Enhancement of the Safety of the Jordan Research and Training Reactor (JRTR)

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Facility Description

Reactor Type	Open Pool
Thermal Power (MW)	5 (upgradable up to 10)
Max. Thermal Neutron Flux ($n/cm^2 \cdot s$)	1.5×10^{14} in the core (central trap) 0.4×10^{14} in the reflector region
Fuel Type & Material	Plate type; 19.75% enriched, U_3Si_2 in Al matrix
Fuel Loading	18 fuel assemblies, 7.0 kg of U^{235} (Equilibrium cycle)
Coolant/Moderator Cooling Method	H_2O Downward, forced convection flow
Reflector	Be + D_2O
Utilization	Multipurpose - Neutron beam applications (n science, n radiography, etc.) - Neutron irradiation services (RI production, NAA, NTD, etc.)

Nuclear Safety Objectives

General Nuclear Safety Objective: To protect individuals, society and the environment from harm by establishing and maintaining in nuclear installations effective defenses against radiological hazards

Radiation Protection Objective: To ensure that in all operational states radiation exposure within the installation or due to any planned release of radioactive material from the installation is kept below prescribed limits and ALARA, and to ensure mitigation of the radiological consequences of any accidents

Technical Safety Objective: To take all reasonably practicable measures to prevent accidents in nuclear installations and to mitigate their consequences should they occur.

Philosophy of design (1/2)

Defence in depth

The concept of defence in depth is applied in the design to provide protection against various reactor transients, including transients resulting from equipment failure and human error and from internal or external events that could lead to a Design Base Accidents (DBA).

In particular, the **following aspects** are considered in the design:

- ✓ The use of **conservative** design margins, the implementation of a quality assurance program and the organization of surveillance activities.
- ✓ The provision of **successive physical barriers** to the release of radioactive material from the reactor. Examples of such barriers are the fuel matrix, the fuel cladding, the primary heat transport system, the pool and the reactor building. Also, provision, as appropriate, for ensuring the effectiveness of these barriers, and for their surveillance and protection.

Philosophy of design (2/2)

- ✓ Application of the **single failure criterion** by ensuring the fulfillment of each of the following basic safety functions:
  - ➢ Shutting down the reactor and maintaining it in a safe shutdown state for all operational states or DBAs.
  - ➢ Providing for adequate removal of heat after shutdown, in particular from the core, including in DBAs;
  - ➢ Confining radioactive material in order to prevent or mitigate its unplanned release to the environment.
- ✓ The use of on-site and off-site emergency plans aimed at mitigating the consequences for the public and the environment in the event of a substantial release of radioactive effluents to the environment.

Safety functions

- Safety functions are the essential characteristic functions associated with **SSCs** that ensure the safety of the reactor. In normal operation, the equipment needed to perform safety functions are the operating systems, which must be supplemented by other Engineered Safety Features (**ESF**) to perform their functions for Anticipated Operational Occurrences (**AOO**) and in **DBAs**.
- In the design of the safety systems, including **ESFs**, that are used to achieve the three basic safety functions: shutting down the reactor, cooling, in particular the reactor core, and confining radioactive material, the single failure criterion is applied, high reliability is ensured and provisions is included to facilitate regular inspection, testing and maintenance.
- Acceptance criteria are established for operational states and for **DBAs**. In particular, the **DBAs** considered in the design of the JRTR and selected **BDBAs** are identified for the purposes of establishing acceptance criteria.

ESFs in JRTR

A **SSC** is relied upon during or following design basis events to ensure the capability to prevent or mitigate the consequences of those design basis events that could result in potential offsite exposures comparable to the guideline exposures*.

