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The Nuclear Safety Case for the Replacement Research Reactor

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SUMMARY
This paper presents a broad overview of the safety case being used in the licensing of Australia's Replacement Research Reactor. The reactor is a 20 MW pool-type research reactor and is being constructed at the Lucas Heights Science and Technology Centre in Sydney's south. It will be owned and operated by the Australian Nuclear Science and Technology Organisation (ANSTO) and will take over the duties currently performed by HIFAR, a DIDO-type reactor currently operating at the site.

1 INTRODUCTION

In order to site, construct and operate a Commonwealth nuclear installation in Australia, a case for demonstrated safe operation needs to be made to the regulator, ARPANSA. This demonstration of the safety case is made primarily by way of the installation's Safety Analysis Report (SAR) and the subsidiary documentation referenced therein[1]. The purpose of this paper is to describe the safety case that has been, and is being, prepared for Australia's Replacement Research Reactor (RRR). The RRR is being built at the Lucas Heights Science and Technology Centre in Sydney's south by the Argentinian company INVAP on behalf of ANSTO, the future owner and operator of the facility.

In addition to describing the aims of the safety case for the RRR, we shall also consider its content and future use.

2 AIMS OF THE SAFETY CASE

In building and operating the Replacement Research Reactor, the responsibility for ensuring safety rests with the operator, ANSTO. Compliance with applicable regulatory criteria does not relieve ANSTO of the fundamental obligation to ensure the protection of site personnel, the general public and the environment. The mechanism by which ANSTO demonstrates to the regulatory body how this responsibility is discharged is the safety case.

The regulatory body has primary responsibility for determining that the RRR can be sited, constructed, commissioned, operated, utilised, modified and decommissioned without undue radiological risk to the personnel on site, the surrounding population and the environment.

The primary basis for the review and assessment of the nuclear safety aspects of the RRR is the information contained within the Safety Analysis Report submitted by ANSTO. One of the aims of the review and assessment is to determine whether the RRR has met the necessary regulatory acceptance criteria. These criteria are set for both the operational states of the reactor and the accident conditions considered in the design of the facility.

The regulatory body has set out the principles and criteria that it will use to assess the RRR in its document "Regulatory Assessment Principles for Controlled Facilities" (1). These are mainly qualitative in nature. The quantitative criteria are primarily those associated with dose limits for facility staff at the site and the general public together with accident frequency-dose limits. Quantitative

[1] As the safety case being presented to the regulator for the RRR is the collection of arguments and evidence necessary to demonstrate the safety of the facility and its operations and as this information is contained primarily in the SAR, in this paper we shall consider the safety case for a nuclear installation to be synonymous with its SAR.

criteria are also set for safety system reliability and the likelihood of significant damage to the reactor core.

3 SCOPE OF THE SAFETY ANALYSIS

In making a case of the safety for a proposed activity, the question arises, 'How far is it necessary to go to make the argument for adequate safety?' It is perhaps this aspect of nuclear safety cases that differs most markedly from those of other hazardous, but non-nuclear, facilities.

The safety case for the RRR considers all aspects of normal operation and anticipated operational occurrences (together termed 'operational states'). Wherever there is an activity associated with the operational states of the RRR that has the potential to impact nuclear safety or radiological protection, then that activity is proceduralised and training given to the relevant operators. Even normal operational activities with no nuclear safety or radiological protection issues will tend to be proceduralised as part of the smooth running an efficient facility. In this respect, however, the RRR is no different to any other hazardous facility.

It is in the area of accidents and their prevention and mitigation, however, that the greatest differences arise.

The design and operation of the RRR is reviewed to determine what failures of equipment and operators could occur that have the potential to challenge the integrity of the reactor core or irradiation rigs. The failures are then grouped under the following headings;

- Loss of External Power Supply,
- Loss of Regulation
- Loss of Flow,
- Loss of Heat Sink,
- Loss of Coolant,
- Loss of Heavy Water,
- Erroneous handling or failure of equipment or components relating to fuel assemblies,
- Special Internal Events,
- Reactor Utilisation Events,
- Spurious Triggering of Safety Systems,
- External Events, and
- Human Errors.

Within each group the identified failures are assessed to determine what safety systems are required to operate to ensure integrity of the core or irradiation rigs. This results in the generation of fault sequences. The fault sequences then undergo qualitative screening to determine which are limiting in terms of coming closest to challenging the safety of the reactor. The limiting fault sequences are then quantitatively analysed. Because a qualitative approach is used to screen the fault sequences, a number of fault sequences tend to be identified within each group for quantification.

In postulating failures with the potential to challenge the integrity of the core or rigs, consideration is given to the likelihood of the failures. As a general statement, any postulated initiating event (PIE) with a likelihood of greater than 1 in 1,000,000 per year will be considered to lie within the design basis and be included as part of the safety analysis. Events of lesser likelihood, such as meteorite impact, are considered to be so unlikely as to be incredible and therefore beyond the design basis.

In setting such a low 'cut-off' frequency for events, fault sequences arising from relatively frequent initiating events but including failure of a safety system are also considered. The likelihood of an initiating event coincident with failure of two or more safety systems is considered sufficiently remote as to be incredible.

