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Assessing PRA Quality for Risk-Informed Activities: Insights from Regulatory Guides and Standards and Their Potential Application in Nigeria's Nuclear Regulations

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1. Introduction

In 2017, Rosatom and the Nigeria Atomic Energy Commission (NAEC) signed a partnership agreement for the construction and operation of Nuclear power plants. In this regard, Nigeria has been collaborating with multiple countries and international organizations to advance its nuclear program. [1]

The safety of nuclear power plants (NPPs) is a paramount concern, to the public, Nigerian Nuclear Regulatory Authority (NNRA) and utility alike. Nuclear safety is administered by a comprehensive framework that includes regulatory standards and guides, safety assessments, and operational controls.

The establishment of regulations for nuclear safety and regulatory guides on how to meet regulatory requirements is one of the major role of the Nigerian Nuclear Regulatory Authority (NNRA). With regards to advancing a national nuclear program, NNRA has published a draft regulation on "safety operation of NPPs".

One of the requirements of this regulation states that, "If a probabilistic assessment of risk is to be used for decision-making purposes, the Operating Organization shall ensure that the risk analysis is of appropriate quality and scope for decision-making purposes." However, regulatory guidance as to what is appropriate quality and scope for decision-making purpose is not yet published.

The objective of this study is to review published guidance documents and standard documents regarding assessing PRA quality for risk-informed activities (RIA). This study will draw from guidance, requirements and recommendations provided by US NRC (as outlined in Regulatory Guide 1.200) and IAEA standards.

2. IAEA Standard and US NRC

With the goal of attaining the fundamental safety objective of "protection of the people (workers and public) and environment from the harmful effects of ionizing radiation", the IAEA established ten (10) fundamental safety principles (as in Fundamental Safety Principles –SF 1), general safety requirements- GSRs and specific safety requirements- SSRs, general safety guides (GSGs) and specific safety guides (SSGs) as its safety standard structure in Fig 1. In addition, inputs were also taken IAEA TECDOC-1804.

The US NRC guidance document used in this study is the regulatory guide 1.200 which provides guidance to operating organization to in determining the technical adequacy of the base PRA used in a risk-informed regulatory activity

Although, the mentioned safety standards and guidance documents covers the scope of level 1 and level 2 PRA for all hazards at full power condition and low-power and shutdown conditions, the scope of this study will be limited to just level 1 internal events PRA at full power.

3. Quality PRA adequate for RIA as Recommended by IAEA and US NRC

3.1 Quality PRA adequate for RIA as Recommended by IAEA

3.1.1 Scope of a Quality PRA

Three term are used for definition of PRA scope: plant operating states for which the risk assessment was done, the metric used for risk characterization and the hazard groups that were covered in the assessment.

A full-scope level 1, 2 and 3 PRA covering a comprehensive list of initiating events, hazards, and all operational states is recommended. [2]

3.1.2 Technical Adequacy of a Quality PRA

In evaluating the technical adequacy of a PRA, nine technical elements identified as crucial in a level 1 internal events PRA as highlighted in IAEA TECDOC-1084 and IAEA SSG-3 are:

- Initiating Events Analysis
- Accident Sequence Analysis
- Success Criteria Formulation and Supporting Analysis
- Systems Analysis
- Human Reliability Analysis
- Data Analysis
- Dependent Failures Analysis
- Model Integration and Risk Metric Frequency Quantification
- Results Analysis and Interpretation [3] [4]

Initiating event analysis: Attributes of this element should entail a comprehensive list of identified initiating events (IEs) for internal events, internal hazards, and external hazards, covering all plant operational states (POS), IE screening process to exclude irrelevant events, IEs grouping, Generic and plant-specific data are collection and evaluation for assessment IE frequencies and quantification of the frequency for each IE or IE group. [5]

Accident Sequence Analysis: attributes of this element should include selection of a suitable approach and tools for modeling accident sequences, identification of key safety functions necessary to achieve a successful outcome and clear definition of success and non-success end states for each group of initiating events (IEs) across all plant operational states (POS), modelled map out of accident progression for each IE group, reflecting realistic plant responses, operator actions, and mitigation systems, and established success criteria for each accident sequence with details of requirements for safety functions, operator actions, systems, and equipment needed to maintain a stable, safe state. [5]

