SAFARI-1 Safety Reassessment and Modifications in light of Fukushima Daiichi Accident

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Where is SAFARI-1 in South Africa?

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SAFARI-1 OVERVIEW

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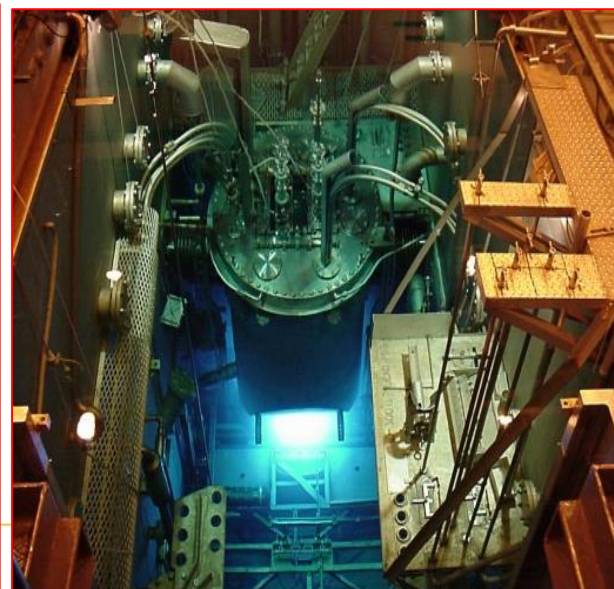
- SAFARI-1 **20 MW Tank-in-Pool MTR reacto**r of ORR design – **light water moderated and cooled, Be reflected.**
- The reactor has been in operation since 18 March1965 **(~3 943 458 MWh)**
- Fully Core Converted to LEU in 2008-9 (LEU < 20%)
- Highly utilised reactor (>300 FPD/Year) for over 15 years
- Primary activities: **Isotope production**; NTD ***Si doping*** and ***beam port research & ET***
- Significant Investment in the ageing management program of SAFARI-1, to ensure safe continued operation > ***objective to operate beyond 2030***



SAFARI-1 Safety Reassessment (SR)

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- Following the Fukushima nuclear accident in March 2011, a ***directive from South Africa's National Nuclear Regulator (NNR)*** was received which required a ***SR of the SAFARI-1 research reactor (RR)***

- The SR consisted of: ***Evaluation of the response of the SAFARI-1 RR*** when facing a set of ***extreme external events (EEE)*** and

- **Verification of the *preventive and mitigation measures*** - defence-in-depth (DiD) logic:
  - initiating events,
  - consequential loss of safety functions,
  - severe accident management
- **Evaluations carried out** in accordance with the ***ENSREG stress test specification***

SAFARI-1 Safety Reassessment (SR)

- A **comprehensive list of EEE were considered** for the SR ,
  - **Earthquakes**
  - **External flooding** , Tornadoes , tornado missiles
  - **High winds** -Sandstorms -**Storms and lightning**
  - Hurricanes -Tropical cyclones - **Bush Fires**
  - **Explosions** , **Toxic spills**
  - **Accidents on transport routes**
  - **Effects from adjacent facilities**

    (e.g. nuclear facilities, chemical facilities & waste management facilities)
  - **Biological hazards** such as microbial corrosion
  - **Power or voltage surges** - SBO

Prominent features of SAFARI-1

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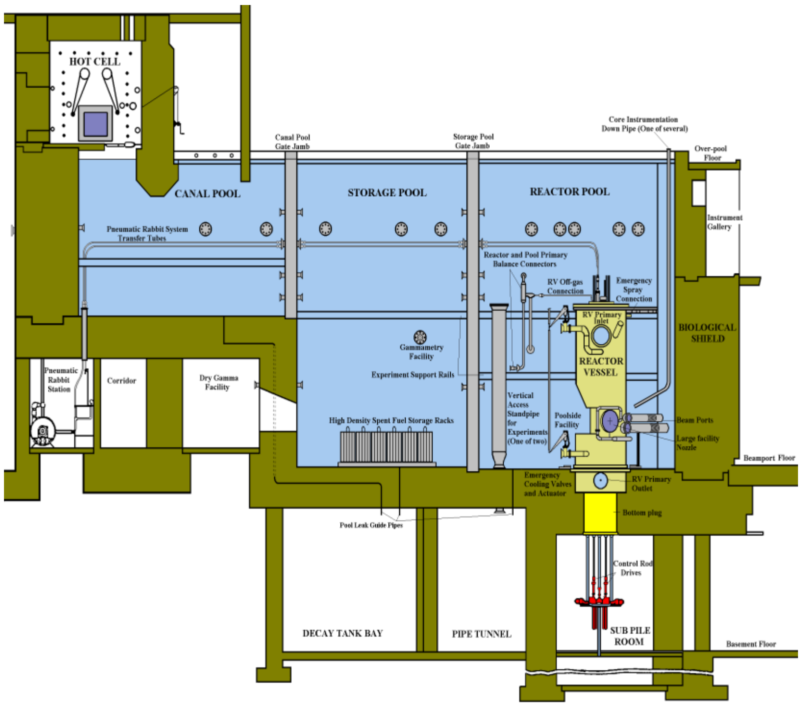

Reactor Primary System

- The reactor primary system is fully enclosed and circulated separately from the pool system.

