PROJECT EXECUTION PLAN

SSHAC Level 3 Probabilistic Seismic Hazard Analysis For Vibratory Ground Motion for the Thyspunt Nuclear Siting Project, South Africa

Julian J. Bommer and Kevin J. Coppersmith

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AUTHORS			
			ACCEPTED BY:
J.J. Bommer	K.J. Coppersmith		N. Keyser
			AUTHORISED BY:
			G. Graham

REVISION	DESCRIPTION OF REVISION	DATE	MINOR REVISIONS APPROVAL
0		Dec 2010	
1	p.22 A. Graham and M. Grouveneur will assist the Project Manager p.75 Portal address was added p.102 Corrected Gantt Chart was added	Feb 2011	
2	p.4 Limited scope of hazard due to natural earthquakes p.13 Eliminated references to CAV reports by EPRI p.29 Added mention of contribution by Keshav Prasad p.29 Eliminated names of individual members of GIS team p.32 Noted 'Kainos South Africa' affiliation for M. Goedhart p.41 Replaced Fig.5.2 with expanded version from WS1 p.42 Change designation of Task T-4 in Table 5.1 p.49 Change designation of Task T-4 in section heading p.53 Added mention of contribution by Keshav Prasad p.54 Added mention of contribution by Keshav Prasad p.63 Deleted reference to CAV filter p.69 Updated dates for WS2 p.69 Updated date for delivery of draft report to PPRP p.75 Eliminated names of individual members of GIS team p.81 Updated affiliation of Dr Julian Bommer p.83 Deletion of final sentence p.102 Inserted corrected Gantt Chart	May 2011	
3	p.61 Hazard results will be shown without normalisation at Workshop #3 p.25 and p.52 Vunganai Midzi replace Sbonelo Zulu	Jan 2012	
4	Section 2 (References): Coppersmith et al. (2010) paper from PSAM10 referring to draft NUREG replaced with published NUREG-2117; text altered accordingly. Section 4.2: Nico Keyser named as CGS Management Representative Section 4.9: Resignations and new appointment of PPRP members noted, including dates of exit and entry Section 5.5: Table 5.3 added with Working Meeting dates Section 7.1: Text added explain Data Summary Reports and White Papers as GMC equivalent of Data Summary and Evaluation Tables used by SSC TI Team	March 2012	

5	p.11:RD-0034 corrected to indicate that it is no longer a draft report p.12: Publication date of NUREG-2117 changed to 2012 p.18: Figure 4.2 updated to reflect communication and reporting link between PPRP and Project Sponsor in a SSHAC Level 3 study p.19: Figure 4.3 updated to reflect communication and reporting link between PPRP and Eskom in the TNSP SSHAC Level 3 study p.25: Laura Glaiser removed from SSC TI Team and Vunganai Midzi removed from GMC TI Team p.31: Text modified to reflect final structure of Hazard Calculation Team p.52: Text modified to emphasise role of Vunganai Midzi in leading the compilation of the Intensity Database p. 55: Text modified to change the duration of the workshop to 7 days and explained the reasoning why. Also changes the text to indicate that the PPRP “will” convene rather than “may” p.61: Text modified to clarify the composition and structure of the Hazard Calculation Team, and to note the final arrangements for independent checks on the final hazard calculations p. 62: Text modified to change the duration of the workshop to 5 days and explained the reasoning why. p.67: Table 5.2 modified to clarify sequence of review of draft final report by PPRP and submission to Eskom		

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1. SCOPE

1.1. Purpose

This document presents the plan for the execution of a site-specific probabilistic seismic hazard analysis (PSHA) undertaken for Eskom. The specific purpose of the PSHA is to provide input to the development of a Site Safety Report (SSR), which, in turn, will provide input to the Safety Assessment Report (SAR) that Eskom will submit to the National Nuclear Regulator (NNR) in support of their application to build and operate a nuclear power plant (NPP) at the Thyspunt site in the Eastern Cape, South Africa.

The purpose of this document is to provide every participant in the project, as well as the client and any observers of the project, a single point of reference that identifies the overall framework for the execution of the project.

After this Introduction (Chapter 1), references (Chapter 2), and definitions, acronyms, and symbols (Chapter 3), this document presents the organisational framework for the project, including the roles and responsibilities of all the participants (Chapter 4). Chapter 5 presents the detailed work plan including all tasks to be executed, the project schedule, and the technical deliverables that will be produced by the PSHA study. Chapter 6 summarises the processes by which the project will be monitored, and Chapter 7 identifies the records that will be produced in the project to document progress and the final deliverables.

1.2. Scope of the PSHA Project

The scope of the PSHA for the Thyspunt site is exclusively focused on the hazard associated with vibratory motion (due to natural earthquakes) at the appropriate foundation levels at the Thyspunt site, represented in various forms as listed in Section 5.1 of this document. The influence of near-surface geo-materials on the ground motion will be included in the characterisation of ground-shaking hazard, but the characterisation of other potentially destructive earthquake effects at the Thyspunt site is outside the scope of this project.

The scope of the project does not include the characterisation of other earthquake-related hazards that could affect the site (Figure 1.1), such as seismically-triggered landsliding and liquefaction. However, the vibratory ground motion hazard, once it is defined by this project, can provide input to the studies of other seismic hazards. For example, the seismic source characterization (SSC) model will define local seismic sources and will consider the potential activity of faults within the site region and the site vicinity. These elements of the SSC model can provide input to the assessment of the potential hazard of surface rupture due to faulting at the site that must be considered as part of the SSR, as well as the local seismic sources that, along with distant seismic sources and offshore landslides must be considered in the analysis of tsunami hazard at this coastal site. Although this study will provide inputs to studies of other hazards, they are not addressed in the PSHA project.

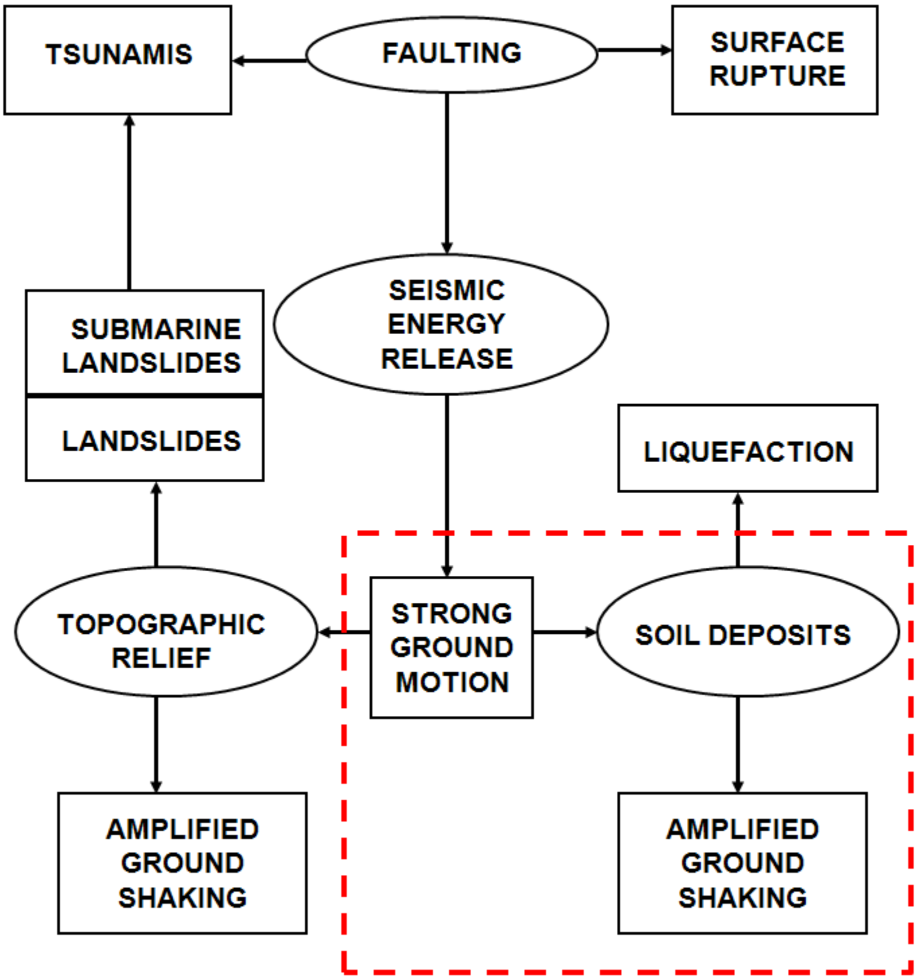

Figure 1.1. Potentially destructive effects of earthquakes, showing the elements of the earthquake generation process and the natural environment (*ellipses*) and the resulting seismic hazards (*rectangles*); adapted from Bommer & Boore (2004). The red dashed line encloses the elements that are the focus of this study.

