Transactions, **SMiRT-24**
BEXCO, Busan, Korea - August 20-25, 2017
Division IX (include assigned division number from I to X)

SSHAC Level 3 PSHA Conducted for the Ikata NPP Site, Japan

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ABSTRACT

An on-going project for implementation of a Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 probabilistic seismic hazard analysis (PSHA) for the Ikata Nuclear Power Plant (NPP) site in Japan is presented. The project is being conducted as part of efforts by utilities to enhance their seismic risk assessment capabilities. The SSHAC guidelines are given in NUREG-2117 and it is a process for PSHA focused on evaluating and quantifying uncertainties in the assessment. The SSHAC process has been used to develop PSHAs at all NPPs in the U.S. and in several other countries. Although Japan is a country with high seismicity, Japan has not conducted PSHAs according to the SSHAC guidelines. After the Fukushima accident in 2011, the Japanese nuclear industry realized the importance of quantitative risk assessment as well as the objective evaluation and treatment of uncertainties in the field of natural external events. Under such circumstances, the Nuclear Risk Research Center (NRRC) was established in 2014. One of the activities of the NRRC is to conduct a PSHA according to the SSHAC guidelines with the collaboration of Shikoku EPCO. The project is being conducted using a SSHAC Level 3 process with strict adherence to all of the essential elements specified in NUREG-2117 and including leading researchers in both seismic source characterization (SSC) and ground motion characterization (GMC).This paper describes the significance and importance of SSHAC in Japan, outlines the Ikata SSHAC process being followed, and provides a brief status of the technical assessments being made for the Ikata SSHAC project.

PROJECT OBJECTIVE AND SIGNIFICANCE OF SSHAC IN JAPAN

Like many countries, the design-basis ground motions of nuclear facilities in Japan were evaluated deterministically according to Japanese nuclear regulations. Probabilistic seismic hazard analyses curves were only utilized as a basis for assessing the reference for the deterministic design-basis ground motion. However, after the tragic Fukushima nuclear accident in 2011, it was realized that Probabilistic Risk Assessment (PRA) and Risk Informed Decision Making (RIDM) should be developed and utilized in Japan to assess seismic safety, as one of the lessons learned from the accident.

Seismic events are potential common-cause accident initiators that can compromise both prevention and mitigation measures and multiple barriers of defence in depth, and therefore, can be important contributors to risk. A Probabilistic Seismic Hazard Assessment (PSHA) provides seismic initiating event frequencies. As there are large uncertainties inherent in natural external events hazard assessments, it is important to characterize these uncertainties rigorously, as PSHA strongly affects the results of a seismic PRA.

This project aims to develop the probabilistic seismic hazard curves for Ikata Nuclear Power Plant (NPP) according to the SSHAC guidelines as the first application in Japan. This is the initial step and will lead the Japanese nuclear power industry to the next stage of PRA/RIDM. One of the facts worthy of special mention is that this SSHAC project was not initiated by a regulatory requirement but by the utilities voluntarily.

SSHAC GUIDANCE

With the recognition of the importance of assessing seismic hazard probabilistically in the early 1980s came the understanding that treatment of uncertainties was vitally important and involved the use of expert judgment. In a major study in the US sponsored by the nuclear utilities, USNRC, and the US Department of Energy, the Senior Seismic Hazard Analysis Committee (SSHAC) proposed a practical and transparent process that provides a high degree of regulatory assurance for robust PSHA results accounting for inherent uncertainties in a systematic manner using expert judgment. The SSHAC guidance (NUREG/CR-6372) was published in 1997 (Budnitz, et al, 1997) and described four levels of study, with SSHAC Levels 3 and 4 being the most rigorous and appropriate for nuclear facilities. More than 15 years later and with the completion of several SSHAC projects, the USNRC issued practical implementation guidelines for SSHAC Level 3 and 4 studies (USNRC, 2012). In that document, the USNRC concludes that no difference exists between SSHAC Level 3 and 4 studies from the standpoint of regulatory assurance. Subsequent to the issuance of those guidelines, all nuclear power plants and nuclear facilities in the U.S. have developed SSHAC Level 3 PSHAs. The current Ikata SSHAC project is structured to be consistent with all guidance documents for a SSHAC Level 3 PSHA.