Pool Structure

- **A prominent feature of the reactor building is the pool structure,** which comprises three pools separated by removable gates;

✓ **the reactor pool (where the reactor vessel is located),**

✓ **the spent fuel pool (SFP) and**

✓ **the canal pool.**

Confinement System

- The reactor building is **not a containment structure**.
- **Confinement of releases is controlled by means of active ventilation systems**

Heat Sink

- The ***heat sink***, to which the heat from the reactor core, reactor vessel and SFP is transferred, **consists of**:-

✓ the **reactor primary system** and

✓ the **pool primary system from where the heat is transferred through shell and tube type HX** to the secondary system.

✓ **Heat is dissipated** to the atmosphere from the secondary system **via** forced convection wet **cooling towers**.

SR GENERAL RECOMMENDATIONS

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- In the past 52 years of the SAFARI-1 RR operation, no seismic event or severe adverse weather phenomena have been encountered that impacted nuclear safety or the safe continued operation of the reactor.
- The feasibility and **effectiveness of accident management measures** are however regularly **tested during emergency preparedness exercises.**
- The Safety Reassessment indicated that hardware modifications could be investigated to enhance the robustness of the plant against EEE

SR GENERAL RECOMMENDATIONS

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- An early severe weather warning notification system which could be beneficial to alert operators of approaching adverse weather conditions.
- Ensuring communication between control room and the site Emergency Services.
- Bringing the plant to a safe state before the any EEE strikes.
- Stopping the intake ventilation systems to ensure that a negative pressure difference between the radiological areas and the outside environment is maintained during a severe event challenging the confinement.
- Execution of the plant emergency procedures to take action as required (e.g. evacuating personnel from areas affected by the unavailability of intake ventilation systems).

SR POPOSED PLANT MODIFICATIONS

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SR MOD	Objective
1. Stabilisation of Fresh Fuel Vault	• ***Secure fresh fuel element and control rod rack structures*** *against toppling over.* • ***Stabilise brick wall*** • ***Improve fire protection mechanism***
2. Emergency Water Return System	• ***Provide the means and equipment to return cooling water*****,** lost through breaches in cooling systems during an EEE, from the reactor and process wing basements and from the external waste tanks back to the core and storage pool, with multiple redundancy. • **Also** ***exploit alternative sources of water*** **(e.g.** ***the cooling tower ponds*****)**
3. Portable External Plug-In Power Supplies	• ***Provide power using external portable generators*** to some essential functions during extreme external events. • Standardised plug-in points at various locations, with multiple redundancy**.**
4. Emergency Control Room and Diverse Instrumentation	***Provide an external Emergency Control Room (ECR) and dedicated instrumentation to assist in management of an extreme external event*** that could render the main control room and parts of the reactor building unavailable.
5. Re-flooding Nozzle	• ***Provide an additional re-flooding nozzle*** (pathway in addition to existing pathways) to ***limit / prevent fuel damage during certain Loss of Coolant Accident*** (LOCA) conditions caused by an extreme external event

SR PROPOSED PLANT MODIFICATIONS

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SR MOD	Objective
6. Seismic Trip	• ***Provide a means to implement pre-emptive shutdown of the reactor during the build-up of a severe (beyond design basis) seismic event***, should the reactor shutdown by the normal trip systems be inhibited.
7. Second Shutdown System	• ***Provision of a 2nd shutdown system for the reactor following an extreme external event that renders the existing shutdown system (control rods) unable to insert*** • *A "second shutdown system" therefore needs to take the form of a procedure of numerous actions the operators can follow to reduce the reactivity of the core systematically over a period of time.*
8. Reactor Building Reinforcement	• ***Assess the toughness of SAFARI-1 building structures against an extreme external event and to identify means to increase its robustness where necessary.*** • *A detailed seismic assessment was conducted by expert structural engineers organisation.*
9. Emergency Procedures	• ***Adapt the facility emergency procedures for the management of an extreme external event.***

STABILISATION OF THE FRESH FUEL VAULT

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Close-up View of the Fuel Assembly Cradles

- *Stabilisation of the fuel and control racks frames to ensure they remain geometrically safe*
- *Stabilisation of Internal Brick wall*
- *Improvement of Fire Loading & Protection in the vault*