An overview of the basic elements of PSHA, in terms of assessing the hazard due to earthquake-induced ground shaking, is provided in Appendix A of this document. The work and methodology identified in this Project Execution Plan are intended to achieve the goal of regulatory acceptance of the results. To enhance the probability of acceptance by the National Nuclear Regulator (NNR), including satisfaction of RD-0016 (NNR, 2006a), RD-0018 (NNR, 2006b) and RD-0034 (NNR, 2008), methodologies with considerable precedence and recognition by the US Nuclear Regulatory Commission (NRC) and regulators from other countries are being used. For example, the study is consistent with the following regulatory guidance, which stipulates the manner in which a PSHA should be carried out and defines acceptable approaches to specifying design basis ground motions for the design of nuclear facilities:

- Regulatory Guide 1.208. *A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion* (NRC, 2007)
- ASCE/SEI 43-05 *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities* (ASCE, 2005)

These documents are widely regarded as representing international best practice and the most stringent procedures for conducting analyses of the seismic loading to be considered in the design of nuclear power plants. Satisfying the requirements of these stringent guidelines means that the study will satisfy the requirements and standards specified by the International Atomic Energy Authority (IAEA) including the recently published Safety Guide SSG-9 (IAEA, 2010).

The outputs from the PSHA study, which will form the technical deliverables of the project, are listed in Section 5.1 of this document. These will essentially conform with the specifications of Regulatory Guide 1.208 (NRC, 2007).

Fundamental to providing a basis for regulatory assurance is demonstrating that the seismic hazard calculation has duly considered all uncertainties in the calculation of the earthquake loading to be considered in design and in safety analyses. As explained in Appendix A, uncertainties are classified into two categories, aleatory variability and epistemic uncertainty. The first category, aleatory variability, reflects the inherent randomness in earthquake processes, including the location, time of occurrence and magnitude of future earthquakes, and the resulting level of ground motion at a particular site, with respect to median predictions. The probabilistic approach to seismic hazard analysis is specifically formulated to integrate all these sources of variability into the estimation of the annual exceedance frequency of different levels of each ground-motion parameter. Therefore, adoption of PSHA as the basis for determining the seismic design loads, and executing the PSHA in terms of characterising design ground motions according to the specification of RG 1.208 (NRC, 2007), ensures adequate consideration of aleatory variability.

The second category of uncertainty is epistemic uncertainty, and this is the uncertainty that results from our incomplete knowledge regarding earthquake processes in general and specifically in the region under study. The treatment of epistemic uncertainties in seismic hazard analysis, as explained in Appendix A, requires expert judgement to identify the best estimate for each component of the seismic hazard model, and then to estimate the range of uncertainty associated with each model or parameter in view of the limited and incomplete data available for its constraint. The tool most widely used in PSHA to incorporate epistemic uncertainties is the logic-tree (see Section A1.5) and this is the primary tool that will be used in the Thyspunt PSHA project to incorporate epistemic uncertainties. In some cases, continuous parameter distributions may be used and, if appropriate, these will be represented by a limited number of discrete logic-tree branches.

The key issue in successful implementation of a logic-tree for PSHA is a structured process to identify and quantify epistemic uncertainty through objective evaluation of the range of diverse technical interpretations from the larger scientific community, making full use of all available data and avoiding cognitive biases on the part of the evaluators. The US Nuclear Regulatory Commission (NRC) endorses the use of the approaches to such multi-expert assessments outlined in NUREG/CR-6372 *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts* (Budnitz *et al*., 1997). This document is generally referred to as the *SSHAC Guidelines* after the group that was formed by NRC, the US Department of Energy and the Electric Power Research Institute (EPRI) to produce this guidance. The *SSHAC Guidelines* are explicitly identified as an approved approach in RG 1.208 (NRC, 2007) and are adopted in this project as the framework for the identification, quantification and incorporation of epistemic uncertainties.

1.3. Procedural Framework for the Project

The *SSHAC Guidelines* (Budnitz *et al*., 1997) define four Study Levels for conducting a PSHA, increasing in complexity from Level 1 to Level 4. The SSHAC Study Level adopted for the Thyspunt PSHA is Level 3. This choice explained in detail in another document (Coppersmith & Bommer, 2011) but some brief notes are provided here on the rationale for adopting a SSHAC Level 3 framework for the conduct of this site-specific PSHA.

As one progresses from a Level 1 assessment study to a Level 4 assessment study, the process becomes more elaborate and the project more resource-intensive. The recompense for adopting a higher study level is that the higher levels provide greater regulatory assurance that the full range of uncertainties have been captured and incorporated into the seismic hazard analysis.

The original *SSHAC Guidelines* (Budnitz *et al*., 1997) focused primarily on defining the procedures to be followed for a Level 4 study, and relatively little detailed guidance on organising and conducting a Level 3 assessment study. As a consequence of this focus, it has often been perceived that the most significant increment in the degree of regulatory assurance is associated with the step up from a Level 3 to a Level 4 study. This is not in fact the case, and the most significant increase in complexity, effort and cost (and also in degree of regulatory assurance) is the step from a Level 2 study to Level 3.

In 2008, the Research Division of US NRC, sponsored a research study entitled *Implementation of the SSHAC Guidelines for Level 3 and 4 PSHAs: Experience Gained from Actual Applications*, which included three workshops involving participants from hazard assessment studies employing these approaches. Among the conclusions from this project, summarised by Hanks *et al*. (2009), is that more detailed guidelines need to be developed regarding the conduct of Level 3 assessment studies. Such guidance is currently being drafted in the form a new NRC NUREG that was published in 2012 (USNRC, 2012). This NUREG will recommend that SSHAC Study Levels 3 and 4 should be employed for PSHAs to be used for new nuclear power plants.

The guidance being developed in the forthcoming NUREG show that Level 3 and 4 studies are similar in most respects, and are built around common elements in terms of data collection, workshops, evaluation, documentation and peer review. The essential difference is that whereas the technical evaluations are made by a team of experts working together in a Level 3 study, in a Level 4 study evaluations are made by individual experts forming a panel, and their evaluations are integrated by a Technical Facilitator Integrator, or TFI. Experience suggests that Level 4 studies can be resource-intensive relative to both time and budget, generally costing more than a Level 3 study and requiring an appreciable increase of the schedule. Although a Level 4 study may provide a slightly greater degree of regulatory assurance, Level 3 studies are currently being used for PSHA studies for safety-critical facilities, including the *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities Project* (CEUS SSC), the *NGA-East Project* to develop ground-motion prediction equations for PSHA in Central and Eastern United States, and *PSHA Project for Hydroelectric Dam Sites in British Columbia*, Canada, being conducted by BC Hydro. Also, in its new SSHAC implementation guidance (USNRC, 2012), the US NRC makes no distinction between Levels 3 and 4 in its recommendations for their application at new nuclear power plants.