Success Criteria Formulation and Supporting Analysis: Establishment and definition of overall success criteria for the PRA and detailed success criteria and event timing for SSCs and human action in alignment with the plant's features, procedures, and operating practices using thermal hydraulic analyses and other evaluation methods. [5]

System Analysis: definition of characteristics and boundaries for all systems involved in the functions identified in the accident sequence analysis, identification and modelling of failure cause and dependencies **for** systems across all plant operational states (POS) for internal events, internal hazards, and external hazards. [5]

Human Reliability Analysis: Human Reliability Analysis (HRA) in PRA Level 1 involves identifying and evaluating potential human errors. For all types of human error (Type A, B, and C), it involves identification of routine activities, operator responses and test and maintenance activities that could result in unavailability of necessary components, failure of response to an IE and an initiating event respectively. It should also involve screening, definition and quantification of the identified human failure events (HFEs) [5]

Data Analysis: data analysis should involves identifying and defining parameters for models like fault trees and event trees, grouping of components for parameter estimation, collection and evaluation generic and plant-specific data, derivation of plant specific parameters by integration of generic and plant specific information including those for common cause failures, and use of mechanistic models, such as fragility analysis. [5]

Dependent Failures Analysis: this element of PRA should include design related dependencies, operational related dependencies, physical dependencies, common cause failure analysis and subtle interactions. [4] [5]

Model Integration and Risk Metric Frequency Quantification: this element of PRA involves integration of all elements of PRA, quantification using appropriate code and review and modification of the results.

Results Analysis and Interpretation: this element of PRA should include identification of significant contributors to the estimated risk of the plant, assessment of assumptions and model uncertainties by sensitivity analysis and uncertainty analysis respectively

3.1.3 PRA maintenance, upgrade and documentation

Maintaining and updating the PRA model is essential to accurately reflect the as-designed, as-built, and as-operated plant, thereby incorporating relevant changes and advancements in PRA techniques, changes in plant design and operation and updating operational data for SSCs. Therefore, a quality PRA should take into account these changes in its updated risk estimates. Maintenance and upgrade of PRA should take into account the following:

- Continuous monitoring PRA inputs and gathering of new data.
- Execution of maintenance and update of PRA
- Maintaining configuration control of the computer codes used in the PRA.
- Documentation of maintenance and upgrade. [3][4]

3.2 Quality PRA adequate for RIA as Recommended by US NRC

3.2.1 Scope of a Quality PRA.

The scope of a PRA is influenced by its anticipated use and also defined by these three terms:

- Metrics for risk characterization such as CDF (level 1) and LERF (level 2)
- Plant operating states (POS) such as full-power or LPSD for a given initiating event, and
- Hazard groups such as external events (seismic events, high winds and external floods) and internal hazards (internal fire and internal flood) and internal events that could cause of initiating events. [6]

Full-scope Level 1 and Level 2 PRAs typically cover a broad range of these factors, ensuring comprehensive risk assessments.

3.2.2 Level of Details of Quality PRA.

For each technical element, there are three degrees for level of details for PRA. This include

1. PRA model reflecting as-designed, as-built and as-operated

2. PRA model incorporate specific plant experience and
3. PRA model incorporates realism that reflect expected plant response.

While the required, level of details may vary depending on the application of PRA and plant “stage”, for base PRA, a model reflecting as designed, as-built should be a minimum.

3.2.3 Technical Adequacy of a Quality PRA.

In describing the technical adequacy of a PRA, the term elements and attributes were also used in US NRC 1.200 regulatory guide.
Technical element and attributes as presented by US NRC are listed below.