External events are always of particular interest in nuclear safety cases as they have the potential to act as initiating events and to fail safety systems, i.e. common cause failures. For the RRR the external event of greatest interest is earthquake. For this event a 10,000 year return period seismic event was chosen, resulting in a Peak Horizontal Ground Acceleration applied to the facility of over 0.4g.

Even though the likelihood of aircraft impact is considered to be so unlikely as to place it beyond the design basis, the decision was taken to ensure that the RRR would be capable of withstanding the impact of a light aircraft. The input parameters in this case were for a jet with a 5.7 tonne takeoff mass and capable of a maximum speed of 450 knots.

4 RESULTS OF THE SAFEY ANALYSIS

All limiting design basis fault sequences are quantified in a conservative manner to ensure that, in the highly unlikely event of their occurrence, the actual consequences would be less than those estimated.

The success criterion adopted for the analysis was departure from nucleate boiling in any part of the core or rigs. Regulatory interest centres around the potential for significant core damage (i.e. melting of a large fraction of the core). The success criterion adopted, being applicable at any time and to any point of fuel assembly or irradiation rig surface, is considered to be a conservative surrogate for 'significant damage'.

The results for the RRR have shown that no design basis fault sequence will lead to significant damage to the core. A number of fault sequences were identified, however, that would lead to gross damage of irradiation rigs at likelihoods in excess of 1 in 1,000,000 years. The radiological consequences of these fault sequences were determined. Assuming a person were to be downwind of the RRR following the occurrence of the worst fault sequence, then, under conservative, non-dispersing weather conditions, that person could expect to receive a dose of some 70 μSv. This should be compared with the average dose received annually by adults resident in Australia of 2,000 μSv. The likelihood of the particular fault sequence resulting in this dose was approximately 3 in 1,000,000 per year. Overall, the RRR was found to sit comfortably within the regulatory risk limits.

5 CONTENT OF THE SAFETY CASE

The SAR has been prepared by INVAP and ANSTO and justifies the design and basis for safe operation of the RRR.

The SAR gives a detailed description of the reactor site, the reactor itself, the experimental facilities and all other facilities of safety significance. It provides a detailed description of the general safety principles and criteria applied to the design and protection of the reactor, the operating personnel, the general public and the environment. It analyses the potential hazards associated with the operation of the reactor and its facilities. It contains the safety analyses of accident sequences and of the safety features incorporated in the design to avoid and minimise the likelihood of accidents or to mitigate their consequences through design provisions and operating procedures.

The SAR also provides a set of operational limits and conditions to be incorporated into the licence for operation. It provides details of the conduct of operations by ANSTO, including the reactor management organisation and the QA programme established for the design and operation of the facility. Details of the emergency plan are also provided.

Table 1 details the contents of each chapter of the Preliminary Safety Analysis Report (PSAR) submitted to the regulator as part of the obtaining of a Construction Licence.

6 EVOLUTION OF THE SAFETY CASE

The safety case for the RRR has evolved as the design and construction have progressed and as the licensing requirements have changed.

At the time when a Site Licence was sought in April 1999, the design of the RRR was known only in a generic sense. Consequently, the safety case made for the licence application consisted of the proposed management plans to be put in place, the results of an environmental assessment, an assessment of the site characteristics and a bounding assessment of the likely radiological consequences of a worst-case accident scenario. This latter scenario was termed the 'Reference Accident' and was assessed as part of demonstrating that the RRR would be able to meet the regulator siting criteria.

At the time a Construction Licence was sought in May 2001, the basic engineering of the RRR had been completed. This allowed a far more detailed presentation of safety arguments to be made. The document submitted to the regulators was termed the Preliminary Safety Analysis Report (PSAR), and served to;

- Aid the designer in confirming that individual systems are integrated correctly,
- Ensure that the safety analysis has properly identified the safety issues relevant to the design and that the safety analysis and design are consistent,
- Aid in the appreciation of the relevant design criteria, their limitations and requirements and in the evaluation of hazards posed by the facility,
- Provide the basis for the development of the Final Safety Analysis Report (FSAR), and
- Aid in operator training and familiarisation with the RRR during the construction and commissioning phase.

The application for an ongoing Operating Licence is planned to be made to the regulator in 2004 and will involve the production of a Draft Final Safety Analysis Report. This is an update of the PSAR to take into account the 'as built' state of the plant, rather than its proposed design. It will be submitted to the regulator in order to allow commissioning activities involving nuclear fuel to go ahead. Following satisfactory completion of the commissioning phase, the results of the commissioning tests will be incorporated resulting in the production of the FSAR. It is this document that will then form the basis for demonstration of safety of continued operation.

The Safety Case of the RRR will be 'living' in that it will be subject to periodic review and regularly updated in line with evolving methodologies and modifications to plant and procedures.

7 CONCLUSIONS

The safety case being prepared for the RRR ranks as one of the most detailed produced for any research reactor in the world and is comparable with those produced for nuclear power plants.