- **Pool water inventory**
  - Reactor and service pools themselves and siphon breakers (fail-safe open)
- **Passive decay heat removal**
  - PCS pump flywheels and flap valves (fail-safe open)
- **Confinement**
  - Reactor building and isolation dampers (fail-safe close)

*this excludes the reactor coolant pressure boundary (RCPB) and reactor protection system (RPS) items. (ANSI/ANS 58.14)

Safety Analysis of JRTR at a glance

- Deterministic **SA** complimented by **PSA**
- Combined Approach using **RELAP5**
  - ✓ Best estimate code.
  - ✓ Conservative set of input data and assumptions.
- Identification of the **JRTR Postulated Initiating Events**
  - ✓ Review on IAEA documents, Survey on SARs of other RRs.
  - ✓ Examination of the JRTR Design Characteristics.
  - ✓ Engineering Judgment.
  - ✓ Consistent with **IAEA Safety Standard** (NS-R-4).
  - ✓ Learning from **Fukushima** Accident 2011.

Acceptance Criteria (1/2)

Rx. Cond. (Estimated O.F.)	Events	Acceptance Criteria
Normal Operation	• Start-up • Power operation • Shutdown • Training operation	• Fuel integrity ensured • Within normal dose limit
Anticipated Operational Occurrences ($10^{-2} \leq$ O.F.)	• Loss of normal electric power • Failure of all PCS pumps • Failure of a PCS pump • Loss of SCS flow • Loss of HWS flow • Start-up accident • Inadvertent withdrawal of a control rod • Influence from experiments and experimental facility	• Fuel integrity ensured • Within normal dose limit
Accidents ($10^{-4} \leq$ O.F. $< 10^{-2}$)	• Small LOCA • Shaft seizure of a PCS pump • Core flow reduction due to flap valve open • Pipe rupture in HWS • Flow blockage of subchannel • Failure of a fuel plate cladding	• Coolable geometry ensured • Not exceed 10% of the reactor site acceptance criteria
Limiting Accidents ($10^{-6} \leq$ O.F. $< 10^{-4}$)	• Complete flow blockage • Large LOCA due to a pump casing failure	• Coolable geometry ensured • Within the reactor site acceptance criteria

Acceptance Criteria (2/2)

	Effective Dose for Whole Body	Effective Dose for Thyroid
EAB **Exclusion Area Boundary**	250 mSv/2hrs	3 Sv/2 hrs
LPZ **Low Population Zone**	250 mSv/event	3 Sv/event

Ref.: NSSC Notice 2012-03 (10 CFR 100.11)

Personnel	Effective Dose
Workers	20 mSv/yr for 5 consecutive years or 50mSv/yr for 1year
The public	1 mSv/yr

Ref.: Presidential Decree of AESA, 10 CFR 20

General Requirements for Design

Classification of SSCs

- Appropriate design interfaces between **SSCs** of various classes have been provided to ensure that the failure of any item of a lower safety class will not cause the failure of an item of a higher safety class.
- **SSCs** and software for instrumentation and control that are important to safety have been specified and classified according to their function and significance for safety.
- Codes and standards applicable to **SSCs** have been identified and their use are in accordance with their classification.
- The method for classifying the safety significance of **SSCs**, including software, was based on deterministic methods, complemented where appropriate by probabilistic methods and engineering judgment.
- Consistency between different types, codes and standards have been demonstrated.
- In the absence of codes and standards, the results of experience, tests, analysis or a combination of these have been applied, and this based approach has been justified.