The SSHAC guidelines are designed to conduct and document the two key activities of a SSHAC project: *Evaluation*, which is the consideration of data, models, and methods that have been proposed by the larger technical community; and *Integration*, which is the construction of models that capture the center, body, and range of technically defensible interpretations. In order to achieve these goals, SSHAC guidelines describe essential tasks and procedures in detail for practical implementation. Several SSHAC projects have been implemented for nuclear facilities in the U.S., Europe, Africa, and other countries and key issues to be considered for the success of projects have been described in papers (e.g., Bommer and Coppersmith, 2013).

SUMMARY OF THE IKATA SSHAC LEVEL 3 PROJECT

IKATA SSHAC ORGANIZATION

The organization of the Ikata SSHAC Level 3 project is shown in Figure 1. Because this is the first SSHAC project in Japan, the management team identified a few experts who had experience in the implementation of SSHAC projects: Dr. Kevin Coppersmith, who is one of the authors of the SSHAC report and has led several SSHAC Level 3 projects, assumed the position of an advisor for the Ikata SSHAC project; Dr. George Apostolakis, who is also one of the authors of the SSHAC report and the head of NRRC, is also an advisor to this project; and Dr. Martin McCann is a member of the Participatory Peer Review Panel (PPRP) and has considerable project experience on SSHAC Level 3 projects. Based on the experience of these individuals, a Project Plan was developed for the Ikata SSHAC project and organized according to NUREG-2117 strictly, considering the roles and responsibilities of each participant. Special consideration was given to the participation of seismic experts from Japan for future

SSHAC studies for other facilities in Japan. The key participants of the project are the members of the Seismic Source Characterization (SSC) and Ground Motion Characterization (GMC) Technical Integration (TI) teams, who are responsible for the technical assessments of the project.

STUDY SCHEDULE

Figure 2 shows the simplified project schedule of the Ikata SSHAC project, which entails a total duration of about 30 months. In the planning of the project schedule, consideration was given to the fact that Shikoku EPCO had already studied PSHA before this SSHAC project. This provided insights and sensitivity analyses from the previous studies to assist in the early phases of the formal SSHAC project. The SSHAC study schedule was finalized at 30 months of project length, which is comparable to other such studies conducted worldwide and is consistent with the duration recommended in light of other studies (Bommer and Coppersmith, 2013). Due to the large amounts of studies and data previously conducted by Shikoku EPCO, it was decided that there was no need for additional field data collection activities prior to the start of the SSHAC project.

The Kick-off meeting was held in March 2016. Dr. Kevin Coppersmith conducted SSHAC training for all Japanese SSHAC participants. SSHAC training was done not only for the Ikata SSHAC project participants but also for other electric utilities' staff for the future SSHAC development in Japan. The first two workshops in a SSHAC process are part of the *Evaluation* process and include the consideration of hazard significant issues (HSI), the identification of data to address the HSIs in Workshop #1 (WS1), and the identification of models and methods regarding the HSIs in WS2. WS1 was held in September 2016 and WS2 in March 2017. Much of the work in a SSHAC project occurs in a series of Working Meetings held with the TI Teams between the workshops. The first Working Meeting was held prior to Workshop #1 to ensure that all SSHAC participants understood the significance, objectives and procedures of a formal SSHAC project. With the conclusion of WS2, the project will move into the *Integration* stage of the project during which preliminary SSC and GMC models will be constructed and preliminary PSHA calculations conducted for discussion at WS3, which will be held in March, 2018. After WS3 the TI teams will develop their final SSC and GMC models, final hazard calculations will be conducted, and the project documentation will be developed. We are going to finish the 1st formal SSHAC project in Japan by the end of 2018.