The regulatory assurance provided by a SSHAC Level 3 or 4 process is derived from a structured procedure in which a large number of suitably-qualified experts are engaged, each adopting a clearly defined role, which requires certain attributes and which imposes specific responsibilities (see Chapter 4). The experts examine all available data, methods and models, and engage in structured interactions of technical challenge and defence, in the setting of formal workshops. Considerable project resources are devoted to ensuring a thorough examination and evaluation of all applicable datasets and to the evaluation of alternative hypotheses that exist within the technical community. This assures the regulators that the data compilation and evaluation process is complete, plus an exhaustive and transparent consideration of the breadth of the technical community's viewpoints has been undertaken. Regulatory assurance is additionally provided by rigorous peer review throughout the project of both process and of technical assessments, including the final project documentation (see Section 4.9).

The fundamental objective of a SSHAC process is as summarised in the often-cited statement from Budnitz *et al.* (1997): "*Regardless of the scale of the PSHA study the goal remains the same: to represent the center, the body, and the range of technical interpretations that the larger informed technical community would have if they were to* *conduct the study*”. The wording of this statement, and in particular the use of the term ‘informed technical community’ (ITC), has generated some confusion and misunderstanding. According to the SSHAC guidelines, the goal of representing the centre, the body and the range (CBR) of technical interpretations of the ITC is achieved through a two-stage process of evaluation followed by integration. By the definition given in the SSHAC guidelines, the “informed” technical community is one that (1) has detailed knowledge of project-specific databases, and (2) has been through the interactive SSHAC process of workshops and technical debate. Literally, the TI Team is the only group of experts that possesses these attributes, but the SSHAC guidelines call for the TI Team to consider hypothetically that the larger technical community had the same attributes. This concept encourages the TI Team to consider beyond their own points of view and to thoroughly explore the range of models that exist in the larger technical community. This is a valuable concept and experience has shown that it can be successful, but the notion of imagining what the views of the larger technical community would be is difficult to explain, is subject to variable interpretation, and distracts from the real goal of properly and completely capturing knowledge and uncertainties. Therefore, rather than offer lengthy explanations of the concept of the CBR of the ITC, it may be more useful to find an alternative formulation that is easier to grasp, as discussed below.

The SSHAC guidelines define two distinct responsibilities of the TI Team: evaluation and integration. A SSHAC Level 3 process starts by the TI Team (Section 4.4) identifying, with input from resource and proponent experts (Sections 4.6 and 4.7), the available body of hazard-relevant data, models and methods, including, to the extent possible, all those produced by the technical community, and supplemented by new data gathered within the project (Section 4.5).

The TI Team then evaluates these data, models and methods, and documents both the process by which this evaluation was undertaken and the technical bases for all decisions regarding the quality and usefulness of these data, models and methods. This evaluation process includes interaction with and amongst members of the technical community and subjecting their data, models and methods to technical challenge and defence. The successful execution of the evaluation is confirmed by the concurrence of the PPRP (Section 4.9) that the TI Team has provided adequate technical bases for its conclusions about the quality and usefulness of the data, models and methods, and has adhered to the SSHAC assessment process. The PPRP will also provide guidance regarding the objective of considering all of the views and models presented by the technical community

Informed by this evaluation process, the TI Team then performs an *integration* process which may include incorporation of existing models and methods, developing new methods, and building new models. The objective of this integration process is to capture the centre, the body and the range of technically defensible interpretations of the available data, models and methods. The technical bases for the weights on different models in the final distribution, and also for the exclusion of any models and methods proposed by the technical community, need to be justified to the satisfaction of the PPRP. To satisfactorily conclude the project, the PPRP will also need to confirm that the SSHAC assessment process was adhered to throughout.

Therefore, it may be clearer to refer to the CBR of TDI, where TDI stands for “technically-defensible interpretations [of available data, methods and models]”, instead of CBR of the ITC. For clarity, in this project this alternative expression will be used.

1.4. Applicability

This Project Execution Plan is applicable to all project participants, whose roles within the project are defined in Chapter 4. The plan will be finalised prior to commencement of the project and will be valid for its entire duration, unless there are compelling reasons for modifications to schedule. The scope of the work defined in this document, has been promulgated into the Terms of Reference for all project participants, and will not be changed without negotiation of new contracts.

2. REFERENCES

2.1. CGS references

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Processes, Classification and Technical Procedures	CGS Report 2010-0171
Safety Culture Enhancement Programme	CGS Report 2010-0192
Compliance Matrix	CGS Report 2010-0175
Safety Plan for the SSHAC Level 3 PSHA for the Thyspunt Site	CGS Report 2010-0243
Risk Register	TNSP-RR-10-0001

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3. DEFINITIONS, ACRONYMS AND SYMBOLS

A full list of definitions, abbreviations, acronyms and symbols can be found in CGS Report 2010-0168: IMS Manual and Procedures: CGS/QA10/MN01 Integrated Management System Manual: Appendix B.

Terms specific to the structure of a SSHAC Level 3 study are explained in Section 1.3 of this report, and those related to Probabilistic Seismic Hazard Analysis (PSHA) are explain in Appendix A. For ease of reference, a list of acronyms and symbols specific to this Project Execution Plan is presented herein.

Acronym or Symbol	***Definition***
CBR	Centre, Body and Range
CD	Compact Disk
CFR	Code of Federal Regulations
CGS	Council for Geoscience
DEM	Digital Elevation Model
DOE	Department of Energy, USA
EPRI-SOG	Electric Power Research Institute and Seismicity Owners Group
Eskom	Electricity Company in South Africa
GIS	Geographical Information System
GMC	Ground Motion Characterisation
GMPE	Ground Motion Prediction Equation
GMRS	Ground Motion Response Spectrum
GPS	Global Positioning System
HID	Hazard Input Document
IAEA	International Atomic Energy Agency
IMS	Integrated Management System
ISO	International Organisation for Standardisation
ITC	Informed Technical Community
MASW	Multichannel analysis of surface waves
M	Magnitude
M_w	Moment magnitude
m_{max}	Upper limit of magnitude for a given region
m_{min}	Minimum threshold magnitude

Acronym or Symbol	*Definition*
MMI	Modified Mercalli Intensity
MSc	Master of Science
N/A	Not applicable
NECSA	Nuclear Energy Corporation of South Africa
NNR	National Nuclear Regulator (South Africa)
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission, USA
NSIP	Nuclear Siting Investigation Programme (Eskom)
OSL	Optically stimulated luminescence
PBMR	Pebble Bed Modular Reactor
PDF	Portable Document Format (*.pdf)
PEP	Project Execution Plan
PGA	Peak Ground Acceleration
PM	Project Manager
PMT	Project Management Team
PNI&I	Palaeoseismic and Neotectonic Investigation and Integration
PPE	Personal protective equipment
PPRP	Participatory Peer Review Panel
PQP	Project Quality Plan
PSHA	Probabilistic Seismic Hazard Assessment
PSM	Project Safety Manager
PTI Lead	Project Technical Integration Leader
QA	Quality Assurance
QADP	Quality Assurance Data Package
QC	Quality Control
QCP	Quality Control Plan
QM	Quality Manual
QMS	Quality Management System
R	Distance of site from source of earthquake
ROI	Region of interest
RSA	Republic of South Africa
S&QM	Safety and Quality Manual
SA	Spectral acceleration
SABS	South African Bureau of Standards
SANS	South African National Standard

Acronym or Symbol	*Definition*
SANSN	South African National Seismograph Network
SDM	Spatial Data Management Unit, CGS
SEE	Safety Evaluation Earthquake
SHA	Seismic Hazard Analysis
SHE	Safety, Health and Environment
SM	Safety Manual
SMS	Safety Management System
SOW	Scope of work
SPOT	Satellite Pour l'Observation de la Terre
SRK	Engineering consultancy firm, Eskom's contractor for the SSRs
SSC	Seismic Source Characterisation
SSHAC	Senior Seismic Hazard Analysis Committee
SSR	Site Safety Report
TBA	To be announced
TBC	To be confirmed
TDI	Technically-defensible Interpretations
TI	Technical Integrator
TI Leads	Technical Integration Leaders
TI Team	Technical Integrator Team
TOR	Terms of reference
TNSP	Thyspunt Nuclear Siting Project
UHS	Uniform hazard spectrum
USNRC	US Nuclear Regulatory Commission
V&V	Verification and Validation
WS	Workshop
WITS	University of Witwatersrand, Johannesburg
ε	Epsilon: Logarithmic ground-motion residual normalised by standard deviation
V_{s30}	Average shear-wave velocity over the uppermost 30 m at the site
κ	Kappa: high-frequency attenuation parameter
Δ	Sigma: Logarithmic standard deviation of ground-motion residuals

4. ROLES AND RESPONSIBILITIES

This Chapter defines the role and responsibilities of the different participants in the PSHA project, illustrating how their contributions fit into the overall process. The following sections also describe the nature and timing of the interactions of different participants with the project. Where appropriate, the necessary attributes of individuals assigned to certain roles are specified, since these define the criteria used to select the project participants.