EMERGENCY WATER RETURN CONCEPT

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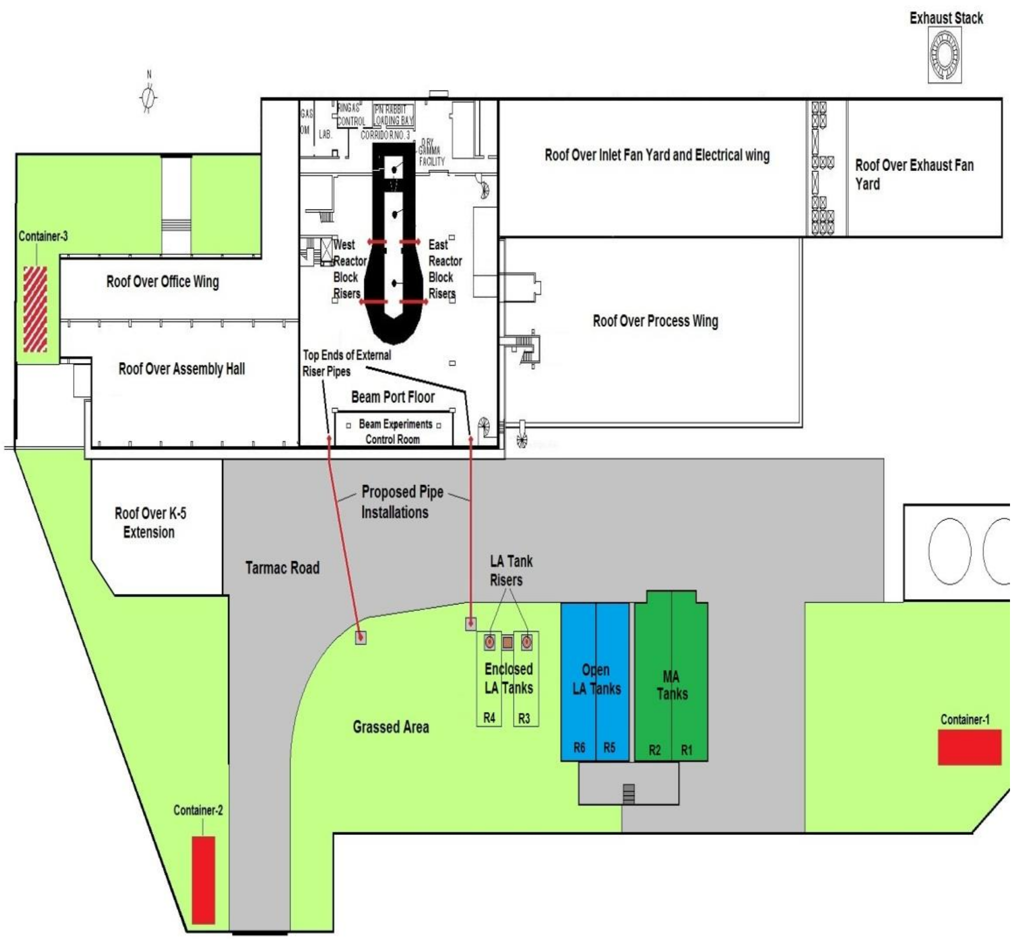
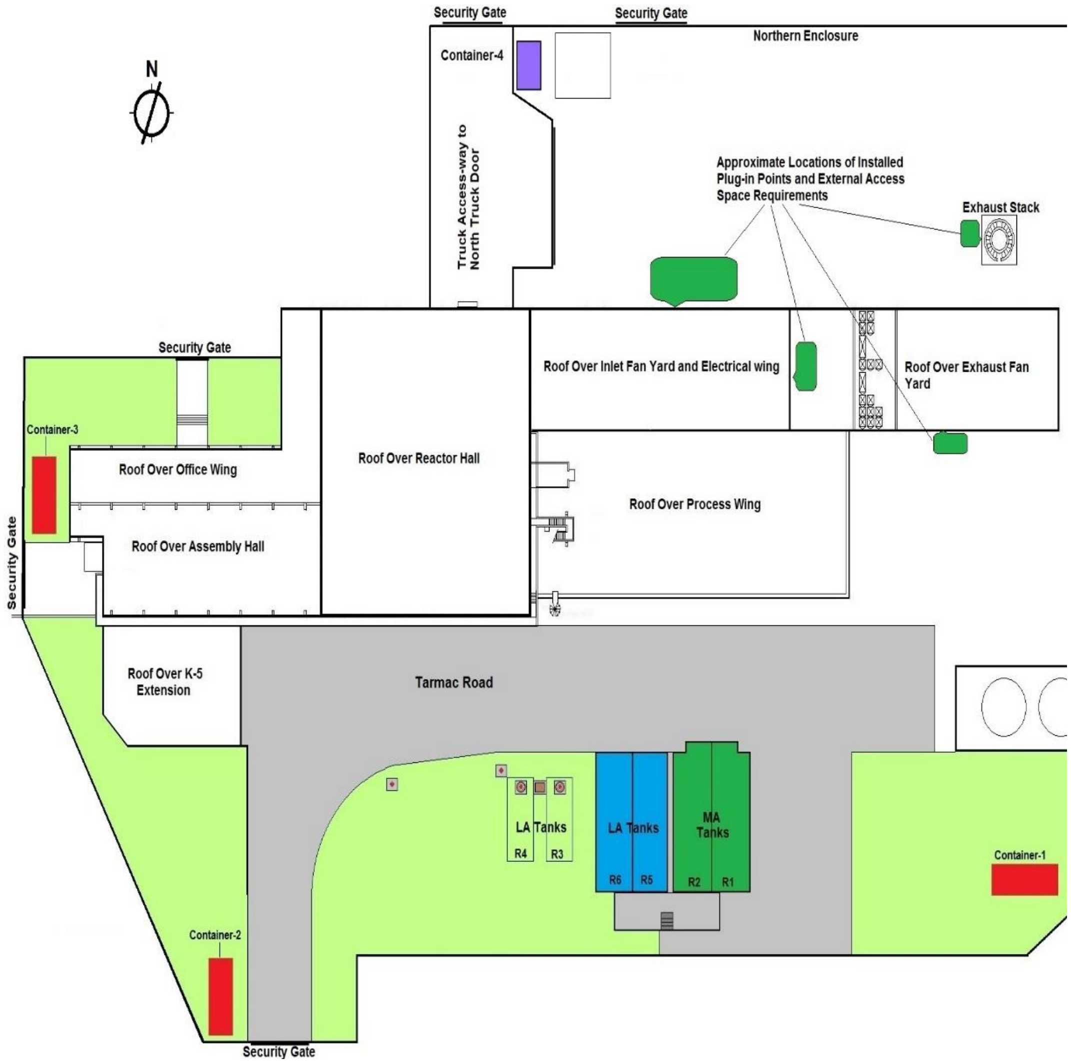