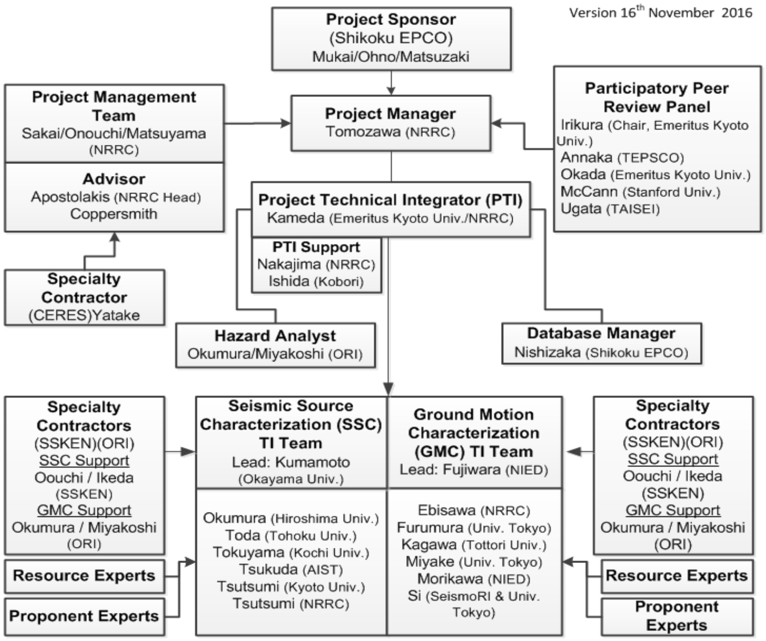

Figure 1. Ikata SSHAC Level 3 PSHA Project Organization.

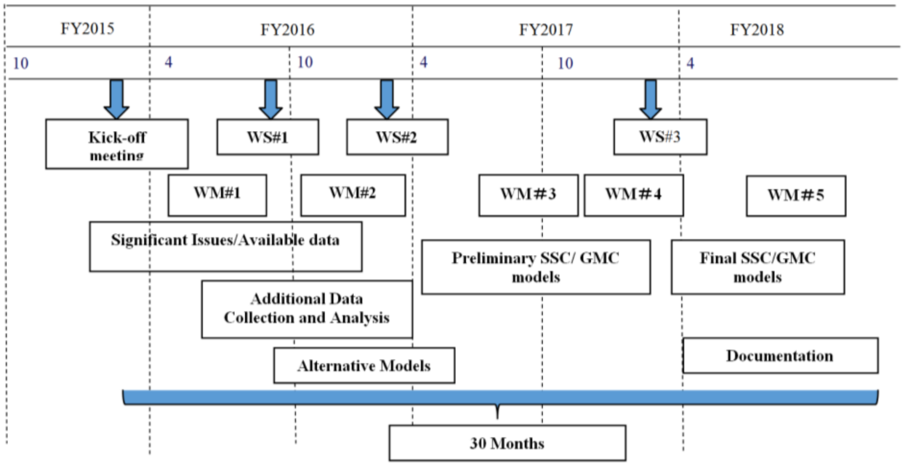

Figure 2 : Project Schedule

TECHNICAL ISSUES UNDER DISCUSSION

GEOLOGICAL AND SEISMOLOGICAL CHARACTERISTICS OF THE IKATA NPP SITE

Figure 3 shows the location of Ikata NPP. The site is located in Western Japan on Shikoku island, where there are three PWR units. Fig.3 also shows the plate boundary around Western Japan. The subduction zone near Ikata NPP is the Nankai trough. The plate interface between the Philippine-sea plate and the Eurasian plate is about 30-40 km depth under the Ikata NPP site.