Most of the key technical participants in the project are identified by name in this document, with the exception of some contractors and the proponent experts to be invited to Workshop 2, since the full list of these participants may only be identified after Workshop 1. Reference can then be made to this Chapter in order to identify the responsibilities and duties that correspond to each SSHAC-specific role, which will be identified in each participant's contract. The reader should refer to contracts and letters of appointment for specific terms of reference and the scope of work for each participant.

4.1. Overview of Project Structure

Figure 4.1 shows a schematic overview of the process of a SSHAC Level 3 assessment study. In this figure, the different participant groups are identified and the duration of their participation is indicated by the vertical position of their activities in the diagram: time is effectively the vertical axis of the figure, with the project start date at the top. Some of the participants are therefore engaged throughout the entire project, such as the TI Team and the PPRP, whereas others only participate during the earlier phases of the project or, in the case of proponent experts and some resource experts, at a single workshop.

At this point, it is worth clarifying issues of ownership, which was emphasised in the original *SSHAC Guidelines*: "*It is absolutely necessary that there be a clear definition of ownership of the inputs into the PSHA, and hence ownership of the results of the PSHA*" (Budnitz *et al*., 1997). The deliverables of the project (Section 5.1) and final documentation of the PSHA (Section 7.5) are obviously owned by the project sponsor, Eskom. However, the above quote from the *SSHAC Guidelines* refers to intellectual ownership, which in this context means taking responsibility for the technical evaluations and providing defence and justification of the technical bases for these evaluations and the integrated distribution that is finally used as input to the hazard calculations. This ownership resides exclusively with the Technical Integration (TI) Teams and with the Project TI (PTI) whose roles are defined in Sections 4.4 and 4.3 respectively.

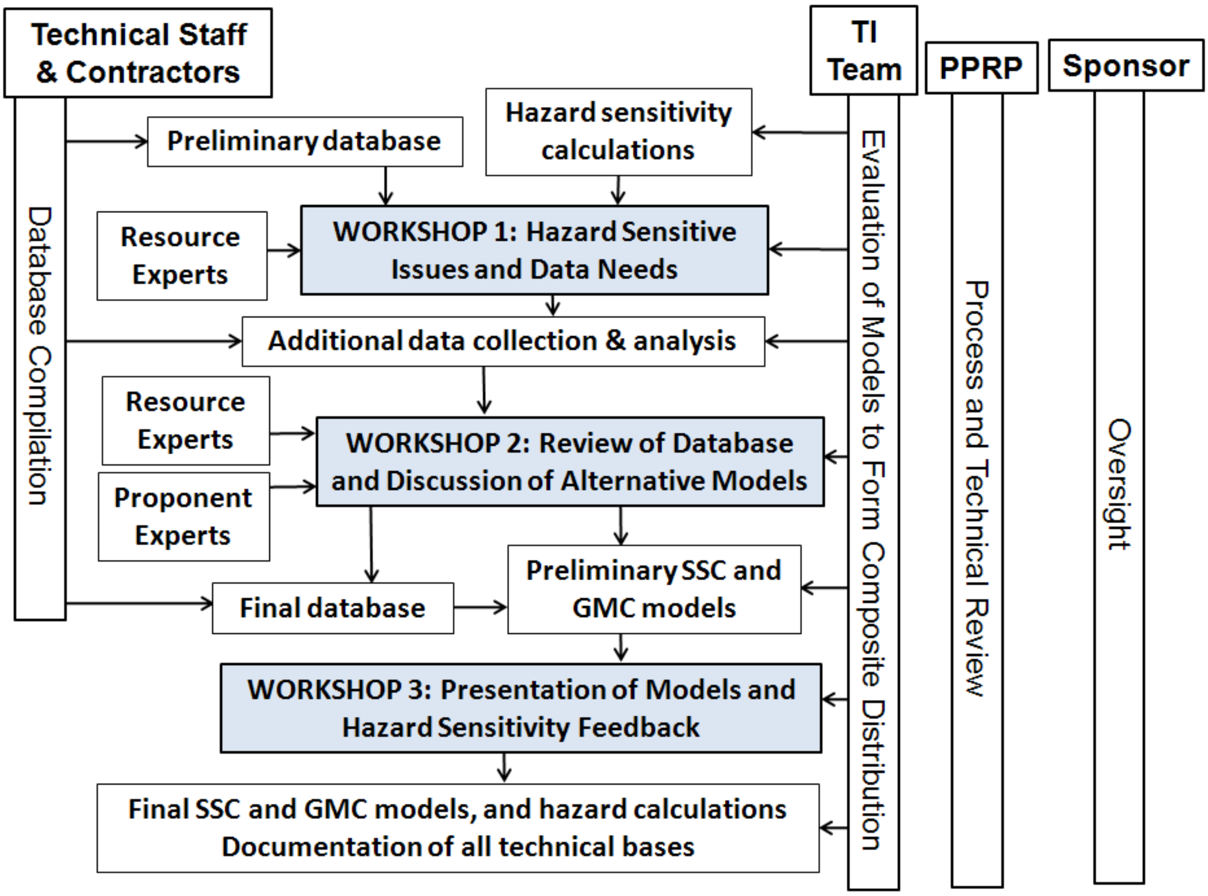


Figure 4.1. Schematic overview of the activities involved in the execution of a SSHAC Level 3 PHSA (adapted from Bommer, 2010).

One vital component of the execution of a SSHAC Level 3 study is not shown in Figure 4.1, and that is the Project Manager (PM). The PM plays an absolutely central role in the project implementation, providing overall coordination of all organisation and administrative aspects, which is discussed in greater detail in the following section. Figure 4.2 shows the relationships between the different groups shown in Figure 4.1 and the Project Manager, and lines of communication that define the interactions and points of contact among the participants.

