely undertaken. This will in turn require that robust initial characterisation has been carried out prior to or on receipt into the interim storage facility and that a robust system of acceptance conditions has been developed on the basis of a sound understanding of the potential degradation processes which might adversely affect integrity under very long-term storage and the conditions necessary to minimise those effects. Finally, it will be essential that there is no ambiguity as to the identity of each stored item and its location such that it is certain that the correct item is retrieved and the recorded data relating to condition certainly refers to that particular item.

The above issues will be addressed by compliance with the following DSPs in particular:

Characterisation:	DSP 19	*Characterisation prior to storage*
	DSP 20	*Facilities for characterisation*
	DSP 21	*Characterisation for final disposal*
	DSP 23	*Inspection against acceptance conditions*
Acceptance Conditions:	DSP 22	*Definition of acceptance conditions*
Records:	DSP 18	*Unique identification*
	DSP 24	*Recording of information*

7.3 MAINTENANCE STRATEGIES

In addition to maintaining the fuel condition over the extended storage period, it is essential that the machinery and facilities required for fuel handling operations are maintained (and if necessary refurbished or replaced) over the interim store's lifetime to ensure that final retrieval operations can be carried out safely and with operational efficiency. In accordance with good engineering practice, routine maintenance, refurbishment and component replacement schedules will be determined on the basis of an understanding of the failure behaviour and useful operational lives of specific systems and will adopt an anticipatory and preventive approach.

Most importantly, the design of all fuel handling and transfer systems will be designed to have appropriate longevity (or to be readily replaceable) and integrity and reliability commensurate with their importance to safety. It will also ensure that no damage to fuel occurs during its handling which could compromise its integrity. In particular the design of such systems will:

- Avoid features which could damage fuel claddings or skeleton structures during handling operations (see DSP 15);
- Include safety systems (preferably passive or at least fail-safe) to avoid dropping of fuel, or dropped loads onto the fuel;
- Provision of handling operation areas located to avoid travelling above the fuels;
- Include engineered features to limit travel speeds;
- Include redundant power sources and diverse emergency systems (to a degree commensurate with their importance to safety);
- Include engineered provisions to ensure that loads can be safely put down following any reasonably foreseeable intrinsic failures or internal or external hazards;
- Include interlock systems, physical travel limitations and load sensor based cut-outs to prevent or halt dangerous operation;
- Ensure that they are located such as to facilitate access for maintenance, provide adequate space for effective maintenance, restrict hazards to maintainers and minimise the risk of inadvertent damage to other safety related systems.

It will also be essential to maintain the availability on the facility site of:

- Diagnostic and testing facilities for equipment known to exhibit wear-out failure mechanisms;
- Suitable workshop facilities for repair, refurbishment or replacement of faulty or age-degraded components;
- A spare parts management system with the maintained stock of items based on an understanding of the failure behaviour and useful operational life of the item and its operational and safety importance.

The final point will be of particular importance given the very long operational life of the facility. Obsolescence of components and systems will require to be anticipated and systems put in place to identify and safety justify potential alternative means of delivering function.

An additional issue pertinent to the operation of facilities over very long time periods is the maintenance of a suitably qualified and experienced workforce familiar with the systems to be operated and maintained. This is particularly important since the demands on the work force will vary considerably over the various phases of the facility's operation, with considerably more demand during the relatively intensive receipt and emplacement and final retrieval phases of operation in comparison with the relatively low demands over the period of passive storage operations. This will be addressed through a policy addressing recruitment, retention and training of personnel to ensure adequate resourcing during each operational phase.

7.4 DATA RETENTION AND RECORD MAINTENANCE

Suitable and sufficient records of stored fuel inventory and associated facilities will be made and managed so as to provide continuing assurance in relation to the potential environmental impact and radiological risks associated with the operation of the plant. Particularly important, in this context, will be the retention of data pertinent to the final retrieval and preparation for disposal of stored fuel. This will be essential data for the development of the safety justifications for these final activities.

The data collection and record keeping system will meet the following performance objectives:

- Provide comprehensive and accurate baseline information about the condition of the facility's stored spent fuels and equipment;
- Provide comprehensive and currently accurate information about the condition of the facility's stored spent fuels and equipment;
- Provide historical information about operational management of the facility and maintenance history data;
- Provide the means for the secure storage of this information;
- Provide the means for timely and accurate retrieval of the information when required;
- Provide adequate tools for data analysis.