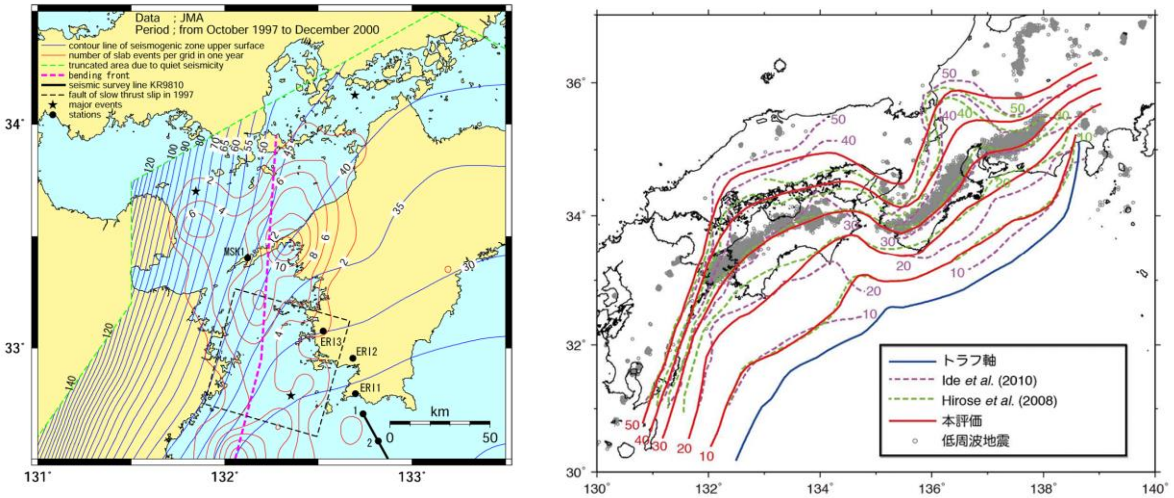

Figure 3 Site location/ Plate Boundary

In addition to subduction zone sources, there are also crustal fault sources and Fig.4 shows the distribution of active faults around the Ikata NPP site. There is a long active fault system named Median Tectonic Line (MTL) passing at a closest distance of 8 km from the Ikata NPP site. MTL is one of the longest and the most well-known active fault system in Japan. In the past, Shikoku EPCO conducted deterministic studies to evaluate the implication of various segmentation models to the possible magnitudes that might be generated on the MTL. These deterministic studies have little meaning to probabilistic studies because they do not consider the recurrence rates for earthquakes. Probabilistic sensitivity studies conducted for the Ikata PSHA confirm the importance of the MTL to the PSHA. Fortunately, there have been numerous studies, including Shikoku EPCO's vast and valuable field survey that assess the MTL, which is one of the longest fault systems in Japan. Evaluating these data and integrating the models will be one of the most important parts of seismic source characterization for Ikata PSHA study.

In addition, due to the proximity of the MTL to the site, the GMC modelling will need to consider not only the existing ground motion prediction equations (GMPE) but also fault simulations that supplement the existing ground motion data in the close distance and larger magnitude range. Recent SSHAC studies with nearby fault sources have also used fault simulations to supplement observed strong motion data.

