PRA GROUP RESPONSIBILITIES AND CHALLENGES FOR A NEW NUCLEAR POWER PLANT IN UAE: BARAKAH NPP

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The purpose of this paper is to provide a summary of the responsibilities and challenges that a young PRA group is experiencing for a new NPP being constructed in the United Arab Emirates (UAE). The plant is Barakah NPP (BNPP) that is located near the town of Al Ruwais, which is about 240 kilometers west of Abu Dhabi. The 4-unit Barakah plant is being designed by KEPCO E&C and being constructed by KEPCO and KHNP. Unit 1 is planned to start commercial operation in late 2017 and the other units follow up afterwards within few years. The owner of Barakah NPP is the Emirates Nuclear Energy Corporation (ENEC) and the Regulatory Agency in UAE is the Federal Authority for Nuclear Regulation (FANR).

I. INTRODUCTION

The Barakah NPP (BNPP) is located near the town of Al Ruwais, which is about 240 kilometers west of Abu Dhabi. The 4-unit Barakah plant is being designed by KEPCO E&C and being constructed by KEPCO and KHNP. Barakah NPPs design is based on APR1400 which has advanced system configurations to enhance safety. APR1400 design is originally developed through a joint effort between ABBCE and KEPCO in the 1990s. The Barakah NPPs design is an adaptation of the APR1400 to conform to the codes, standards, and regulatory requirements of UAE.

The requirement for implementing the PRA is stated in the FANR regulations FANR-REG-03, Article 46 (Ref. 1) and FANR-REG-05 (Ref. 2). In this regard, Article 46 of REG-003 states that:

"A Design and site specific PRA shall be performed and a summary report shall be submitted to the Authority for review. The PRA shall be conducted in accordance with FANR-REG-05, Regulation for the Application of PRA at Nuclear Facilities. The results of the PRA shall be considered in the Design of the Power Plant."

Furthermore, Article 3 of REG-005 provides the following requirements regarding the scope of the PRA, which is required to be conducted in support of the plant Construction and Operating License:

"The PRA shall include an Assessment that takes into consideration internal and external events and all modes of plant operation. Measures should be implemented consistent with the applicant's/licensee's management system to ensure the quality of the PRA, including data and information used in the analyses. The PRA shall be based on realistic analysis using state-of-the-art tools, methods and data to calculate the radiological release and consequences of spectrum of events ranging from those of high anticipated frequency through those of rare anticipated frequency, e.g., severe reactor accidents. This requires addressing uncertainties and conforming to internationally recognized PRA standards and best practice."

Additionally, Article 4 in REG-005 provides the following requirements with regard to PRA Quality:

"A high quality PRA shall be performed and used to complement the Nuclear Facility Design, Construction, Operation and Safety analysis. The PRA shall be based upon the design of the nuclear power plant and site-specific information. The PRA shall assess accident sequences leading up to and including reactor core damage and loss of containment integrity, and the corresponding quantity and composition of Radioactive Material available for release to the environment (i.e. Level 2 PRA)."

The Barakah NPP PRA has been developed in accordance with the FANR regulations related to the scope and quality as well as other requirements.

II. ENEC PRA GROUP

The PRA group currently resides in the ENEC offices in Abu Dhabi and is comprised of the following members:

- Nuclear Risk Management (NRM) Director
- PRA Group Manager
- Two Senior PRA Engineers
- Two PRA Engineers
- Severe Risk Management Program (SRMP) Manager and his staff

The NRM department has the responsibility for both PRA and SRMP for BNPP. The SRMP activities include supporting the development and review of the Severe Accident Management Guidelines (SAMGs), Extensive Damage Mitigation Guidelines (EDMGs), and post Fukushima activities such as FLEX Support Guidelines (FSGs) for BNPP. The PRA group extensively works with the BNPP designer and architect companies (KEPCO E&C and KHNP), FANR and other external organizations such as IAEA, WANO, EPRI, USNRC, and contractors. The PRA group has many responsibilities and challenges, some of which are organized in the following key categories for the purpose of this paper:

- Review and submittal of FSAR Chapter 19.1 (PRA) and PRA Summary Report in support of FSAR 19.1 to FANR as part of plant licensing
- Support the development and review of SAMGs, EDMGs and FSGs
- Review of PRA models, reports and notebooks prepared by KEPCO E&C
- Review of PRA Peer Review reports prepared by Peer Review teams including F&O (Fact & Observation) resolutions
- Review and support in addressing FANR's RAIs (Request for Additional Information) related to PRA and SRMP
- Development of BNPP online risk monitor tools for at-power and shutdown modes
- PRA engineer training and qualification
- PRA applications
- PRA group procedures

The list is not intended to be complete, but to show selected key areas of PRA group roles and responsibilities and challenges at ENEC. The items on the list above are briefly described next.