7.4.1 Baseline Data

The baseline data of particular importance and interest will concern:

- Spent fuel assemblies' characteristics, including reactor power history, transport data and all information obtained prior to storage (burn-up, cooling time, decay heat power, surface contaminants, minor cladding damage) via the initial characterisation process;
- Individual spent fuel assemblies' location within the storage arrays (storage pool, the storage wells or storage cask position on the storage pad depending on the preferred storage option);
- Design specifications and drawings and manufacturer's data (including material data, manufacturing procedures) to permit the manufacture of any replacement component or system over the lifetime of the facility.

7.4.2 Operating and Maintenance History Data

Operating and maintenance data relating to the following will require to be retained and managed:

- Process conditions (temperature, pressure, environmental conditions) during handling and storage required for safe and reliable operation of all aspects of the facility;
- Data obtained from continuous monitoring and sampling (e.g. pool water chemistry and temperature, passive cooling air condition, activity and gas pressure in sealed storage and transport containers, airborne activity and gaseous discharge activity levels);
- Timing of maintenance actions (including identification of failures, malfunctions and repair actions) to optimise operating conditions;
- Date, type and description of maintenance actions to provide continuous feedback on the effectiveness of preventive maintenance to enable optimisation of the maintenance strategy;
- Identification of the occurrence of age-related degradation effects on components and materials. Assessment of this data may provide early detection of ageing phenomena, permit intervention to prevent potential operational problems and safety-related failures and, again, produce feedback input to optimisation of the maintenance strategy.

7.4.3 Secure Storage of Information

A wide range of data collection and record keeping systems is commonly used in nuclear facilities.

A number of factors will be relevant to the selection of the most appropriate system for the proposed facility. However, it is essential that the selected system afford the following features:

- Redundancy, and segregation of records: Maintaining redundant sets of records in several places not only removes the risk of complete loss of records through common cause events but also will assist in the retention of adequate expertise so that the stored information may be retrieved and used efficiently to address any situation;
- Diversity of recording systems: It is inevitable that, over the very extended operational period that the information will be of use, significant developments will take place in information storage and management technologies just as have been witnessed over the past decades. Employing diverse recording and management systems (e.g. hard copies, electronic files on hard drives and portable media, diverse software for data management and analysis) will facilitate keeping up with the evolution of technologies (including software and hardware) to keep the system capable of information retrieval at any time, even at the time of the final operations at the interim storage facility. The employment of diversity in this area will again reduce the potential for loss of all records through some common cause such as viral infection.

7.5 PREPARATION FOR FINAL FACILITY OPERATIONS

The baseline strategy for the interim fuel storage facility requires that it must cater for safe and secure storage of spent fuel arising from EPR plant for 100 years after receipt of the first assembly from the reactor storage pool [2].

This requirement entails not only the safe storage of fuels while the reactor is operational, but also the surveillance and monitoring over a period of some years after final reactor shutdown before export for further processing or disposal commences.

The storage period preceding final retrieval will be a less active phase involving:

- No fuel transfer operations from the reactor;
- Low frequency of spent fuel handling operations other than for retrieval for ex-situ inspection (if required) and retrieval and remediation of leaking fuel (if required);
- Monitoring, surveillance and maintenance activities.

These restricted operations will require far fewer staff than the initial (receipt) and final (processing for transfer or disposal) phases.

It follows that carrying out the required operations for spent fuel final export will require the implementation of a preparatory phase, whose main stages can be outlined as follows:

1. Starting over a year before final export, staffing of the interim facility must be increased to the necessary levels for safe and efficient operation. This will include increasing the numbers of suitably qualified and experienced personnel in a number of disciplines (e.g. maintenance personnel, workshop workers, lifting and handling equipment operators, supervisory personnel, safety specialists).
2. Retrieval and processing of large amounts of data from the record keeping system including:
    a. Data on the spent fuel assembly locations and characterisation;
    b. Data on the procedures for spent fuel retrieval, checking and export;
    c. Data on all equipment linked to spent fuel storage (e.g. data on historical water and gas sampling results, impact of ageing phenomena on civils structures and metal storage containers from the samples surveillance programs);
    d. Manufacturing data files (in case of failed equipment requiring complete replacement).
3. All of the above data must be thoroughly analysed before any export operation can take place, in particular to identify any suspect spent fuel and adapt the procedure accordingly.
4. Technical review of all equipment necessary for exporting spent fuel assemblies:
    a. In the case of wet storage: Operational capability of the mast crane, the pool overhead crane, the basket transfer device, the transfer channel equipment, and the equipment specific to the unloading cell;

   b. In the case of dry storage: Operational capability of the canister handling machine, transfer tunnel equipment, welding and cutting machines, contamination control equipment, unloading cell equipment:

      i. Unloading cell handling crane;

      ii. Docking station equipment;

      iii. In-cell CCTV systems for spent fuel identification before loading into transport container.