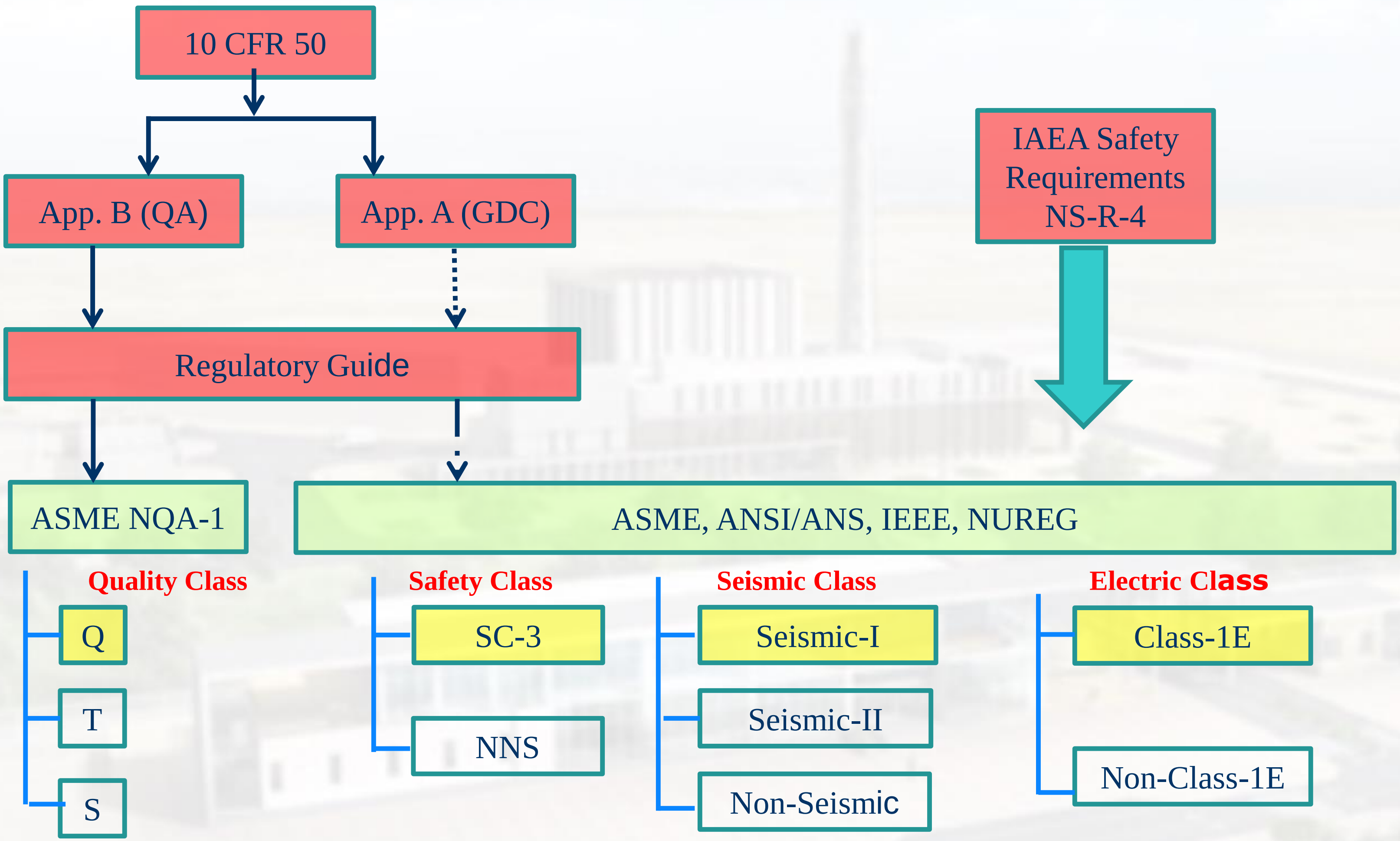
Hierarchy of IAEA Safety Standards

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation.

HAS THREE CATEGORIES:

- **Safety Fundamentals**: The Safety Fundamentals SF-1 presents the fundamental safety objective and principles of protection and safety and provides the basis for the safety requirements.
- **Safety Requirements**: An integrated and consistent set of Safety Requirements establish the requirements that must be met to ensure the protection of people and the environment. (**SHALL**)
- **Safety Guides**: Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended. The Safety Guides reflect best practices, to help users striving to achieve high levels of safety. (**SHOULD**)

Safety Classification of JRTR SSC



IAEA General concept (for instance, in NS-R-4)	Items important to safety		Items not Important to Safety
	Safety system	Safety-Related items	
JRTR	Safety Class 3 (Quality Class Q)	NNS Class with specified functions (Quality Class T/Q)	NNS Class (Quality Class S)
ANSI 51.1	SC-1, 2 and 3 (ASME NQA-1)	NNS Class with specified functions (selected requirements from ASME NQA-1)	Other NNS