The implementation considered various viable water supplies:-

- *Water collection from the* ***Reactor Basement Area***
- *Returning Water from the* ***Pipe Tunnel Area***
- *Returning Water from the* ***Primary Process Wing Area***
- *Water collection from Outside* ***LA and MA Tanks***
- *Pumping Water from the* ***Cooling Towers ponds***

EXTERNAL PLUG IN POWER SUPPLY CONCEPT



OPTION-1: PLUG-IN POWER SUPPLIED AS INPUT TO THE UPS'

- ✓ The first approach is to ***supply power at the common points where the combined failure of offsite and Genset power is initially manifested***, namely at the inputs to the UPSs

OPTION-2: PLUG-IN POWER SUPPLIED AT THE OUTPUT OF EACH UPS

- ✓ This allows the ability to ***connect directly to the output cables from each UPS, enabling the selective provision of power even when the UPSs, or their supply cables, have been damaged beyond usefulness***

RE-FLOOD NOZZLE CONCEPT

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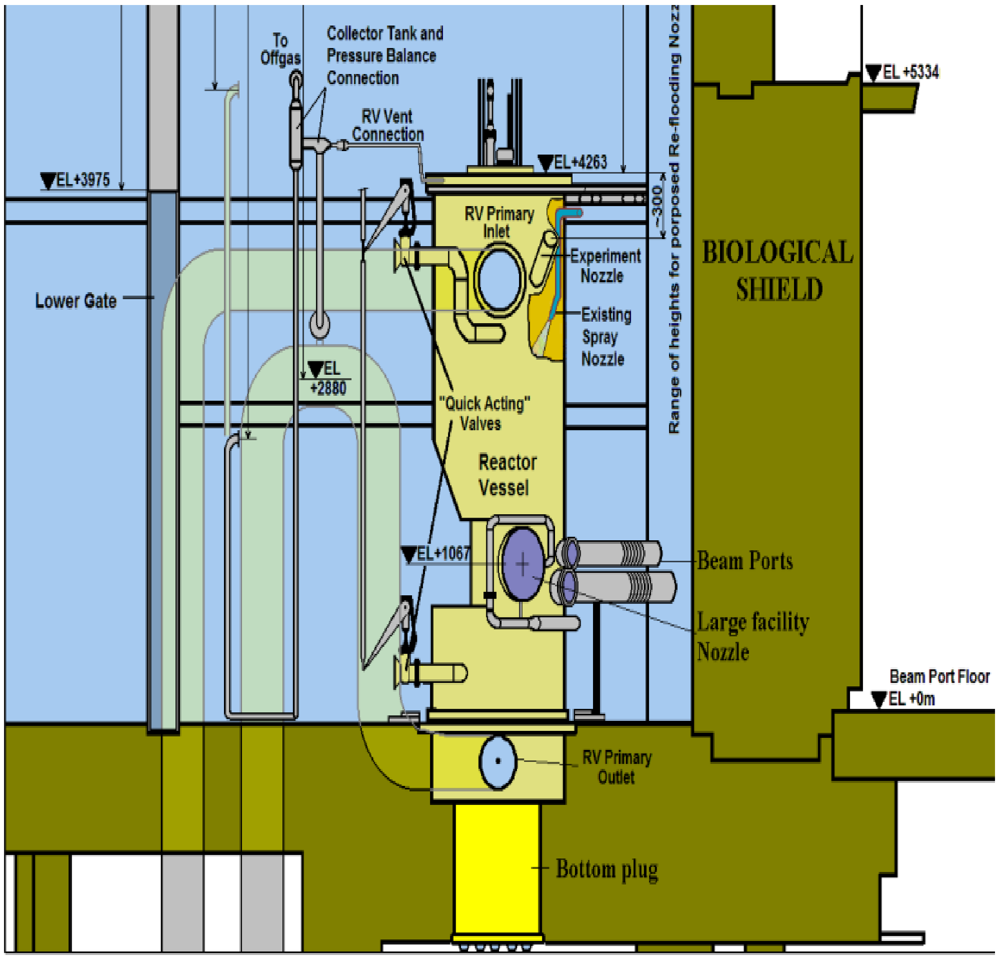

Vertical Section Through Reactor Pool Showing Components of the Primary Pressure Reference and vent system and the existing Spray Nozzle

Investigate ways of improving the re-filling of the reactor vessel after it has drained following a large loss of coolant accident (LOCA) in the primary system:-

- ***Grid of Spray Nozzles*** *above the Core under the Hatch Cover*
- *Directing the* ***Re-flooding Flow Straight from Above the Core***
- *Directing the* ***Re-flooding Flow at an Angle***
- ***Integrate the Re-flood nozzle with the emergency water return***
- ***Elevation of the goose neck since it is below the inlet of the spray nozzle***