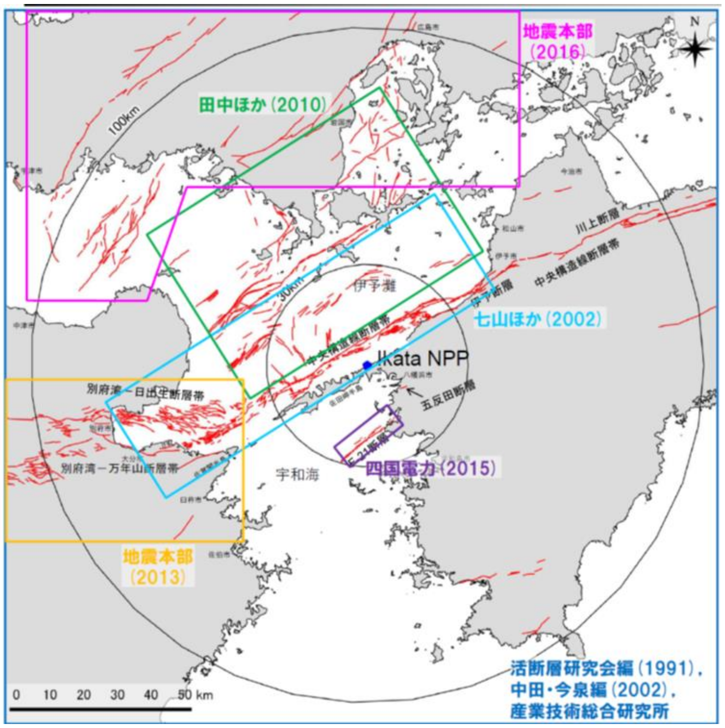

Figure 4 Active Faults Distribution

MAJOR HAZARD SIGNIFICANT ISSUES

Major hazard significant issues (HSI) discussed at WS1 are listed in Table 1.The TI teams identified these HSIs based on the results of previous sensitivity analyses and their experience in PSHA. Figure 5 shows the relative contribution of various seismic sources for the hazard at spectral accelerations with structural periods of 0.02 sec. Earthquakes in the Nankai trough are dominant at high annual frequencies and lower ground motions, while the MTL and other inland seismic sources are dominant at low annual frequencies and larger ground motions. Past seismic PRA results in Japan and elsewhere show that Core Damage Frequency (CDF) is controlled by ground motions having annual frequencies in the range of 10^{-4}/y - 10^{-6}/y. Considering these facts and using experience from other PSHA studies, the TI teams selected the hazard significant issues shown in Table 1.

Table 1 Major Hazard Significant Issues:
SSC Issues in Yellow; GMC Issues in Green

Outline of models		(a)	(b)	(c)	(d)	(e)	(f)
		Position / Shape	Magnitude	Earthquake occurrence probability	Location of asperity	Estimation of hypocenter	Methodology of seismic motion evaluation
(1)	Nankai Trough Megathrust Earthquake	•Region(east-west direction) •Region(north-south direction)	•Calculated for each pattern	•Calculated in BPT •Simultaneous rupturing model	–	–	•Attenuation model
(2)	Earthquake in/on the Philippine Sea Plate whose seismic source is difficult to identify	•Region to be examined •Depth •Ratio of earthquake in/on the Philippine Sea Plate	•Largest magnitude •Smallest magnitude	•Calculated in the Poisson process	–	–	•Attenuation model
(3)	Earthquake along the Median Tectonic Line Fault Zone	•Position •Dip angle •Thickness of the seismogenic layer	•Segmentation •Simultaneous rupturing model •Empirical Magnitude Estimation	•Calculated in the BPT /Poisson process •Simultaneous rupturing model	•Number /location of asperity	•Method of setting the hypocenter	•Attenuation model •Fault rupture model
(4)	Inland earthquake on minor faults	•Active fault to be examined •Thickness of the seismogenic layer	•Empirical Magnitude Estimation	•Calculated in the BPT /Poisson process	–	–	•Attenuation model
(5)	Minor inland earthquake whose magnitude is smaller than its assumed characteristic size	•Active fault to be examined •Thickness of the seismogenic layer	•Largest magnitude •Smallest magnitude	•Calculated in the Poisson process	–	–	•Attenuation model
(6)	Inland earthquake whose seismic source is difficult to identify	•Region to be examined •Depth	•Largest magnitude •Smallest magnitude	•Calculated in the Poisson process	–	–	•Attenuation model

As expected, the SSC TI team members agreed on the importance of MTL evaluation, especially uncertainty in evaluating the segmentation and recurrence. The MTL has been a target for many researchers studying the paleoseismic history of the fault. National institute evaluated MTL in detail since the seismic impact of the MTL is critical for the people in this region. The HSIs for GMC include considerations of applicable GMPEs, such as those for the plate interface and intraslab seismic sources. Two major challenging issues for GMC are caused by the site condition. One is shear wave velocity (Vs) of the site bedrock, which at Ikata is 2.6 km/s. The GMC model will need to take the shear wave velocity profile into account in correcting the applicable GMPEs, as well as to include corrections for the kappa in the vicinity of the site. Such consideration is essential for the site specific study. The other significant issue to be considered in GMC is the treatment of the fault rupture model. Especially, treatment of uncertainty in the fault rupture model and the associated simulations. Similar to SSHAC PSHA studies conducted close to active faults at Diablo Canyon and Hanford, fault rupture simulations will be needed to supplement the relatively few ground motion records at applicable distances and magnitudes needed for a full GMC models for the PSHA. Up to now, most studies which have utilized a fault rupture model in Japan have been done as deterministic assessments and the treatment of uncertainty was considered as conservative. It is necessary for the Ikata SSHAC project to treat the uncertainty of the fault rupture model appropriately in the GMC logic tree model.