Classification Guidance on IAEA NS-G-1.3

Plant Equipment

- **Items important to safety**
  - **Safety related Items**
    - RRS
    - ASTS
    - APS
    - Control Room I&C
  - **Safety Items**
    - **Protection system**
      - RPS
      - PAMS
    - **Safety actuation system**
      - CRDM
      - SSDM
      - ESFs
        (ECCS)
        (Decay Heat Removal)
        (Containment Spray)
    - **Safety system supports**
      - Diesel Generators
      - UPS

      PCS, RSA
- Items not important to safety
  - RMS
  - IPS

Measures

Adequacy of		In JRTR
Design Stage	Safe Shutdown Earthquake	0.3g from DSHA & PSHA
	Emergency Area Boundary	120 m satisfying NSSC Notice 2012 (10 CFR 100.11)
	Classification of SSCs	Generally NS-G-1.3; Safety Class according to NSSC Notice 2012 (ANSI/ANS 51.1)
	Engineered Safety Features	Selected according to ANSI/ANS 58.14
	Design Bases Events & Safety Analysis	Carefully selected DBEs, Meeting acceptance criteria
	Operation Limits and Conditions	OLCs developed
O & M Stage	Emergency Management	Developed
	O&M Procedures	Developed
	Fire Protection Plan	Developed
	Security Plan	Developed

Safety Class 3 (SC-3)

- Provide secondary containment for radioactive material holdup, isolation, or heat removal.
- Maintain geometry within the reactor [illegible] core cooling capability (e.g., core support structures).

- Remove radioactive material from the atmosphere of confined spaces outside primary containment (e.g., control room or fuel building) containing **SC-3** equipment.
- Structurally load-bear or protect **SC-3** equipment.
- Provide radiation shielding for the control room or off-site personnel.

- Introduce negative reactivity to achieve or maintain subcritical reactor condition.
- Ensure required cooling for liquid-cooled stored fuel (e.g., spent fuel storage pool and cooling system).
- Ensure nuclear safety functions provided by **SC-1, SC-2, or SC-3** equipment (e.g., provide heat removal for **SC-1, SC-2, or SC-3** heat exchangers, provide lubrication of **SC-2 or SC-3** pumps, or provide fuel oil to the diesel engine).
- Provide or maintain sufficient reactor coolant inventory for core cooling.

Safety Class 3 (SC-3)

- Provide actuation or motive power for **SC-1,SC-2, or SC-3** equipment.

- Provide information or controls to **ensure** capability for manual or automatic actuation of nuclear safety functions required of **SC-1, SC-2, or SC**-3 equipment.

- Supply or process signals or supply power required for **SC-1, SC-2, or SC-3** equipment to **perform** their required nuclear safety functions.

- Provide a manual or automatic interlock function to **ensure** or **maintain** proper performance of nuclear safety function required of **SC-1, SC-2, or SC-3** equipment.

- Provide an acceptable environment for **SC-1, SC-2, or SC-3** equipment and operating personnel.

Seismic Category

Seismic Category I

- **SSC** equipment shall be designed, fabricated, installed, and tested according to the specification requirements.
- **SSC** equipment shall maintain safety functions as well as structural integrity during and after a Safe Shutdown Earthquake (**SSE**).
- Structural integrity shall be maintained within the elastic stress limits during impact of an Operating Basis Earthquake (**OBE**).
- **SSC** equipment shall be sufficiently isolated or protected from other structures to ensure that their integrity is maintained at all times.

Seismic Category II

- The **SSC** shall be defined separately from **seismic category I SSC**.
- Although the **SSC** is not safety related, the failure and physical proximity to safety-related **SSC** could prevent the safety-related **SSC** from performing its safety functions I
- The **SSC** shall be designed to maintain its structural integrity under loads induced by the **SSE**.