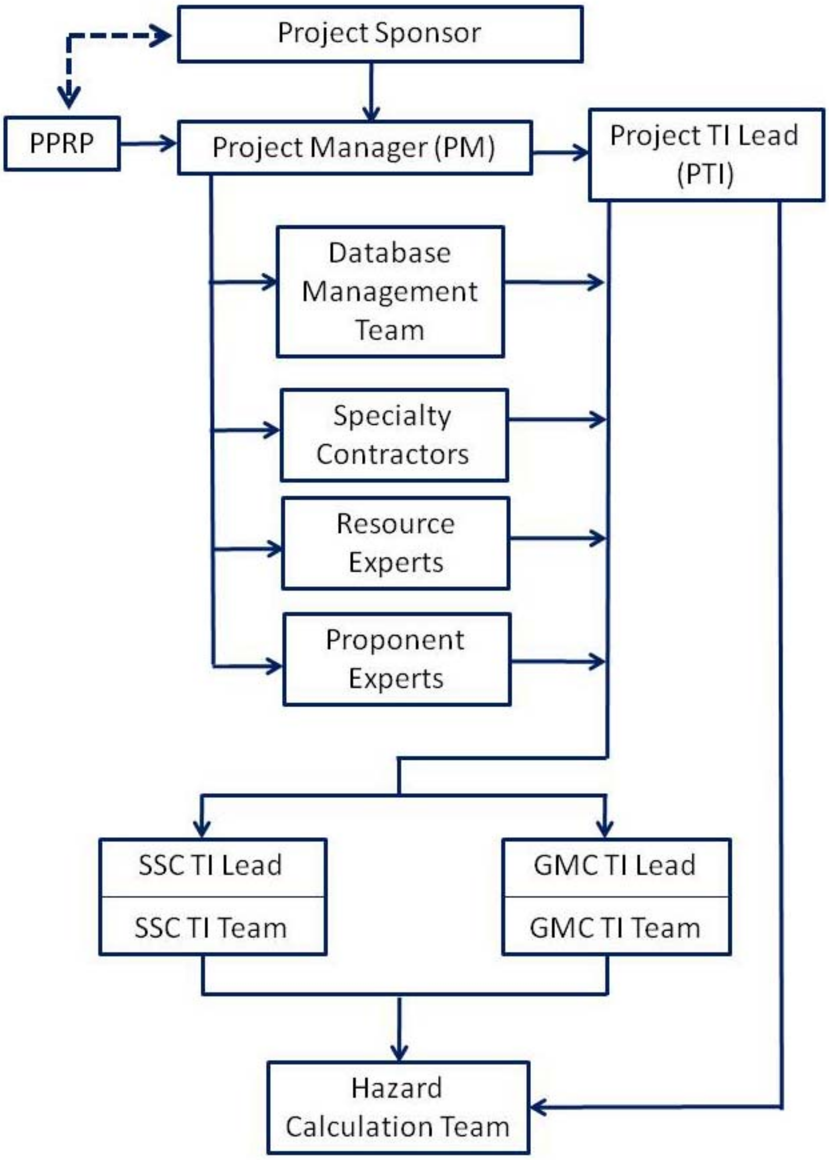


Figure 4.2. Lines of communication amongst the participants in a SSHAC Level 3 PSHA project

The remaining sections in this Chapter discuss the roles and responsibilities of each of the participants identified in Figures 4.1 and 4.2. The box labelled as *Technical Staff & Contractors* in Figure 4.1 represents both the *Database Management Team* and the *Specialty Contractors* identified in the centre of Figure 4.2. Both of these groups are discussed in Section 4.5 *Database Developers*.

4.2. Project Management

The Project Management Team (PMT) is pivotal to the successful execution of the project, as implied by Figure 4.2. The specific organisational structure of the Thyspunt PSHA project is depicted in Figure 4.3, which is adapted from Figure 4.2 and also names key individuals in specific roles. The formal name of the project is the Thyspunt Nuclear Siting Project (TNSP) and the participants, both from CGS and all their external contractors, are collectively referred to as the TNSP Team.

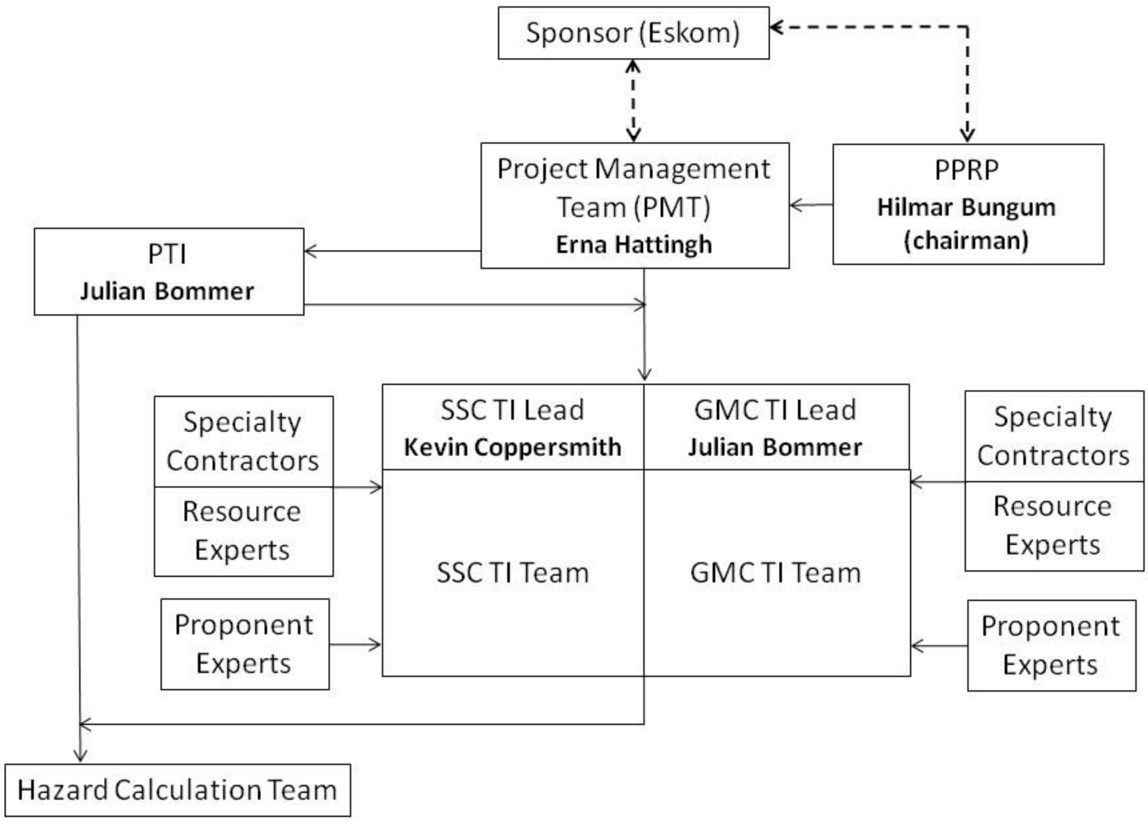


Figure 4.3. Organisational structure for the Thyspunt Nuclear Siting Project (TNSP)

There must always be a full-time dedicated Project Manager (PM) who assumes overall responsibility for the administration and organisation of the project. The PM may be supported by others, forming a Project Management Team (PMT), but the PM is the clear single point of contact with the project sponsor and coordinates all administration-related activities.

A key responsibility of the PM is providing liaison with the sponsor (Eskom) to ensure that they are able to exercise oversight of the project, be kept informed of progress in terms of scope, budget and schedule, and have a clear single point of contact through which to channel communication to the project participants. In particular, the PM will facilitate communication between the sponsor and the PTI as required on any technical issues or concerns that arise.

The PM is responsible for ensuring adherence to scope, schedule and budget. The PM is required to develop contracts with all technical personnel and sub-contractors, and to ensure fulfilment of those contractual obligations. The PM is responsible for resolving all contractual issues that arise during the course of the project, including any changes in scope and budget. The responsibilities of the PM include holding each participant to their assigned role and responsibilities, as specified in their contract.

The PM is also the official point of contact with the Participatory Peer Review Panel (PPRP), taking receipt of their comments and observations, communicating these to the PTI and TI Leads, and ensuring that the PTI and TI Leads follow through on the resulting actions.

The PM is also responsible for organisation of the workshops, including reservation of suitable venues and provision of audio-visual equipment, issuing invitations to all participants and observers, and ensuring that the Workshop Summary Reports (Section 7.2) are produced on time and distributed as necessary.

The Project Manager for the Thyspunt PSHA project is Erna Hattingh of CGS, who will be assisted in management and administration matters by Annabel Graham and Michelle Gouverneur, also from CGS. Other staff members of CGS will support the PM as required, particularly for the organisation of the workshops.

Dr Gerhard Graham of CGS will assume the role of Executive Project Manager, a role which will be invoked if there is a need for communication with CGS management regarding the organisation and execution of the project.

Mr Nico Keyser will be the Management Representative within the Council for Geoscience for this project.

4.3. Project Technical Integrator (PTI)

The Project Technical Integrator (PTI) role is effectively that of overall technical leader of the project, with ultimate responsibility for the delivery and defence of the technical results of the PSHA as embodied in the final project report. Accountability for the technical products of the project ultimately resides with the PTI, strongly supported by the TI Leads.