RE-FLOODING SPRAY NOZZLE CONCEPT DEPICTION

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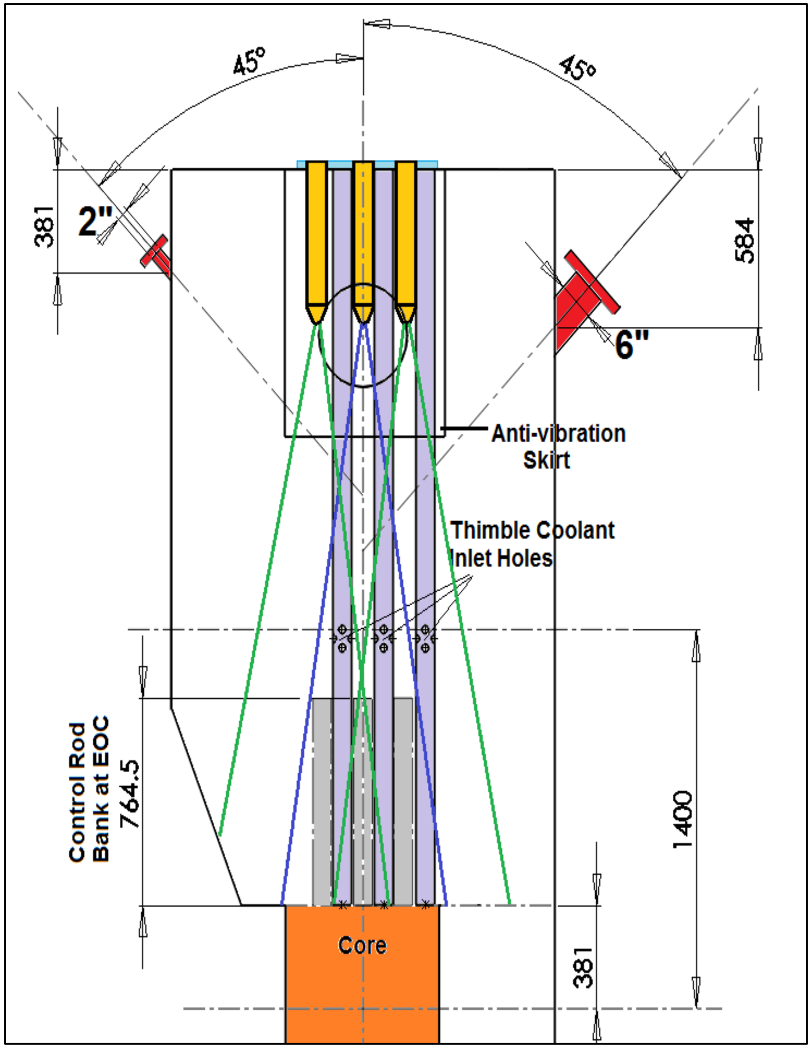
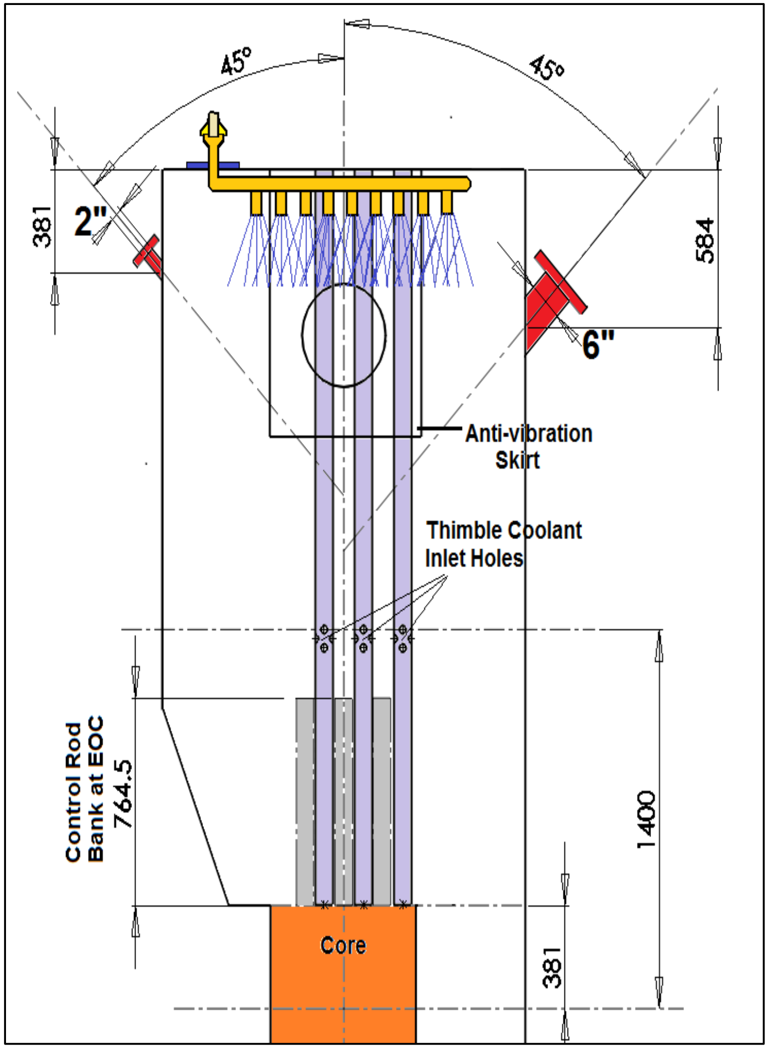
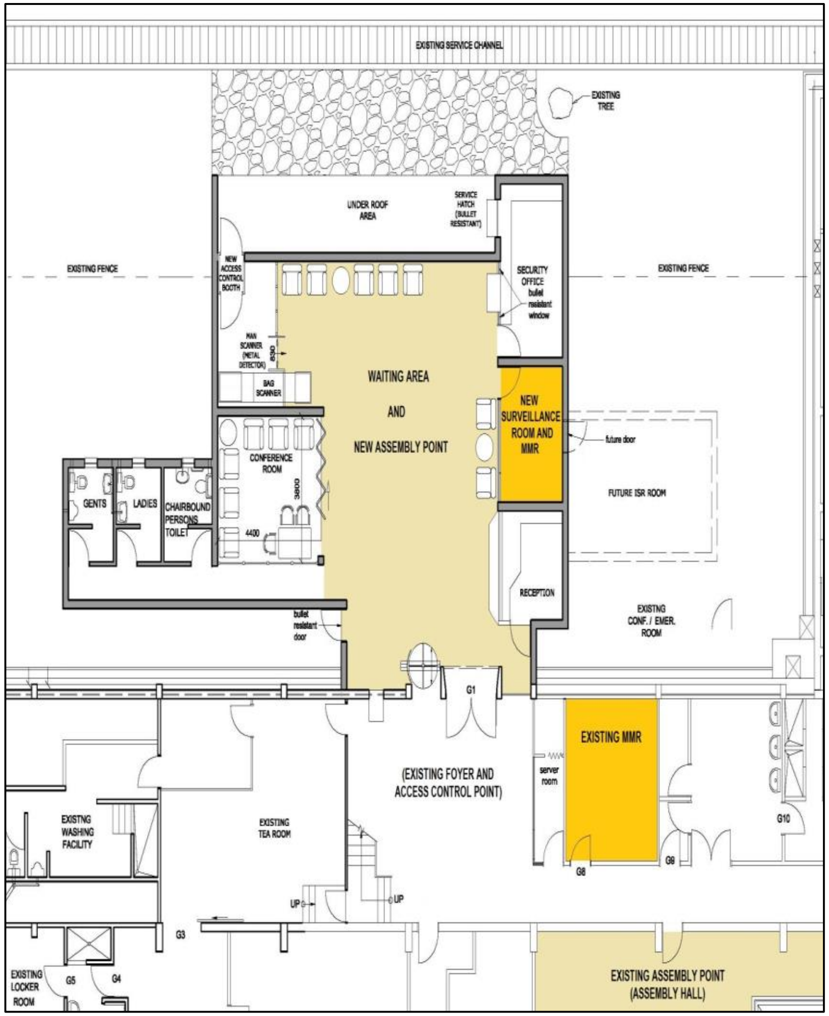