Quality Class

Quality Class T

Non-Safety-related SSCs:

a) Whose failure could reduce **the functioning** of any safety-related feature to an unacceptable safety level.

b) Whose function is essential to **the reliability** of normal reactor operation, or

c) Which provide permanent shielding **for protection** of safety class equipment or of onsite personnel.

d) Which structurally load-bear or protect any **T class** equipment.

e) Which handle spent fuel.

For quality **class T** SSCs, selected QA program requirements of quality class Q or QA program requirements of applicable codes and standards are applied.

Quality Class Q

All **SSCs** that are classified as **SC-3**, Quality Assurance Program (**QAP**) requirements in KEPIC QAP, 2005 edition (ASME NQA-1, 1994 edition, 1995 addenda) or other equivalent codes and standards are applied.

JRTR Examples

Radiation Monitoring System (RMS)

- The three radiation monitoring are SC-3.
- They shall work in normal and abnormal operating conditions.
- JRTR has specially classified some of the radiation monitoring channels to safety class as the trip parameters of the RPS.
- The safety class RMS channels are Reactor Gamma Monitoring System (RGMS), PCS Neutron Monitoring System, PCS Gamma Monitoring System and Pool Radiation Monitoring System.
- The general-purpose RMS channels are classified to non-nuclear safety system but upgraded from S to T quality class.

Alternative Protection System (APS)

- Acts as a diverse protection system to perform prevention and mitigation of anticipated transient without scram.

- APS is to mitigate the effect of postulated common cause failure of the Reactor Protection System.

- Therefore, the APS is an item important to safety and should not be classified as a NNS as based on the Korean regulations, but as recommended, it is considered as safety related system of “items important to safety” as per the IAEA guidelines.

Automatic Seismic Trip System (ASTS)

- The ASTS is the only system that is responsible to safely trip the reactor in case of a seismic event (A Postulated Initiating Event).

- No operator action is credited within 30 minutes following a **PIE**.

- **ASTS** of JRTR is a non-nuclear safety system according to the Korean and American. It is qualified as T-class, seismic category I (similar to the Korean and USA classification for the NPP).

- In addition, an additional uninterruptible power supply is built in the cabinet to store the earthquake-related data.

Process Instrumentation and Control System (PICS)

- **Primary Cooling System** (PCS) pumps are stopped based on low-low-low water level signal and high or low **PCS** flow signals (low and large LOCA).

- The **pool water** is preserved at a certain level so that the reactor core is always covered with coolant. Consequently, the **PICS** has no reason to be designed as Nuclear Safety Class because it has no function to mitigate the consequences of the LOCA.

- The **nuclear safety** function of core cooling is guaranteed by LOCA flow. Thus, the **PICS** function of turning the **PCS** pumps off is not for guaranteeing core cooling but only for protecting the **PCS** pumps. For that reason, turning the **PCS** pumps off signal by the **PICS** should not be considered as the nuclear safety function.

Emergency Water Supply System (EWSS)

- The **EWS**S is designed to cover the reactor core with water when multiple rupture of a beam tube occurs (**BDBA**).

- Because multiple rupture of a beam tube is classified as a **BDBA, EWS**S is classified as a non-nuclear safety system.

- The portion of the system between the flow orifice outside the reactor pool and the injection nozzle inside the reactor pool is classified as **safety class 3** (Sec. of Safety Class Interfaces of ANSI 51.1).

- The portion from the MOVs to the injection nozzle including the MOVs is classified as **seismic category I**.

Fuel storage and handling systems

Fresh and spent fuel storage racks

According to the IAEA Safety Standards, the fresh and spent fuel storage racks should be classified as items important to safety.

The storage racks for fresh and spent fuel assemblies are classified into non-nuclear safety. They are classified into **seismic category I** and designed in accordance with **KEPIC MNF** (ASME Sec. III, NF).

All anticipated loadings have been considered in the design. Also they were manufactured, installed, and inspected implementing the requirements of **quality class Q**.