Initiating event analysis: Detailed identification and characterization of initiating events, grouping them based on plant response and mitigation needs, and properly screening these events.
Success criteria analysis: This should involves using best-estimate engineering analyses based on the plant’s actual design and operation, along with detailed codes to accurately assess phenomena across specific pressure, temperature, and flow ranges.
Accident sequence analysis: defines SSCs, operator action and timing requirements, necessary to mitigate initiators.
System analysis: FT models should reflect as-designed as-built and as-operated plant, reflecting success criteria of systems and capturing impact of dependencies, common-cause failure, human errors and unavailability caused by test and maintenance.
Parameter estimation analysis: this should include estimation of parameters for components of PRA models such as initiating event, basic events etc using generic data or plant specific data where applicable. Estimation should align with component boundaries and should account for uncertainty.
Human reliability analysis: This should include identification, screening and definition of HFE that would impact the mitigation of initiators or result in initiating event. HEP for HFE impacting mitigation if IE are to be quantified taking into account scenario and plant-specific considerations.
Quantification: all other elements of PRA are integrated for estimation of CDF for the modeled accident sequences for each IE group.
Interpretation of result: this involves identification of major contributors to estimated plant risk using importance measure calculations such as Fussell-Vesely Importance, Birnbaum Importance, risk reduction, and worth risk achieved worth. Impact of uncertainty and assumptions are also assessed by uncertainty analysis and sensitivity analysis respectively.

3.2.4 PRA maintenance, upgrade and documentation

To achieve a quality PRA, a structured quality assurance process for developing, maintaining, and updating the PRA should be implemented and documented. This process involves using relevant plant information, such as design, operation, maintenance, and engineering data, to ensure the PRA realistically assesses risk. The PRA integrates specific information on plant design configurations, operational procedures, testing and maintenance practices, and engineering aspects. Additionally, where possible, plant walkdowns are conducted to verify that the information accurately represents the plant's actual condition.

For a PRA to be quality for RIA, it must be upgraded at periodic interval to account for changes as a result of improved methods changes in availability and reliability of SSC as a result of operational data and changes to plant design and operation.
For adequate maintenance and upgrade of a PRA, necessary attributes include:

- Continuous monitoring PRA inputs and gathering of new data.
- Consideration of the cumulative impact of upcoming plant changes.
- Maintaining configuration control of the computer codes used in the PRA.
- Identifying when the PRA requires updates due to new information, models, techniques, or tools.
- Ensuring peer reviews are conducted for PRA upgrades.

4. Recommendation and Conclusion

4.1 Recommendations

The following recommendations and considerations can be made in establishing a regulatory guide on quality PRA adequate for Risk-Informed Activities (RIA):

Define Scope and Metrics: the regulatory guide should clearly outline the scope of the PRA, including the plant operating states (full-power, low-power, and shutdown conditions) and the hazard groups (internal and external events). Establish metrics for risk characterization, such as Core Damage Frequency (CDF) and Large Early Release Frequency (LERF), to ensure comprehensive risk assessments.

Technical Adequacy: the regulatory guide should incorporate the nine technical elements identified as crucial for a quality PRA, including Initiating Events Analysis, Accident Sequence Analysis, Human Reliability Analysis, and Results Analysis and Interpretation. Attributes and characteristics for each element that is commensurate with RIA application should be states for its technical adequacy.

Continuous Maintenance and Updates of PRA: the regulatory guide should include a structured process for the continuous monitoring of PRA inputs and the gathering of new data, regular updates to the PRA model to reflect changes in plant design, operation, and advancements in PRA techniques. It should include establishing criteria for when updates are necessary, to ensure that the PRA remains relevant and accurate.

Incorporate Realism and Plant-Specific Data: the regulatory guide should also determine the minimum level of details needed to ensure that the PRA models incorporates plant-specific details necessary for risk-informed insights.

Documentation and Transparency: Emphasize the importance of thorough documentation of the PRA process, including assumptions, methodologies, and results. This transparency will facilitate better understanding and confidence in the results of a PRA.

By considering these recommendations, the establishment of a regulatory guide on quality PRA for RIA can be effectively achieved, enhancing the safety and reliability of nuclear power operations.

4.2 Conclusion

In conclusion, the establishment of a regulatory guide on quality Probabilistic Risk Assessment (PRA) adequate for Risk-Informed Activities (RIA) is essential for enhancing the safety and operational integrity of nuclear power plants. By defining clear scopes and metrics, ensuring technical adequacy through established standards, and implementing continuous maintenance and updates, regulatory bodies can foster a robust framework for risk-informed application of PRAs. Establishing this regulatory guide would not only improve the quality of PRA but will also enhance the applicability of PRA. By adopting these recommendations, regulatory authorities can effectively guide the development and implementation of quality PRA, thereby supporting informed decision-making and enhancing public safety in the nuclear sector.

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