EMERGENCY CONTROL ROOM (ECR) CONCEPT



- ***To investigate the provision of an "Independent Shutdown Room"- a place where the reactor operators can continue plant shutdown and monitoring activities when the main control room is unavailable or ceases to function.***

- *ECR Structure: ISO Containers*

- *ECR Power Supplies:*
  - *Mobile / Fixed power supply from UPS-4 for limited requirements*
  - *Built-in generator set sized to supply all power requirements*
  - *Plug-in Power supplies / batteries*

- *Connection to reactor facility*

SAFETY CLASSIFICATION OF SSCs FOR DESIGN EXTENSION CONDITIONS

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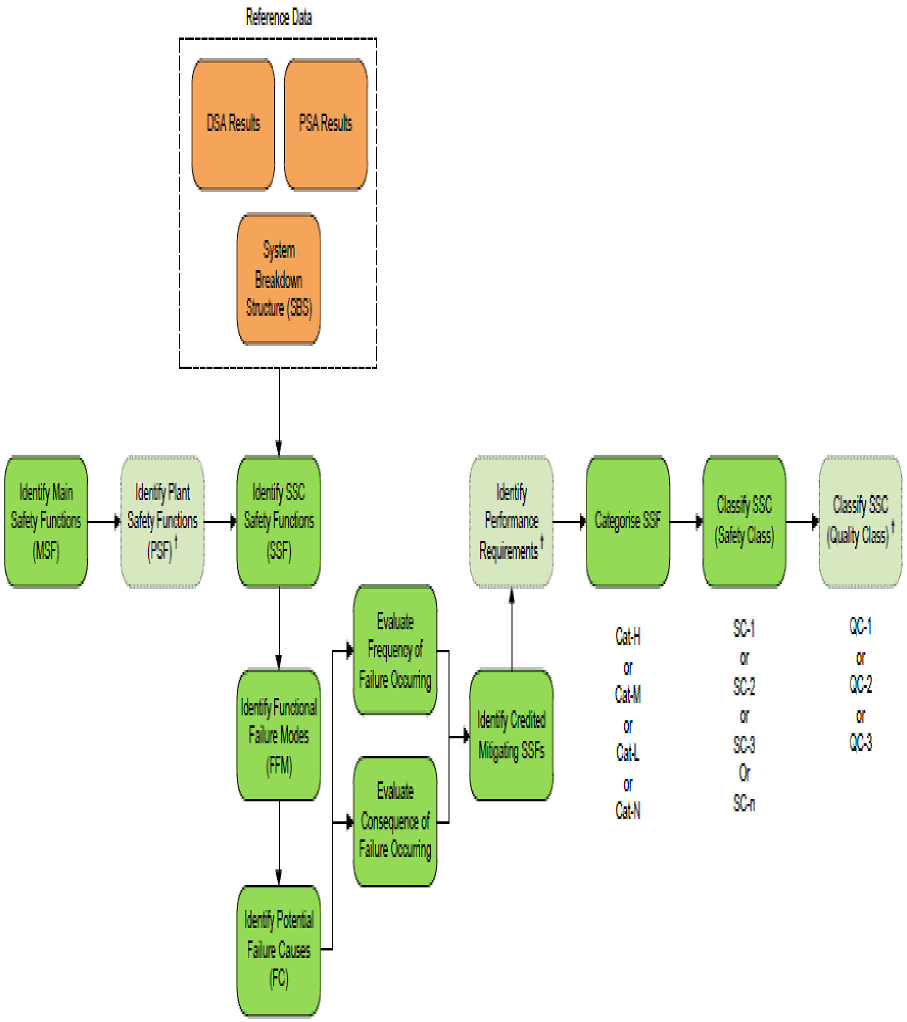

Classification of SSCs earmarked for Extreme External Events (EEE) or Design Extension Conditions

SAFARI-1 Methodology : SSCs that perform or contribute towards SSFs (SSC Safety Functions) during design basis conditions (i.e. Normal Operation, AOOs and DBAs)

The classification methodology is unsuitable for EEE SSCs that only assist in managing the potential effects after the occurrence of a ***beyond design basis Accident***

This is because the methodology requires evaluation of the "risk benefit" of the SSF .

