National Nuclear Regulator

HTGR Workshop

Defence in Depth (DiD) Principle for the HTGR

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Contents

Introduction

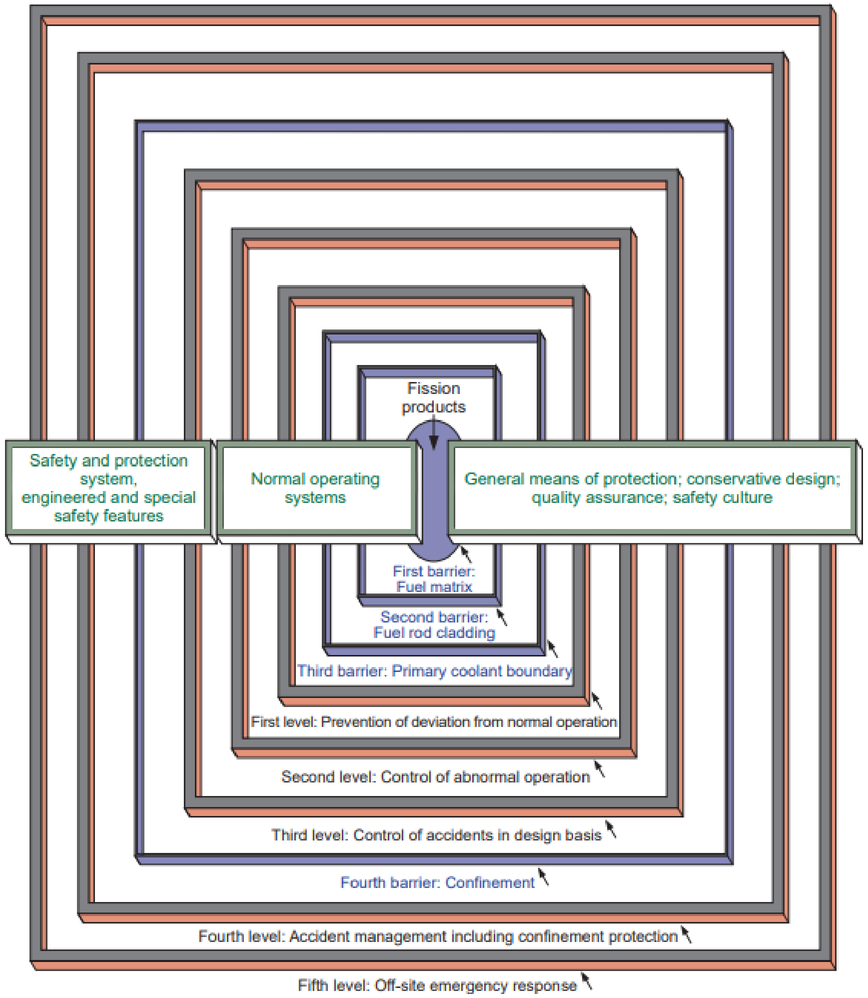
- In terms of the provisions of section 21 of the National Nuclear Regulator Act, Act No. 47 of 1999 (NNRA), the siting, construction, operation, decontamination or decommissioning of any nuclear installation as defined in section 1(xviii) of the NNRA must be authorised by way of a nuclear installation license granted by the National Nuclear Regulator (NNR)
- The legislation authorises the inclusion in the nuclear installation licence of any conditions deemed necessary by the NNR to ensure the protection of persons, property and the environment against nuclear damage or for the rehabilitation of the site
- RD-0018: Basic Licensing Requirements for the Pebble Bed Modular Reactor was approved 9 April 2009 with next revision date of 1 April 2012
- Appendix B of RD-0018 addresses the application of the Defence in Depth (DiD) principle

Introduction

- **Defence in Depth** is a hierarchical deployment of different levels of diverse equipment and procedures to prevent the escalation of anticipated operational occurrences and to maintain the effectiveness of physical barriers placed between a radiation source or radioactive material and workers, members of the public or the environment, in operational states and, for some barriers, in accident conditions - *(Glossary of Reference 5)*

- **Principle** is to compensate for potential human and mechanical failures, a defence in depth concept is implemented, centred on several levels of protection, including successive barriers preventing the release of radioactive material to the environment. The concept includes protection of the barriers by averting damage to the plant and to the barriers themselves. It includes further measures to protect the public and the environment from harm in case these barriers are not fully effective

Relation between physical barriers and levels of protection in defence in depth



Application of the Defence of Depth (DiD) Principle

B-1: Safety functions

Sufficient HTGR *safety functions* shall be provided to ensure that the *FSF* are maintained and to provide the required levels of DiD

As a result of the adoption of the DiD principle, the HTGR shall be designed so that DiD can be substantiated for the HTGR by the provision of:

- Sufficient independent reactivity control functions
- Sufficient independent heat removal functions
- Sufficient independent barriers for confinement of fission and activation products

Application of the Defence of Depth (DiD) Principle

B-2: Levels of defence in depth

The use of the following well-established principles of defence in depth is required:

- Prevention of deviation from ***normal operation***
- Detection of deviations from *normal operation* and provision of means to prevent such deviations leading to category B events - *(**Anticipated operational occurrences**)*
- Provision of engineered safety features (active and passive to control and mitigate the category B events) - (***Design basis accidents***)
- Prevention and mitigation of *beyond category B events* through the consideration of events or combinations of events with an annual frequency $<10^{-6}$. Emphasis shall be put on prevention of beyond category B events. Realistic assumptions and best estimate methods may be used to analyse these conditions - *(**Design extension conditions**)*
- Mitigation of radiological consequences of significant releases of radioactive materials by means of ***off-site emergency response***

Application of the Defence of Depth (DiD) Principle

B-3: Barriers

The *facility* shall be designed so that:

Sufficient independent barriers for confinement of fission products are provided

- The confinement of the fission products is ensured by these barriers with sufficient margins for all category A events
- The integrity of nuclear fuel is maintained for all category A and B events and fuel failures due to accidental conditions are minimised even for *beyond category B events*
- The integrity of the Primary Pressure Boundary (PPB) is maintained for all category A and B events except for the failure assumptions to be set for the PPB itself

Application of the Defence of Depth (DiD) Principle

B-3: Barriers

- The overall radioactivity confinement function of the civil structures forming the confinement functional design shall be ensured with sufficient margins for all category A events
- The integrity of the civil structures forming the confinement functional design of the building shall be ensured for the category B events. Provisions shall be made to minimise the damage of the civil structures for *beyond category B events*
- For *beyond category B events* at least one confinement function must be adequately maintained in such a way that no *cliff edge effects* occur

Application of the Defence of Depth (DiD) Principle

B-4: Accident prevention

- In respect of the principle of defence-in-depth and accident prevention, the design shall ensure that exposures to the personnel and the public exceeding the category A dose criteria are unlikely to occur during the lifetime of the *facility*
- Fuel element design, fabrication and inspection, and the conditions under which the fuel is operated shall be such as to ensure a high degree of integrity
- Integrity of the reactor coolant system
- A *facility* that is simple to operate and maintain.
- Performance capabilities of the personnel

Application of the Defence of Depth (DiD) Principle

B-4: Accident prevention

- Information and recommended practices for incorporation into operating procedures
- Design shall aim for simplicity, adequate margins and forgiving characteristics to minimise the consequences of operator errors
- Experience feedback from nuclear operating power *facilities*
- Proven components
- The requirements for inspections, testing, on-line monitoring and maintenance, also in their potential to prevent accidents
- The controls shall maintain the reactor within the parameters set for *normal operation*

Application of the Defence of Depth (DiD) Principle

B-5: Accident mitigation

- Mitigative measures shall be provided to minimise the radiological consequences through the barriers
- For the *design basis* the confinement system of the building shall be designed to meet the radiological targets specified to meet the *BLR*
- The engineered safety features providing the HTGR *Safety Functions* to control the development of accidents shall be shown to meet the *BLR*
- The use of inherent characteristics and the simplification of systems are seen as important design aims
- Simplification of systems design should facilitate elimination of adverse system interactions.
- Measures shall be addressed to prevent fuel damage

References

1. INSAG-12 Basic Safety Principles for Nuclear Power Plants 75-INSAG-3 Rev.1
2. IAEA (2005), Assessment of Defence in Depth for Nuclear Power Plants, Safety Reports Series No. 46, IAEA, Vienna
3. NEA (2016), Implementation of Defence in Depth at Nuclear Power Plants, OECD Publishing, Paris
4. CSNI Technical Opinion Paper No. 21 Research Recommendations to Support the Safe Deployment of Small Modular Reactors
5. Safety Design Criteria for Generation IV Very High Temperature Reactor System (June 2023)
6. RD-0018 Basic Licensing Requirements for the Pebble Bed Modular Reactor

Conclusion and way forward

To ensure that the concept of defence in depth is maintained, the design shall prevent, as far as is practicable:

- Challenges to the integrity of physical barriers
- Failure of one or more barriers
- Failure of a barrier because of the failure of another barrier
- The possibility of harmful consequences of errors in operation and maintenance

Working group outcomes *(challenge)*:

- Generation-IV nuclear energy systems operations will excel in safety and reliability
- Generation-IV nuclear energy systems with a very low likelihood and degree of reactor core damage
- **Generation-IV nuclear energy systems will eliminate the need for offsite emergency response**

Thank you

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