II.A. FSAR Chapter 19.1 and PRA Summary Report

The BNPP design basis and operating license require a PRA to be submitted as FSAR Chapter 19.1 as well as a PRA Summary Report to the UAE regulatory agency, FANR. The PRA Summary Report is prepared in support of FSAR Chapter 19.1. The FANR regulations require a PRA to be performed and submitted as part of the BNPP design, construction, and operating license. The Design PRA will be later updated and converted into an Operational or Living PRA to be used during plant commercial operation in support of its risk management activities. The FANR-RG-003 (Ref. 3) provides regulatory guidance on the scope and quality of PRA as well as PRA applications. The PRA should include all internal and external initiating events and address all modes of plant operation for both the reactor and spent fuel pool.

To comply with the FANR's requirements, the BNPP PRA scope includes Level 1and Level 2, at-Power and Low Power Shutdown (LPSD) models for internal events, internal flood, internal fire, seismic and other external events. The Level 1 and Level 2 PRA models cover Core Damage Frequency (CDF) and Large Release Frequency (LRF) risk metrics, respectively.

The Spent Fuel Pool (SPF) PRA is also required and is included in the scope. The SFP PRA also covers internal and external events for at-Power and LPSD operating modes and includes Fuel Damage Frequency (FDF) and LRF risk metrics.

The PRA should be of high quality and reflect plant as-designed, as-constructed, and as-operated. The design PRA will be updated once after completion of construction and startup tests and once more (or more often, as required) following commercial operation, to comply with the PRA maintenance and update requirements. The FSAR Chapter 19.1 contains PRA models and results in detail following FSAR format. The required PRA Summary Report provides a summary of the PRA models and results including CDF and LRF estimates for reactor and FDF and LRF estimates for SFP. It also provides the results of the risk significant initiating events, accident scenarios and cutsets, mitigation systems and components, operator actions, and common cause failures (CCFs). The PRA Summary Report also includes a discussion of the PRA uncertainties and sensitivities. The BNPP PRAs have been performed by KEPCO E&C and its contractors.

The ENEC PRA group has the responsibility to review both FSAR Chapter 19.1 and the PRA Summary Report to ensure their quality and completeness before they are submitted to FANR. A key challenge for KEPCO E&C and PRA group has been to ensure the PRA risk results for BNPP meet the FANR's Probabilistic Safety Target requirements of 1.0E-05/yr for CDF and 1.0E-06/yr for LRF for all initiating events combined, as set in FANR-RG-004, Article 6 (Ref. 4). In addition, due to their timing sensitivity and a short turn-around time, ENEC also may get support from contractors to facilitate the review process, as needed. It is noted that the ENEC PRA group has recommended several plant design modifications to reduce the BNPP estimated CDF and LRF values to meet the required probabilistic safety target values. They include EDGs (Emergency Diesel Generators) cross-tie operation among BNPP units and extending the battery life to reduce the risk of Station Blackout (SBO) events, which are among the risk significant initiators for BNPP.

Another challenge for the ENEC PRA group is that the scope of the BNPP PRA should reflect the 1st year design basis and operating/licensing basis per FANR's guidance and licensing requirements. This would make the BNPP PRA a phase dependent model, which will be updated several times in the future as Unit 1 completes its 1st year of operation and constructions of the other units are complete and they start commercial operation as well. To demonstrate the point, for example, no credit should be taken in the PRA model for EDGs cross-tie in the 1st year of operation of BNPP Unit 1 since the other units are not operational yet. Next, there will be a cross-tie credit between Units 1 and 2 when Unit 2 starts commercial operation in the 2nd year. Finally, in a phased fashion, cross-tie among all 4 BNPP units will be credited. To compensate for not having the EDGs cross-tie operation credit, each BNPP unit would have four (4) EDGs and one Alternate AC (AAC). As another example, the LPSD PRA model is not required to be in the baseline configuration until the first outage is performed for Unit 1.