Then an EEE SSC which interfaces with other SSCs in the existing plant is evaluated in terms of ***its effect on the other SSC during design basis conditions***

As result EEE SSC ***shall carry the safety class corresponding to the highest category of safety functions that may be compromised in the event of failure*** *of the EEE SSC*

Seismic considerations : selectively taken into consideration as deemed appropriate

SR IS WITHINN THE INTEGRATED PROGRAMMES / MANAGEMENT SYSTEMS IN SAFARI-1

- ***AGEING MANAGEMENT PROGRAMME***
  - ***MAINTENACE** PROGRAMME*
  - ***ISI** PROGRAMME*
  - *MANAGEMENT OF **CRITICAL SPARES***
  - ***SAFETY CLASSIFICATION OF SSC'S** PROCESS*
  - ***SAFETY REASSESSMENTS MODIFICATIONS FOLLOWING F-D***
- ***REACTOR SAFETY COMMITTEE***
- ***INSARR** (2013) RECOMMENDATIONS*
- ***PLANT** HEALTH STATUS assessment*

  PERIODIC SAFETY REVIEW

STATUS / UPDATE OF SR MODIFICATIONS

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Investigations

2011-2012

Initiating Events / EEE

- *Earthquakes*
- *External flooding ,*
- *High winds*
- *Storms and lightning*
- *Bush Fires*
- *Explosions , Toxic spills*
- *Accidents on transport routes*
- *Effects from adjacent facilities*
- *Biological hazards*
- *Power or voltage surges - SBO*

Recommendations

2012- 2013

- General Recommendations
  - ✓ *Severe weather warning notification system*
  - ✓ *Ensuring Control Room communication with Site Emergency services*
  - ✓ *Bring plant to a safe state before EEE strikes*
- Update Plant emergency procedure
- Hardware Modification

Proposed Plant Modifications

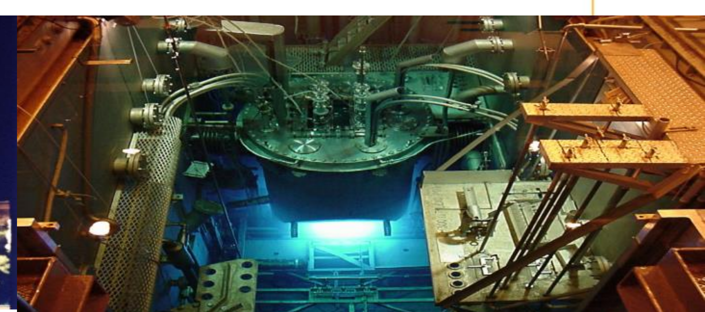
2013-2014

1. Stabilisation of Fresh Fuel Vault
2. Emergency Water Return System
3. Portable External Plug-In Power
4. Emergency Control Room
5. Re-flooding Nozzle
6. Seismic Trip
7. Second Shutdown System
8. Reactor Building Reinforcement
9. Emergency Procedures

Implementation Phase

2014 -2020??

1. *Stabilisation of Fresh Fuel Vault*
2. *Emergency Water Return System*
3. *Portable External Plug-In Power*
4. Emergency Control Room
5. *Re-flooding Nozzle*
6. *Seismic Trip*
7. TBD / On Hold
8. TBD /on Hold
9. *Emergency Procedures*



Conclusion and Lessons Learned

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- The regulatory body has given approval for the implementation of the safety reassessment (SR) subject to **meeting licensing / regulatory requirements**

- The SR have provided an opportunity **to strengthening systems and processes such as design /modification control** based on international best practices and safety guidelines and regulations.

- The SR modifications is centred around **nuclear safety** but more specifically is to **enhance the operational capability of the plant**

Conclusion and Lessons Learned

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- Integrating multiple programmes with **limited resources requires careful management**, the **successful implementation of the SR modifications projects** need **adequate resource allocation & SQEP**.

- The SR implementation process have assisted in the improvement of the safety documents – **SAR, OTS (OLC), Operation & maintenance procedure etc.**

- The Fukushima Daiichi accident demonstrated the **necessity of having strong safety assessments, reliable defence in depth** and ***strong regulatory bodies.***

THANK YOU