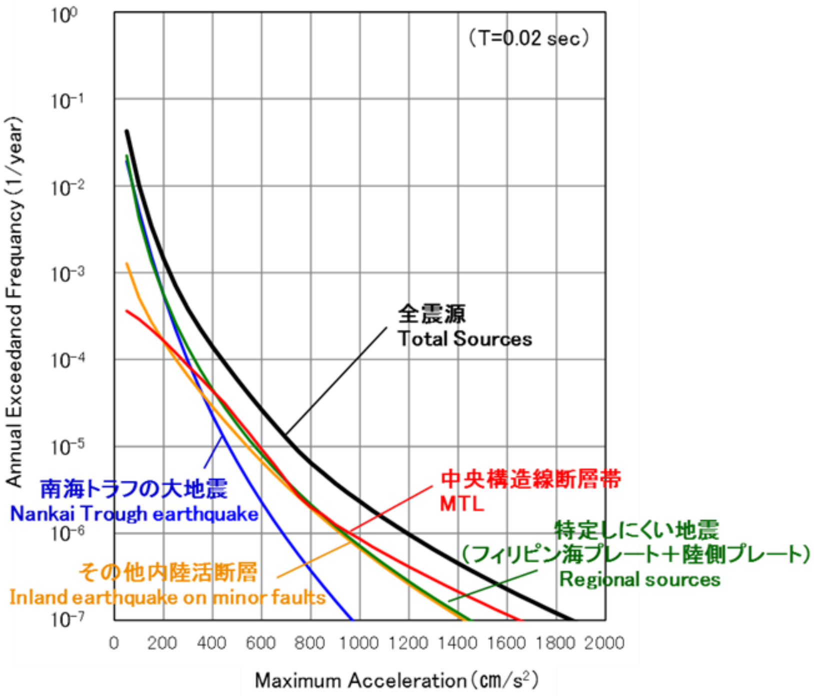

Figure 5 Hazard Sensitivity Analysis Showing the Contributions of Seismic Sources to the Total Hazard

FUTURE TASKS

With the conclusion of WS2, the bulk of the *Evaluation* phase of the project will be complete and the *Integration* or model-building phase will begin. Working Meetings will be held with the SSC and GMC TI teams to prepare their preliminary SSC and GMC models. These will be used to calculate the hazard at the Ikata site including extensive sensitivity analyses. The technical bases for the preliminary models and the hazard results will be discussed in the WS3. During the integration process, the TI teams are considering not only Japanese data and information but also relevant international study results. These perspectives have come not only from the data, models, and methods in the international literature but also from the international Proponent Experts at WS2. At WS3, per the SSHAC Level 3 process, the PPRP will be encouraged to participate in the workshop and to ask questions of the TI teams regarding the technical bases for their models, including the structure of the logic trees and the bases for all branches and weights on the trees.

Following WS3, the SSC and GMC models will be finalized by the teams and the *Documentation* phase will be conducted. Per SSHAC guidance, the documentation will include a complete description of all aspects of the Evaluation and Integration phases of the project, including a complete justification for all technical assessments made. The project database will also be described and the use of that database will be documented such that readers of the report will understand which elements of the database were relied upon to make the technical assessments. The final project report will also include the full PSHA results and sensitivity analyses. These hazard results will be developed as full hazard curves and percentiles such that they can readily be used in subsequent PRA and other decision making.
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CONCLUSION

Described in this paper is the important first SSHAC Level 3 PSHA implementation in Japan. We have discussed the significance and outlined the key technical issues and challenges being faced in the Ikata SSHAC project. This is the first and important step for Japan to develop a solid RIDM application. Defensible RIDM requires a properly conducted PRA and the PSHA is an important part of the PRA as there are large uncertainties inherent in natural external events hazard assessments. Therefore, PSHA based on the formal SSHAC guidelines is an essential step to obtain a “Good PRA” and will lead to a well-established RIDM. In addition to conducting the Ikata SSHAC PSHA properly, it is also important to consider the lessons learned from the Ikata project and their implications to the manner in which the SSHAC methodology can be applied to other NPP sites in Japan.

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