Similarly, a design basis and operating/licensing basis configuration (or a baseline configuration) will be defined for the first 3 years for 4 BNPP units. The initial PRA model should reflect this design basis configuration for all units. As design and procedures are completed and other units are constructed and placed in operation and the design basis configuration changes, PRA sensitivity analyses should be performed to assess the impact of the changes. Consequently, the PRA model and the baseline configuration will be also updated, as needed, to reflect the updated design basis.

II.B. SAMGs, EDMGs and FSGs

The BNPP Severe Accident Management Guidelines (SAMGs) have been developed by KEPCO E&C based on APR-1400 generic SAMGs. They have been reviewed by the ENEC Severe Risk Management Program (SRMP) Manager and his staff and other internal and external organizations. The ENEC Operations is in charge of the Verification & Validation (V&V) of the SAMGs, EDMGs, and FSGs by developing the V&V process, providing operator training, and conducting the V&Vs. The V&V will be performed in October 2016 and will involve 5 to 10 BNPP operators going through table top exercises. The operators will be also timed on the use an installation of credited portable equipment. FANR may send observers to the SAMGs V&V sessions. It is noted that the focus of the post-Fukushima FSGs is on SBO and loss of heat sink scenarios and the EDMGs focus is on scenarios with no MCR availability. The ENEC PRA and SRMP engineers provide support in reviewing and V&V of the SAMGs, EDMGs and FSGs for BNPP.

II.C. Review of PRA Models and Reports

As stated earlier, KEPCO E&C with support from its contractors prepare all PRA models, reports and notebooks. The ENEC PRA group reviews and evaluates the PRA models, reports and notebooks. They also review the responses to their comments. Due the timing sensitivity and specialized nature of some PRA areas (e.g., seismic hazard analysis), ENEC PRA group gets support from contractors, as needed.

II.D. Review of PRA Peer Review Reports and F&O Resolutions

All PRA models for all initiating events and operating modes have been peer reviewed by KEPCO's external contractors, who are recognized PRA experts and are independent from the PRA originators, and the Peer Review Reports have been prepared. The peer review reports provide, in detail, the assessments of the peer review teams on how the BNPP PRAs compare against the technical supporting requirements of the ASME/ANS PRA Standard (Ref. 5), and also include the resulting Facts & Observations (F&Os). The peer review F&Os are addressed by KEPCO E&C and its contractors who performed some of the PRAs. The ENEC PRA engineers also attended the BNPP PRA peer review sessions as observers to oversee the conduct of the peer reviews, gain additional knowledge of the BNPP PRA models and results, and provide support, as needed. The ENEC PRA group with support from contractors, if needed, has the responsibility to review the PRA peer review reports and the F&O resolutions before they are submitted to FANR. This is also a challenging task depending on the extent of the peer review F&Os. The ENEC PRA engineers also support the plant walkdowns performed by KEPCO E&C to verify the plant buildings/rooms layout and equipment location assumptions made in the BNPP fire, flooding, seismic and other external events PRAs. It is noted that PRA peer reviews and meeting the ASME/ANS PRA Standard (Ref. 3) requirements are identified by FANR as an acceptable method to ensure PRA technical quality.

II.E. Review and Support in Addressing FANR's RAIs

Once the PRA models and reports including FSAR Chapter 19.1 and PRA Summary Report are submitted to FANR, it is expected that a large number of RAIs will be issued by FANR. The responses to the FANR's RAIs are drafted by KEPCO E&C and its contractors first. Then, they are reviewed by the ENEC PRA group and its contractor, as needed, before they are submitted to FANR. The responses to the RAIs usually have a relatively short turn-around time and can be challenging since they cover both technical and regulatory requirements.

II.F. BNPP Online Risk Monitor Tools

BNPP is required to have an online risk monitor tool once it starts commercial operation. The online risk monitor will be used in support of BNPP configuration risk management (CRM). The CRM process would be similar to the Maintenance Rule (MR) (a) (4) as required by the USNRC's 10CFR50.65 (Ref. 6). KEPCO E&C and KHNP have developed RIMS and ORION online risk monitor tools for at-power and LPSD modes, respectively. These risk monitor tools use the PRA models developed using KEPCO E&C's SAREX PRA code.