The role of the PTI carries five very specific responsibilities in the project, namely:

- Close coordination with the PM to ensure that the technical and administrative aspects of the project execution are aligned and jointly contribute to the successful completion of the PSHA project
- As required, and through the mediation of the PM, the PTI will communicate with the sponsor to provide clarification and responses on all technical questions raised regarding the project
- To ensure that all interface issues between the SSC and GMC sub-projects (see Section 5.2) are highlighted and addressed early on in the project, so that the output from these activities provide coherent and compatible input into the PSHA calculations; also to ensure that the output from the PSHA will satisfy all of the engineering requirements
- Coordination of the hazard calculation team to ensure that the HIDs (see Sections 5.3 and 7.4) are produced on time and approved, and provide adequate information for the hazard calculations to be executed; may also involve coordinating and checking procedures to simplify the calculations while maintaining accuracy should the logic-tree become excessively large, communicating any such decisions and their consequences to the TI Teams
- Communication with the regulator (NNR) as requested by the sponsor, through the PM, during the project regarding any technical issues

The PTI role requires similar attributes to those described for the TI Leads in the next section, plus experience in all aspects of PSHA and familiarity with both SSC and GMC issues, and an appreciation of the downstream application of PSHA results. The PTI also needs to be able to commit considerable time and effort to the project, and to be available throughout the project duration. The PTI for the Thyspunt PSHA project will be Dr Julian Bommer.

4.4. Technical Integrator (TI) Teams and Leads

There are two Technical Integration (TI) Teams, one for seismic source characterisation (SSC) and the other for ground motion characterisation (GMC). The TI Teams are responsible for developing the SSC and GMC logic-trees, which together define the input to the PSHA calculations. As explained in Section 1.3, this is achieved through a process of evaluation followed by technical integration. Therefore, members of the TI Teams must play the roles of both evaluators and technical integrators.

The evaluator expert is possibly the most important role in a SSHAC process. The *role* of the evaluator expert is to objectively examine available data, diverse models, challenging their technical bases and underlying assumptions, and, where possible, testing the models against observations. The process of evaluation includes identifying the hazard-significant issues and the applicable data to address those issues, compiling the available data into a project database, evaluating the data relative to their quality and relevance for constructing SSC and GMC models, interacting among the experts (challenging other evaluators and proponent experts, interrogating resource experts), and finally consideration of the strengths and weaknesses of alternative models and proponent viewpoints.

The *responsibility* of the evaluator is to identify the full range of data, models, and methods that exist within the technical community, and to then evaluate them according to their consistency and viability in characterising the SSC and GMC components of the PSHA. The full range of legitimate technical interpretations must be identified, as well as the proponents of those interpretations. The evaluator identifies applicable datasets and resource experts with knowledge of those datasets discuss them in the first workshop. The evaluators probe the quality and usefulness of the various datasets at that workshop, and then document their data evaluation process in Data Summary and Data Evaluation Tables (Appendix B). Alternative models and methods are presented by proponents at the second workshop and the evaluators are responsible for probing the alternative interpretations to examine their consistency with the available data and their uncertainties. This evaluation process occurs at the workshops but continues as the TI Team conducts working meetings to evaluate data, models, and methods.

The *attributes* required by an evaluator expert include possession of a strong technical background and the ability to impartially evaluate the quality and applicability of data and the technical strengths and weaknesses of proposed models and methods. The strong technical background is required to enable the evaluator to make informed evaluations of the models in themselves and the impact of the models on seismic hazard. For this reason, evaluator experts also require an understanding of the basic mechanics of PSHA and how the elements that they are charged with evaluating influence and impact upon the hazard estimates. The last criterion, however, should not preclude the selection of an otherwise suitable expert since instruction on these issues should be provided by the project leaders as part of the process.

Additionally, an evaluator must be able to act with objectivity and be willing to forsake the role of proponent, up to and including critical assessment of models that they may have developed. An evaluator expert must also be able to commit significant time and effort to the project; whereas resource and proponent experts generally only need to attend one or perhaps two workshops, an evaluator expert must be present at all workshops and commit to the entire duration of the project. It is also useful for evaluator experts to have a working familiarity with the quantification of uncertainty.

The *role* of technical integrator in a Level 3 study, as noted above, is linked with the role of evaluator. Explicitly, in a Level 3 study an evaluator expert adopts the role of integrator during the second phase of their evaluation when they develop SSC and GMC models that reflect their assessments of the centre, body, and range of technically defensible interpretations. In light of their evaluations of the data, models, and methods in the larger technical community, the integrators build models (logic trees) that capture their assessments of knowledge and uncertainties. If existing models and methods are not judged to be adequate or viable, the integrators may develop their own models and methods, or they may refine or enhance existing models and methods. Much of the interaction with other integrators on the TI Team in the project occurs during working meetings at which the integrators consider available information, discuss model components, and assess weights of logic-tree branches. Once the preliminary SSC and GMC models have been developed, hazard calculations are conducted along with sensitivity analyses to understand the relative contributions that various model components make to the hazard. The bases for the assessments made in the preliminary models as well as the sensitivity analyses are discussed as feedback in the third workshop prior to finalisation of the models. The *responsibility* of an integrator is therefore to engage in these exchanges of technical challenge and defence, and to contribute to the process that leads to a final distribution (logic-tree) that he or she is willing to support and to defend. The main *attributes* of a technical integrator are the ability to assess the technical defensibility of alternative models and methods, a deep appreciation of the influences of different models and parameters on hazard results, and the ability to understand the ways that models developed adequately represent the knowledge and uncertainties that exist within the technical community.

The TI Leads share all of the attributes and responsibilities of the evaluator experts and technical integrators that comprise their TI teams, but they have additional *responsibilities,* including the selection of a team of appropriate evaluators and integrators. Another responsibility is identification of suitable resource and proponent experts, and their invitation to the relevant workshops, including clear instructions regarding the issues to be addressed by their presentation, communicated in the brief for their participation. The responsibilities of the TI Lead also include running the workshop sessions and ensuring that all participants clearly understand the workshop objectives, their individual roles, the required output from the workshops, and the implications of the issues under discussion for the seismic hazard analysis. The TI Lead is also responsible for convening and organising working meetings of the TI Team and ensuring that all members have full access to all of the available data and information. Another key responsibility of the TI Lead is to ensure that the project documentation is complete and comprehensive. The TI Leads may also be asked to provide input to the PTI, or even join the PTI at meetings, to respond to technical questions from the sponsor.

In terms of attributes, the TI Lead, more than any role described so far, must be willing and able to make a very major commitment of time and effort to the project. As well as having extensive knowledge and experience of either SSC or GMC issues, and of the influence of these inputs on PSHA, the TI Lead must have the appropriate personal skills to facilitate working meetings and effective interactions in workshops, ensuring that all cognitive biases are challenged (through repeatedly bringing these issues to the forefront and through encouraging the challenge and defence of all technical judgements), that no member of the

TI Team dominates interactions, and that all members of the TI Team participate fully in both the evaluation and integration phases of the project.

Technical accountability for the SSC and GMC models ultimately rests with the respective TI Leads.

The TI Teams for the Thyspunt PSHA Project are as follows:

	SSC TI Team	**GMC TI Team**
TI Leads:	Kevin J Coppersmith	Julian J Bommer
TI Teams:	Fleur Strasser	Frank Scherbaum
	Azangi A Mangongolo	Ellen Rathje
	Kathryn Hanson	Adrian Rodriguez-Marek
	Refilwe Shelembe	Peter Stafford
	Ryan Coppersmith	
	Johann Neveling	

4.5. Database Developers

A fundamental principle of the SSHAC process is that expert judgement is to be applied to all available data in order to infer the best possible models for earthquake processes that could affect the site under study, and estimate the associated uncertainty. Expert judgement should never be used as a substitute for data that can be retrieved within the time and budget constraints of the project. The project should therefore begin by focusing on the compilation and gathering of data that can be used to constrain models to represent what is known about seismic hazard at the site, and limit the associated uncertainty. The process of capturing the centre, the body and the range of technically-defensible interpretations is aimed at building models that capture our complete knowledge and the uncertainty that remains after all available data has been compiled and evaluated. Building the project databases is therefore of fundamental importance, and involves many members of the TNSP Team.