5. Transport containers review: Technical review of the transport containers for spent fuel export, checking:

   a. Technical characteristics for compatibility with the interim facility docking station, preparation room equipment, handling crane capacity;

   b. The internal structures and furniture of the containers in relation to the provision of safe transport conditions.

At the end of the preparation phase:

- The facility will be appropriately manned;
- All export equipment will be operational;
- Leaking or suspect fuel assemblies will have been identified and evaluated;
- Appropriate procedures for dealing with all fuel assemblies (intact or leaking) will have been developed;
- An adequate fleet of transport containers will be available at the facility to meet the required spent fuel export flow rate.

7.5.1 Export Procedures

This section briefly outlines the arrangements and procedures for final export of the spent fuel from a vault dry storage facility and a wet storage facility. The procedures for options involving storage in dual-purpose casks including modular storage technology options are not described here since they do not require re-handling of the fuel before final transport.

7.5.2 Export from a Storage Pool

The operations described are essentially the reverse of those described in Reference [1] for receipt and emplacement and share a number of common operational steps.

Following the established pool unloading procedure, validated during the preparation phase, all fuel baskets are transferred singly using the pool mast crane (at a rate according with the mast crane availability) to the bottom station of the transfer channel.

The transfer channel device lifts the fuel baskets up to the unloading cell reception station, where the spent fuel assemblies are unloaded from the baskets with the unloading cell crane for loading into the transport container for final export from the interim facility.

Used baskets will be stored inside the pool until the final decommissioning phase. Should any radioactivity be measured in the cooling/rinsing pit water circuit, the potentially failed fuel assembly will be loaded back into the storage basket for later processing employing a purpose-designed containment canister, or a specialised transport container.

After the transport container has been closed, leak-tested, and the internal cavity vacuum dried, the external contamination of the transport container will be checked against the relevant criteria for off-site transport.

The above operations will be repeated until the storage pool has been emptied.

It is noted that these operations are standard operations carried out on many power plants when exporting spent fuel to a storage facility or reprocessing plant.

7.5.3 Export from a Dry Vault Storage Facility

7.5.3.1 General Procedure

Following the established storage vaults unloading procedure, validated during the preparation phase, the designated storage well is prepared for unloading by:

- Removal of the protective plate by ‘hands-on’ means (shield plug still in-situ);
- Removal of the shield plug by remote handling machine.

The upper canister is gripped by the handling machine and transferred to the transfer trolley. The transfer trolley travels through the facility transfer tunnel and the following operations are performed:

- The canister is checked for contamination before opening;
- The canister is cut open using a purpose designed cutting machine;
- The opened canister is lilted up to the unloading cell.

In the unloading cell, the spent fuel assemblies are unloaded one at a time from the canister, checked for integrity and loaded into a transport container docked under the unloading cell. Used canisters will be stored inside the facility awaiting final decommissioning.

After the transport container has been closed, leak-tested, and the internal cavity vacuum dried, the external contamination of the transport container will be checked against the relevant criteria for off-site transport.

The above operations will be repeated until the storage vault has been emptied.

7.5.3.2 Canister Cutting Techniques

Of particular importance in the selection of the technique for cutting open the canister is the minimisation of the likelihood of damaging the fuel cladding during the process.

Different techniques are currently available. All involve machining processes. They include:

- Lateral drilling;

- Use of a circular saw, operating horizontally and progressively penetrating the canister shell.

Both processes generate swarf/chips which could enter the canister cavity and potentially damage the fuel cladding.

An alternative approach with advantages over those listed above, is the use of a cutting wheel which is a mechanical process that forces back the metal by successive applications of the wheel, thereby creating a groove. The pressure operated by the wheel on the metal results in a deformation of the cutting surface with swelling produced on both sides of the groove. A sketch illustrating the principle of operation is provided below.