The SAREX baseline PRA models have to be revised to add model symmetry for operating systems (e.g., component cooling water system, essential service water system, chilled water system, etc.) to allow for system alignments. Once the symmetry logic is added, single top logic models for both CDF and LRF will be developed and transferred from SAREX to RIMS for the purpose of online risk monitoring for at-power configurations. Other databases such as components to basic events mapping and environmental factors are also developed as part of the RIMS and ORION models development. The shutdown logic model developed for ORION is the Defense-in-Depth (DID) model, which includes the following elements: 1) determination of the safety functions monitored, 2) determination of the success criteria for each of the safety functions, and 3) determination of the systems that can fulfill the success criteria.

The ENEC PRA group with support from its contractor has the task of developing the RIMS and ORION online risk monitor tools for BNPP using the SAREX PRA models with revisions described above. The PRA group will also prepare procedures for development, maintenance, and update of the RIMS and ORION risk monitor tools. Initially, the tools will only include Level 1 and LRF for internal events and then they will be expanded to include other events too. The ENEC PRA engineers have been trained on the use of SAREX, RIMS and ORION tools by KEPCO E&C and KHNP.

It is noted that ENEC is a member of EPRI and has access to EPRI R&R (Risk & Reliability) codes including Phoenix. The ENEC PRA group, in parallel, is developing a Phoenix risk monitor model with a long term goal of switching from RIMS and ORION tools to Phoenix as the single online risk monitor tool for both at-power and shutdown modes. The RIMS and ORION models can be used as backup tools, if needed.

II.G. PRA Engineer Training and Qualifications

The ENEC PRA engineers have gone through various PRA trainings in-house and externally. The senior PRA engineers have completed the EPRI PRA engineer training course and have also completed the senior reactor operator (SRO) training including simulator training. The PRA engineers have been trained on the use of KEPCO E&C PRA software, SAREX. They have also attended the EPRI Risk Technology Seminars including training on EPRI R&R codes such as CAFTA, Phoenix, EOOS and HRA Calculator. The PRA group together with the BNPP Training Department will develop PRA Engineers General Training and Specialized PRA Training using a systematic training approach such as Performance Qualification Cards (PQC) or Performance Qualification Standards (PQS) as used by U.S. plants, or other structured training methods.

The ENEC PRA engineers have also been trained and are knowledgeable of the FANR's Regulations and Regulatory Guides (RGs) that address PRA scope and quality requirements, as well as PRA applications.

II.H. PRA Applications

The FANR-RG-003, Article 6 (Ref. 3) states that PRA should be used as much as practical to support the Design, Construction and Operation of the nuclear power plant. This support should be directed toward optimizing and confirming the safety of the NPP in the areas where PRA can model and assess the performance of SSCs (Structures, Systems and Components), and humans. It is noted that PRA applications are also called as Risk-Informed (RI) applications. Up to this point in time, the BNPP PRA results and insights have mainly supported the design, construction, and startup of the units including the preparation of the FSAR Chapter 19.1 and meeting the FANR's Probabilistic Safety Target requirements. PRA applications have been placed on the back burner because the current ENEC activities are being focused on the BNPP Startup, Operational Readiness and Licensing, and development of the supporting Organization, People, and Procedures. Having said that, the following are some examples of PRA applications of interest by ENEC following the plant startup and commercial operation:

- Risk-informed security and use of PRA information in defining the Target Sets for BNPP to meet the FANR and USNRC requirements (Ref. 7)
- EDGs risk-informed Allowed Outage Time (AOT) extension (e.g., from 3 days to 14 days similar to U.S. plants). This application belongs in the NEI Risk-Informed Technical Specifications (RITS) Initiative 4a. The generalized initiative for flexible AOTs or also called as Risk-Informed Completion Times (RICT) is NEI RITS 4b (Ref. 8).
- EDGs risk-informed reduction of testing frequency to prevent their potential excessive wear outs. This application belongs in the NEI RITS Initiative 5b (Ref. 9).
- Graded QA or 10CFR50.69 to procure low risk significant, safety-related equipment with commercial grade qualifications. It is noted that the Graded QA application has been superseded by 10CFR50.69 (Refs. 10 and 11).
- Increase Flexibility in Mode Restraints, Limiting Condition for Operation (LCO) 3.0.4, which permits, for most systems, transitioning up in mode with inoperable equipment, relying on compliance with the technical specification actions of the higher mode, after assessing and managing the risk. This application belongs in the NEI RITS Initiative 3 (Ref. 12).