The work of compiling the databases will be led by the two TI Leads and considerable effort and support will be provided by the members of the two TI Teams (for SSC and GMC). The work of gathering data will be supported by staff members from CGS who are not members of the TI Teams, since they will not be formally involved in the technical evaluations, but who nonetheless provide invaluable input to the project. The work will also be supported by several Specialty Contractors from outside CGS, who are engaged to gather, compile or process specific data sets, documenting the source of their information, the methods used, and any limitations and caveats that apply to the data. The charge of the Specialty Contractors is to provide the documented datasets without interpretation that has implications for the seismic hazard at the Thyspunt site. The responsibilities of the Specialty Contractors and CGS staff members engaged in data collection, compilation and processing tasks is to ensure that all accessible sources of information are exhausted, that the work is comprehensively documented with complete objectivity, and delivered on time to allow the evaluator experts to make full use of the data, with knowledge of its origins and limitations. In many cases, the Specialty Contractors and other database developers will be required to present a summary of their tasks and data at a workshop, and respond to questions from members of the TI Teams.

All of the data collected by the TI Team members, by CGS staff and by Specialty Contractors, will be made accessible to authorised project participants through a password-protected data portal maintained and backed-up by CGS. Spatially-referenced data will be converted to a GIS (Geographical Information Systems) format for ease of visualisation and to facilitate overlaying of different data sets to explore interactions and spatial correlations. The GIS model development and maintenance will be carried out at CGS, with technical advice from an external Specialty Contractor.

The following paragraphs summarise the database developers for the TNSP, including CGS staff members and external Specialty Contractors, but excluding TI Team members.

Specialty Contractors providing input to the SSC sub-project include Dr Jim McCalpin and Dr Eric Calais, amongst others, whose work was completed during the project that was suspended in April 2009 (Bommer *et al.*, 2009). The data that they provided will be incorporated into the TNSP database but these experts will not be contracted in the current project.

Within the SSC sub-project, three Specialty Contractors will be engaged for the task of extending, improving and processing the earthquake catalogue that will be used to characterise background seismicity rates in the region surrounding the Thyspunt site. The first of these is Dr Paola Albini (INGV, Milan, Italy), who will continue her work investigating pre-instrumental earthquakes from historical documents and newspapers in archives in South Africa and in Europe. Support for this work will be provided by Nicky Flint at CGS. The second Specialty Contractor working on the earthquake catalogue is Dr Céline Beauval (University Joseph Fourier, Grenoble, France) who will be providing expert advice on conversion of historical intensity data to source parameters, homogenisation of the magnitudes, completeness analysis and de-clustering of the earthquake catalogue. Work related to the instrumental earthquake catalogue will be supported by Martin Brandt and Ian Saunders at CGS. Finally, Professor Stefan Wiemer (SED, ETH Zurich, Switzerland) will provide input in the form of review of the earthquake catalogue compilation work.

The measurements of shear-wave velocity at the Thyspunt site (and non-invasively at the Buffelsbos seismograph station) will be coordinated by CGS, with some of the work undertaken by contractors. The P-S Suspension Logging will be undertaken at Thyspunt by Robertson Geologging from the UK. The passive MASW will be conducted by ISS International from South Africa. The active MASW measurements will be conducted by Dr Artur Cichowicz, supported by Denver Birch, Robert Kometsi, Vincent Jele and Leonard Tabane, all from CGS. Parks Seismic, a US-based consultant, will assist with the processing of the recorded data.

The inversions of weak-motion seismograph recordings to estimate stochastic source, path and site parameters will be conducted by Professor Andreas Rietbrock (University of Liverpool, UK), who will complete the work begun in the original project, including its extension to recordings from the last two years. Dr Stéphane Drouet (GEOTER, France) will also be engaged as a Specialty Contractor to perform inversions on the same dataset processed by Prof. Rietbrock but using an alternative procedure. Ian Saunders will again provide support to this work in making the data available to Prof. Rietbrock for processing and analysis. Keshav Prasad from CGS will assist with the classification of seismograph stations.

The GIS database will be developed by the GIS database team at the CGS, with advice and guidance provided by Specialty Contractor Dr Serkan Bozkhurt of AMEC Geomatrix.

The database portal will be maintained by Magda Roos, who will receive support and guidance on the design of the database structure from Dr Serkan Bozkhurt.

4.6. Resource Experts

Resource experts play a similar role in the project to Speciality Contractors in so much as they contribute data, methods and models that inform the evaluations of the TI Teams. The difference between a Resource Expert and a Specialty Contractor is essentially that whereas the latter is charged with conducting specialised work within the project to gather, compile or process data, a Resource Expert is charged with presenting data, method or models that already exist. This will often be done in the context of a Workshop, and the engagement as a Resource Expert will therefore often be of shorter duration than a Specialty Contractor. An important point to note is that members of the TNSP Team can adopt this role within a Workshop without relinquishing other roles that the individual may execute throughout the project, provided that during the engagement they adhere to the roles and responsibilities that correspond to Resource Experts.

The *role* of a resource expert is to present data, models and methods in an impartial manner. The resource expert will make this presentation in the setting of a formal workshop in a SSHAC Level 3 study. The expert is expected to present either the full range of any data set, including how the data were obtained, or to present a model or a method with their limitations and caveats. In all cases, a resource expert is expected to make the presentation without any interpretation in terms of hazard input. The reason for this is that they are not playing the role of proponents or advocates of particular models or methods.

The main *responsibility* of a resource expert is to be impartial and complete in their presentation. This means that their presentation should make full disclosure including all caveats, assumptions and limitations. The resource expert is also expected to respond candidly and impartially to questions posed by the evaluator experts. A resource expert has full responsibility for the material that they present, but does not participate in any way in the ownership of the hazard models.

The necessary *attributes* of a resource expert are knowledge and impartiality. A resource expert must possess a deep and broad knowledge of the tectonics, geology, seismicity or ground-motion characteristics of a particular region, or a data set, model or method, and will often have worked on that topic for many years and have a number of publications related to the subject of their presentation. A resource expert must be able to be objective with regards to hazard implications of the material that he or she presents.

Individuals whose unique role in the project will be as resource experts are all from South Africa and all related to the SSC sub-project, and include geologists, geophysicists and seismologist from CGS and other organisations.

4.7. Proponent Experts

The *role* of a proponent expert is to advocate a specific model or method for use in the hazard analysis. The expert will advocate the model within the forum of a formal workshop. The proponent may be invited to present a model (which will usually be their own) either because the model has been published, is widely known and is therefore considered a credible option, or because the model is controversial. In some cases, a proponent may be invited to present a relatively new model, which may not have even been published at that stage, if it is thought that the model may become prominent in the near future. Proponents of alternative methods of obtaining the required elements of the SSC or GMC models will participate in the project.

The *responsibility* of a proponent is to promote the adoption of his or her model as input to the hazard calculations. The proponent is required to justify this assertion, to demonstrate the technical basis for the model, and to defend the model in the face of technical challenge. The proponent is also charged with making full disclosure about the model in this process, including all underlying assumptions. A proponent expert has full responsibility for the material that they present, but does not participate in any way in the weighting of alternative hypotheses or in the ownership of the hazard models.

The *attribute* required of a proponent expert is the ability to defend his or her model and its basis, and the willingness to submit to questioning from the evaluator experts in a workshop environment in front of their technical peers.

All Proponent Experts will participate only in Workshop WS2. As with Resource Experts, the role of a Proponent Expert can be adopted at WS2 by a member of the TNSP Team engaged by the project in another capacity, provided that this is made clear to all present, and that for that part of WS2 the individual adopts the role and responsibilities outlined in this section.