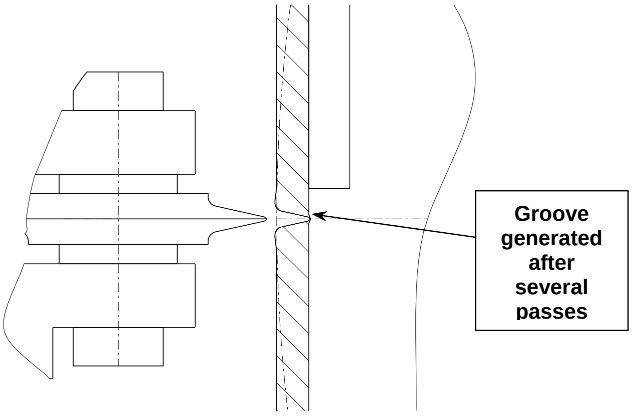

Figure 1: Principle of Operation of the Cutting Wheel Technique

The principal advantages of the cutting wheel technology are as follows:

- No production of swarf/chips thereby precluding material falling into the canister during the cut, where it might potentially damage the fuel rod cladding;
- Ease of implementation, particularly in relation to services since there is no need, for example, for wheel cooling during the cutting process;
- Ease of access for maintenance since the wheel is expendable provided that the replacement procedure is carefully carried out;
- The technology is proven for steel thickness up to 5 mm.

APPENDIX 1: DAMAGED FUEL DETECTION TECHNIQUES

A1.1 AREVA Fuel Sipping Technique

In general, the sipping technique draws gas samples from each fuel assembly tested. These samples can then be analysed for indications of failed pins. Most analyses rely on gas sample monitoring for the presence of inert gas fission product species such as Xe-133 and/or Kr-85.

Sipping is considered to be one of the most reliable methods of identifying a failed assembly. It can experience difficulty when fuel defects are very open (most fission gases have been released) or very tight (releasing very small quantities of activity).

The AREVA vacuum canister sipping technique enables the identification of leaking assemblies by isolating each assembly in a sipping canister under a vacuum that ensures high reliability for leak detection and enables the system to more efficiently obtain an effective count rate of the fission gases released from a fuel failure. This system has been proven to detect leaking fuel assemblies 30 years after operation.

The vacuum sippers incorporate several features to ensure safe and reliable operation. Visible and audible alarms indicate loss of service water or compressed air, high canister temperature, insufficient vacuum or loss of the canister lid seal. Loss of services will automatically cause the canister lid to open and the system to return to the flush mode to prevent damaging the fuel assembly. The sippers' electronic console includes a built-in diagnostic program.

The vacuum sipping system utilises beta scintillation detectors. Gases pulled from the sipping canister via the vacuum pump are passed directly under the detector. Signals produced by the detector are transmitted to the computer-based data acquisition system.

A typical set-up time of 12 hours is required for system installation. Then, 30 minutes are necessary for the assembly transfers and test cycle.

The consoles are designed to be positioned on the deck near the edge of the fuel pool, and are linked to the sipping canister by a series of vacuum lines, water hoses and compressed air lines which allow remote operation of the sipping canister.

Typical arrangements are shown in Figures A1.1 and A1.2.

A1.2 AREVA Ultrasonic Technique

AREVA has developed a technology based on ultrasound to detect failed rods inside a leaking assembly, with high efficiency.

Ultrasonic testing was introduced into the industry in Europe in 1979 and in the USA in 1983. In 1986, AREVA developed a multi-probe single pass system that was used as the primary inspection technique for leaking fuel.

Ultrasonic testing is employed to identify both failed assemblies and to locate the failed rod positions in the assembly. The technique detects water in the rod, through attenuation of the ultrasound signal. The normal inspection process focuses on the lower part of the assembly, which provides the best response with the highest probability of locating water in the failed rod.

The AREVA ECHO-330 system is composed of ultrasonic probes, the probe assembly manipulator and the system command centre (See Figure A1.3).

The mechanical manipulator moves an array of ultrasonic probes through the fuel assembly (see Figure A1.4) under the command of a computerised control and data acquisition system. When passing a rod position each transmitter is energised, introducing an ultrasonic signal into the fuel rod cladding. By monitoring the relative strengths of the return ultrasonic signals for all rods in a row, the system can distinguish between rods containing moisture and dry rods.

Indeed, for a totally dry fuel rod, a large amount of the incident ultrasonic energy travels from the transmitter to the receiver whereas for a rod containing moisture, the water acoustically couples the cladding to the fuel pellets, causing additional signal attenuation and a reduction in the ultrasonic energy reaching the receiver.

The system is controlled from a remote system command centre, which contains the data acquisition system that receives, amplifies, filters records and analyses the electronic pulses received from the electronic probes.

Overall, fuel ultrasonic testing has been the most widely used technique for identifying failed rods in an assembly, and it has been very successful. It remains the most effective tool for identification of failed or potentially failed rods within a fuel assembly which does not require disassembly.