II.I. PRA Group Procedures

The ENEC PRA group will initially mostly rely on PRA procedures developed by KEPCO E&C and KHNP who will be running the Barakah plant for the first ten years. However, they will also revise/develop PRA group procedures to specifically address the following three main areas:

- PRA group oversight procedure to ensure PRA scope and quality including desktop procedures for various PRA technical areas
- PRA model maintenance and update procedure including procedure to evaluate impact of plant design and procedure changes on PRA model and results
- PRA application procedures

The first group of PRA procedures includes a procedure to perform oversight of tasks performed by KEPCO E&C and KHNP to ensure PRA scope and quality meet the regulatory requirements, a detailed checklist to facilitate the acceptance reviews of the PRA documents, and a number of detailed desktop procedures to perform various PRA technical tasks (e.g., initiating events analysis, systems analysis, success criteria development, HRA, accident sequence quantification, uncertainty and sensitivity analyses, etc.). The ENEC PRA group is currently developing desktop procedures for performing various PRA technical tasks.

The PRA model maintenance and update procedure is a key procedure since the BNPP PRA will go through a number of revisions from design to construction and startup tests and finally to commercial operation. As stated earlier, as design and procedures are completed and other units are constructed and placed in operation and the design basis configuration changes, PRA sensitivity analyses will be performed to assess the impact of the changes. Consequently, the PRA model and the baseline configuration will be also updated, as needed, to reflect the updated design basis. This procedure is used to evaluate the potential impact of design and procedure changes as well as identified issues on the PRA models and results and update the models, as needed. This is a requirement for having a Living PRA. The procedure for configuration control and V&V of the PRA software can also belong in this group.

Finally, there is a need to develop procedures for performing PRA applications or RI-applications at BNPP during commercial operation. As stated earlier, examples of future RI applications of interest to ENEC are RI-security and development of Target Sets using PRA information, configuration risk management (CRM), extending EDGs AOT (e.g., from 3 to 14 days), graded QA (or 10CFR50.69, SSC risk significant categorization) to be able to procure low risk significant, safety-related SSCs with commercial grade equipment, RI-IST, RI-ISI, NOEDs, and RITS initiatives (e.g., missed surveillances, Flexible Mode Restraints, extended surveillance intervals or RITS initiative 5b, flexible AOTs, or RITS initiative 4b, etc.). The ENEC PRA group is currently reviewing some example PRA application procedures developed and used at some U.S. plants as a starting point and is also evaluating their applicability to BNPP.

III. CONCLUSIONS

A young PRA group at a new NPP such as Barakah in UAE has many responsibilities and challenges during design, construction, licensing, startup, and commercial operation of the plant. The UAE Regulatory Body, FANR, requires that a plant-specific and full scope PRA be performed as part of the BNPP Construction and Operating License. The PRA will constitute as Chapter 19.1 of the plant FSAR. The ENEC PRA group is involved in reviewing the PRA, its peer review, and submittal to FANR as well as responding to FANR's RAIs. A key challenge has been to ensure that the PRA risk results for BNPP meet the FANR's Probabilistic Safety Target requirements for both CDF and LRF. This has required a number of design improvements to be able to reduce the baseline risk values. The PRA group also supports the development and V&V of the BNPP SAMGs, EDMGs, and FSGs. The PRA engineers are responsible to develop the BNPP online risk monitor tools and also develop all the PRA technical procedures as well as the PRA model maintenance and update procedure. Another challenge for the ENEC PRA group is that the scope of the BNPP PRA should reflect the 1st year design basis and operating/licensing basis per FANR's guidance and licensing requirements. This would make the BNPP PRA a phase dependent model, which will be updated several times in the future as Unit 1 completes its 1st year of operation and constructions of the other units are complete and they start commercial operation as well. Finally, as BNPP starts commercial operation and the PRA model is updated to an Operational PRA, the ENEC PRA group will start performing PRA applications such as risk-informed security and use of PRA information in defining the Target Sets for BNPP, EDGs risk-informed AOT extension, and graded QA or 10CFR50.69 (i.e., risk-informed categorization and treatment of SSCs).

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