Its scope and content and degree of detail ensure that the risks posed to members of the public, operators and the environment are all adequately low and well within regulatory limits.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

1. ARPANSA. (2001). Regulatory Assessment Principles for Controlled Facilities. RB-STD-42-00 Rev 1.

Introduction and General Description of the Facility	
General Description of the Facility Historical Review Comparison with Other Facilities	Safety Principles Utilisation Program Identification of Owners or Agents
Safety Objectives and Engineering Design Requirements	
Safety Objectives and Criteria General Design Requirements Specific Design Requirements Classification of Structures, Systems and Components	Design Criteria to Withstand External Events Codes and Standards Technical Design Methods Design for Internal Fire Protection Qualification of Components
Site Characteristics	
Site Characteristics Compliance with Regulatory Assessment	Requirements
Buildings and Structures	
Overview of Buildings and Structures Comprising the Reactor Facility Design Bases for the Buildings and Structures Comprising the Reactor Facility Reactor Building Reactor Building Internal Structures and Systems	Neutron Guide Hall Auxiliary Services Building and Facility Substation Main Entrance, Conference Centre and Group Tour Areas Other Structures
Reactor	
Reactor Structures Fuel Assemblies Reactivity Control Elements Reactivity Control and Shutdown Systems Neutron Moderator and Reflector	Nuclear Design Thermal and Hydraulic Design Reactor Materials Reactor Design Software
Reactor Cooling System and Connected Systems	
Primary Cooling System Reactor and Service Pools Cooling System Reactor Coolant Purification System Reactor Pool Hot Water Layer System and Purification System	Reactor Cooling and Purification System Emergency Make-up Water System Secondary Cooling System Piping Materials Characteristics
Engineered Safety Features	
Reactor Protection System Post Accident Monitoring System First Shutdown System Second Shutdown System Emergency Core Cooling by Natural Circulation Rigs Cooling by Natural Circulation	Reactor Pool Coolant Boundary Reactor Containment System Emergency Control Centre Ventilation and Pressurisation System Standby Power System
Instrumentation and Control	
Reactor Protection Systems First Shutdown System Instrumentation Second Shutdown System Instrumentation Reactor Containment Systems Instrumentation Post Accident Monitoring System Reactor Control and Monitoring System Primary Cooling System Instrumentation Secondary Cooling System Instrumentation Reflector Cooling and Purification System Instrumentation	Reactor and Service Pools Cooling System Instrumentation Emergency Make-up Water System Instrumentation Reactor Pool Hot Water Layer System Instrumentation Main Control Room Design Emergency Control Centre Design
Electric Power	
Description of Systems Significant Loads Design Evaluation	Analysis of Operating Scenarios Anticipated Load Summary

Auxiliary Systems	
Fuel Storage and Handling System Fire Protection Communications	Heating, Ventilation, and Air Conditioning Systems Compressed Air De-mineralised Water Supply
Reactor Utilisation	
Description of the Facilities Irradiation Facilities	Neutron Beam Facilities Restriction on Utilisation Materials
Operational Radiological Safety	
Reactor Facility Radiation Sources Reactor Facility Design for Radiological Safety	Waste Management System Dose Estimates for Normal Operation
Conduct of Operations	
Organisational Structure Staff Qualification and Training Review and Audit Facility Documents	Maintenance, Testing and Inspection Physical Security Records and Reports
Environmental Assessment	
Physical, Biological and Social Context of the Reactor Site Environmental Management Radioactive Waste Management System	Hazards and Risks Environmental Impacts Decommissioning
Commissioning	
Commissioning Activities during the Period of the Construction Authorisation	Implementation of the Commissioning Program
Safety Analysis	
Defence in Depth Analysis Methodology Reactor Characteristics Classification of Initiating Events General Protection Level Characteristics of the Design Analysis of the Loss of External Power Supply Event Analysis of Reactivity Insertion Events Analysis of Loss of Flow Events Analysis of Loss of Heat Sink Events Analysis of Loss of Coolant Events Analysis of Loss of Heavy Water Events	Analysis of Erroneous Handling or Failure of Equipment or Component Events Relating to Fuel Assemblies Analysis of Special Internal Events Reactor Utilisation Initiating Events Analysis of Events Due to Spurious Triggering of the Safety Systems External Events Human Error Beyond Design Basis Accident Probabilistic Safety Analysis Objectives Comparison of Incidents Occurring in Other Pool Type Reactors
Operational Limits and Conditions	
Safety Limits Safety System Settings Limiting Conditions for Safe Operation	Surveillance Requirements Administrative Requirements
Quality Assurance	
Status of QA Programs	QA Organisation
Decommissioning	
Decommissioning Objectives, Principles and Design Basis Facilities Hazards Decommissioning Waste Types and Management	Decommissioning Strategies Activities During Decommissioning Design Characteristics to Facilitate Decommissioning
Emergency Planning and Preparedness	
Organisation Emergency Control Alarms and Security Systems Emergency Equipment and Supplies	Medical Facilities Procedures for Emergency Response Actions Emergency Plan Maintenance External Actions

Table 1 Contents of the Preliminary Safety Analysis Report