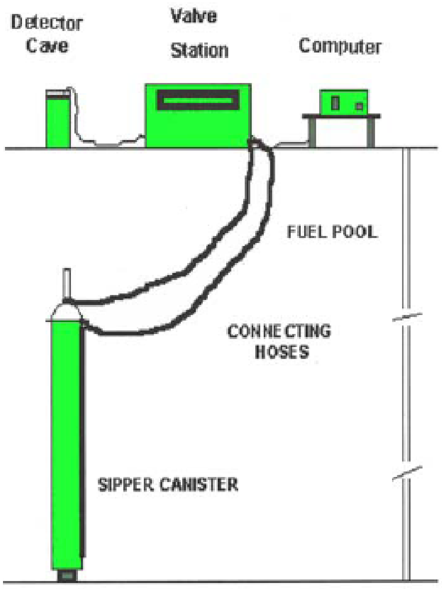

Figure A1.1: Typical Vacuum System Arrangement

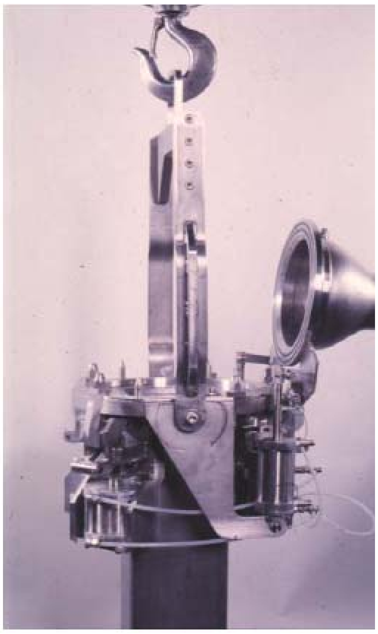

Figure A1.2: Vacuum Canister Cell with Open Lid

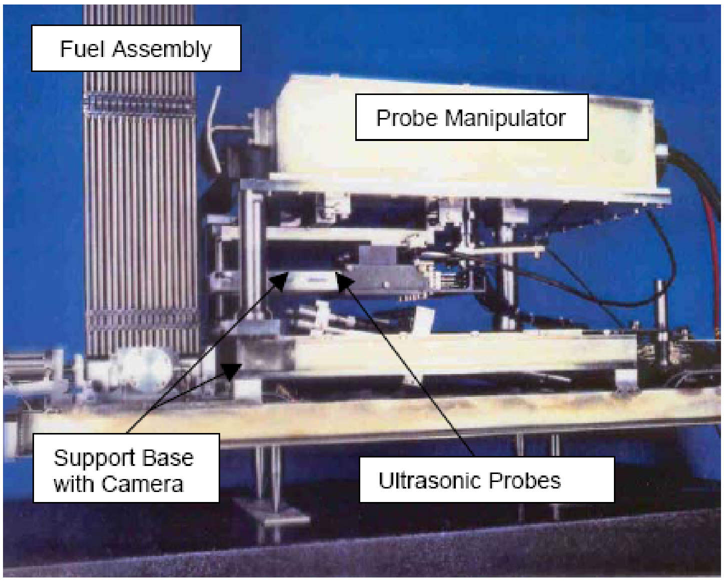

Figure A1.3: **ECHO-330 System Components**

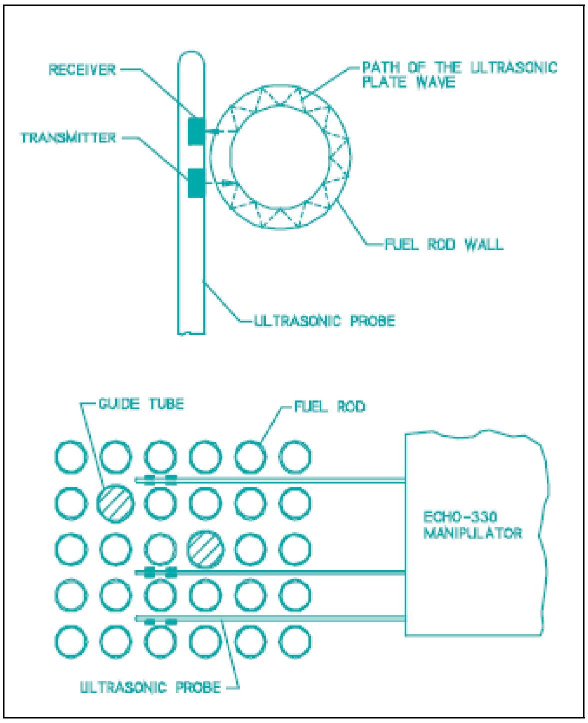

Figure A1.4: **ECHO-330 Probe Arrangement**