Pool Water Management System (PWMS)

In normal operation, **PWMS** maintains the service pool water temperature and controls the pool water quality, and these are **non-nuclear safety functions**.

Even though the **PWMS** loses its function, the spent fuel cooling function will be guaranteed by **natural circulation** of the pool water.

The spent fuel itself is stored inside the ultimate heat sink. To prevent the loss of cooling function, the pool water is **backed up** by safety class siphon breakers.

Heavy Water System (HWS)

Pipe break in the **HWS** is a **PIE**. However, it is classified as a **Non-Nuclear Safety**. It should also be mentioned that the safety analysis shows that the **tritium** removal unit performs a safety function and should be classified as **an item important to safet**y

In summary, **tritium** release accident does not threat the acceptance dose limit at **EAB**. Hence, **HWS** is designed as **NNS**. The predicted dose for a heavy water leakage event without the **TRU** and confinement function of the equipment room, which is the most series from the safety point of view, meets the allowable dose limit. Hence, **HWS** is designed as **NNS**.

Hot cells

- The hot cells are specifically designed for the production of Ir^{192} and I^{131}.
- The hot cells are designed **to protect** the radiation workers from a high radiation environment.
- The quality **class** applied to the manufacturing of the hot cells are "T" to ensure the safety and the functionality.

- One of the design criteria of the hot cells is to provide **enough shielding** to meet the ALARA surface dose rate of 1 μSv/hr.
- The hot cell banks are designed with the criteria of the **SC-3**.
- Ventilation systems for the hot cells and the banks are well established to provide the **controlled** release of the radioactivities to the environments.
- Also, the hot cells are not for the handling nuclear materials.

Information Processing System (IPS)

- IPS provides information to the **MCR** and **SCR**. It also includes the Safety Parameter Display System (SPDS) which has the function to show the status of the reactor safety parameters.
- Essential safety parameters are provided to operators by safety systems/equipment (i.e., RPS and PAMS).
- As a diverse monitoring function, the **IPS** provides operators with safety parameters and non-safety parameters comprehensively.
- **IPS** does neither perform any of three basic safety functions nor credited to mitigate the consequences of design basis accidents. Thus, it is classified as a **non-nuclear safety** system.
- However, the **IPS** is verified and qualified through graded activities for **QA, EQ**, testing and V&V, and has been upgraded from S to T quality class upon recommendations.

Operating WorkStation (OWS)

- **PICS** does not handle the information of Safety Class 3 system and equipment.

- The **OWS** is classified as a non-nuclear safety system because it does neither perform any of the three basic safety functions nor credited to mitigate the consequences of **DBA**.

- The **OWS** is verified and qualified through graded activities for **QA**, **EQ**, testing and **V&V** even though classified as non-nuclear safety system.
- It has been upgraded from S to T on quality class.

Diesel generator

All systems or component for three basic safety functions have been designed in **fail-safe design** concept, which means that no electricity is required to actuate. The **RPS, APS** and **ASTS** are designed so that the **CARs** and **SSRs** will be dropped into the core on Loss Of Electric Power. The core cooling and residual heat removal will be accomplished by natural convection through the flap valve in the pool. No electricity is required for flap valve actuation. The diesel generator for JRTR has a quality **class T**.

If the diesel generator becomes unavailable due to a fire or earthquake, the UPS with battery back-up will last for at least one (1) hour for monitoring the safety status.

The emergency power supply provides an on-site standby source of electrical power to the **Class 1E** load. Emergency power from diesel generator is provided to the emergency load center bus in case of loss of off-site power supply. The **UPS** provides power for control and instrumentation needed for safe shutdown in case of loss of off-site power supply.

Conclusions and Remarks

- We are sure of the adequacy of design bases, construction, operation and utilization and of their implementation.
  - Internationally acceptable codes and standards
  - Well established methodologies
  - Well trained staff
  - Fukushima Lessons have been implemented
- Operational License has been granted.

Thank You