The final list of Proponent Experts cannot be provided at the time of drafting this Plan because one of the activities for WS1 and the related data retrieval exercises is to identify relevant proponents of models and methods, and the PPRP is charged with reviewing the list of invited proponents for completeness. Nonetheless, several Proponent Experts have been identified as possible candidates, which for SSC-related issues include Andrzej Kijko (University of Pretoria), Chris Hartnady (Umvoto), Ray Durrheim (WITS), Marco Andreoli (NECSA), Marc Goedhart (Kainos South Africa) and Martin Brandt, Coenie de Beer,and Hayley Cawthra all from South Africa as well as Bob Youngs and Kathryn Hanson (AMEC) and Paul Bierman. Proponents on GMC-related issues will include Andrzej Kijko, Trevor Allen (Geoscience Australia), Oona Scotti (IRSN, Paris, France), Linda Al Atik (University of California at Berkeley, USA) and Kenneth Campbell (EQECAT).

4.8. Hazard Calculation Team

The hazard calculation team will be based at CGS in Pretoria, and will be responsible for executing all PSHA calculations and disaggregations both for sensitivity studies and for final results. The hazard calculation team will perform three main sets of PSHA calculations, namely:

- Sensitivity studies to identify hazard-significant features for Workshop 1
- Preliminary hazard calculations using preliminary SSC and GMC models developed after Workshop 2, including disaggregations and sensitivity runs to be presented at Workshop 3

- Final hazard calculations, including construction of Uniform Hazard Spectra (UHS) and disaggregations, following Workshop 3 for inclusion in the final project report

The second and third sets of hazard calculations will be executed from the HIDs (see Sections 5.3 and 7.4) prepared by the TI Leads. The hazard calculation team will also liaise with Specialty Contractors Dr Bob Youngs (AMEC Geomatrix), Dr John Douglas (BRGM, France) and Marco Pagani (GEM, Italy) who will be engaged to independently check coding of elements of the SSC and GMC models and to carry out spot checks on the hazard calculations for verification purposes.

The hazard calculation team effectively is a type of Specialty Contractor, and is charged only with executing the hazard calculations according to the logic-trees developed by the SSC and GMC teams. The hazard calculation team should not exercise any judgements regarding the inputs to the hazard calculations, but it works closely with the TI Leads to capture and display hazard results and sensitivity analyses that will provide the maximum amount of information of use to the TI Teams. If the final logic-trees are very large in terms of the total number of branch tips, the hazard calculation team, under the guidance and supervision of the PTI, may explore ways of reducing the total number of hazard runs either through sampling of the branches and/or by removing or merging branches that can be clearly demonstrated not to exert any significant influence on the final distribution of the hazard estimates. There will be an onus on the hazard calculation team to clearly demonstrate to the TI Teams that such operations have not changed (within small margins of tolerance) the hazard estimates that would result from use of the complete and unaltered logic-trees developed through the evaluations and integrations by the TI Teams.

The hazard calculation team is led by Dr Fleur Strasser supported by Dr Vunganai Midzi and Marinda Havenga; the hazard calculation work is coordinated overall by the PTI (Figure 4.3).

4.9. Participatory Peer Review Panel (PPRP)

The Participatory Peer Review Panel (PPRP) is a key and indispensable element of a SSHAC Level 3 study. The PPRP fulfils two parallel *roles*, the first being *technical* review. This means that the PPRP is charged with ensuring that the full range of data, models, and methods have been duly considered in the assessment, and also that all technical decisions are adequately justified and documented. The second role of the PPRP is *process* review, which means ensuring that the project conforms to the requirements of the selected SSHAC process level. Collectively, these two roles imply oversight and assurance that the evaluation and integration aspects of the TI Teams' assessments have been performed appropriately.

The *responsibility* of the PPRP is to provide clear and timely feedback to the PTI and TI Leads, through the Project Manager, to ensure that any technical deficiencies or violations of process are corrected at the earliest possible stage. In terms of technical review, a key responsibility of the PPRP is to highlight any data, models, or methods (and their proponents) that should be considered. In terms of the actual technical assessments, beyond completeness it is not within the remit of the PPRP to judge the weighting of the logic-trees but rather to judge adequacy of the justification provided by the TI Teams for the models included or excluded, and for the weights applied to the logic-tree branches. When undertaking the review of the final product it may be appropriate for the PPRP to review their responsibilities of being objective and ensuring the final model represents the CBR of the TDI (see Section 1.3) and not that it is consistent with judgments of the individual PPRP members.

The PPRP has the clear responsibility to be present at all the formal workshops as observers, and to subsequently submit a consensus report containing comments, questions and suggestions. In some SSHAC Level 3 projects, members of the PPRP have additionally attended, as observers, some working meetings (see Section 5.4) but in the SSHAC Level 3 PSHA for the TNSP – primarily because of the distribution of the PPRP members in several countries – attendance will be limited to the three formal Workshops.

The specific duties of the PPRP are as follows:

- Review of workshop agendas and lists of invited resource and proponent experts
- Attendance at all 3 workshops and timely submission of written reports
- Review of the preliminary SSC and GMC models for capture of the CBR of the TDI
- Review of the final draft project report
- Review of the draft final project report and of TI Lead responses to comments on final draft project report
- Issue of consensus letter report following completion of final project report

All members of the PPRP should be present at all project workshops, but for practical reasons this may not always be possible. For this reason, a quorum may be established for the PPRP on the project, but with the proviso that at each SSC or GMC workshop at least some of panel members who are experts in the respective areas should be present.

The *attributes* of the PPRP can be defined in collective terms for all of the members of the panel as a group. A key requirement is that each member of the group has an understanding of and commitment to the principles of the SSHAC process. Additionally, the members of the panel must collectively cover all technical aspects of building SSC and GMC models and of conducting a PSHA. Similarly, it is desirable that the members of the PPRP are highly regarded within their technical communities.

One point that is important to emphasise is that membership of the PPRP is always on an individual basis and not as an affiliate of any organisation. This must be made clear and each member of the PPRP in the employ of an organisation must ensure that it is understood that as Panel members they are not representing the positions of their respective organisations, but they are serving in their own right as recognised experts in their respective fields and as experts in SSHAC processes.

For several reasons it is highly recommendable that an individual be named as the chair of the PRPP. The *role* of the PPRP chair is to liaise with the Project Manager and coordinate the Panel itself, particularly in relation to the drafting of written reports and organizing pre- and post-workshop meetings of the Panel. The *responsibilities* of the PPRP chair include ensuring that the Panel is able to arrive at a consensus position whenever possible and to ensure that concerns are communicated clearly and in a timely fashion to the project, as well as energetically following up on these issues if a satisfactory response is not received. Another responsibility of the PPRP chair is to ensure that the Panel remains objective by maintaining a suitable distance from the inner workings of the evaluation teams. The *attributes* of the PPRP chair include a working knowledge of PSHA, experience in SSHAC Level 3 or 4 projects, and being held in high regard as a technical expert in their own right. The ability to maintain congenial relationships within a group while being firm regarding the need to reach consensus positions is another important characteristic required of the chair.

The PPRP assembled for the SSHAC Level 3 PSHA for the TNSP is made up of the following individuals, all of whom are internationally-recognised experts in the field of seismic hazard assessment:

Dr Hilmar Bungum (*Chairman*)
Prof. Fabrice Cotton (from February 2012)
Dr Annie Kammerer (until February 2012)**
Dr Roger Musson
Dr Richard Quittmeyer
Dr Leon Reiter (until June 2011)*
Dr Gabriel Toro

* *Resigned for health reasons after WS1*

** *Resigned for personal reasons after WS2*

5. TECHNICAL TASKS AND SCHEDULE

This chapter provides a description of the technical tasks that will be executed in order to carry out and document the PSHA for the Thyspunt site, including validation and verification. The chapter begins with a summary of the final technical deliverables, and then provides an overview of the tasks that will be performed to produce these deliverables, which are then presented in more detail. The chapter also outlines the schedule for the execution of the project.

5.1. Technical Deliverables

The final product of the Thyspunt PSHA will be a report summarising the entire study. The key technical product of the Thyspunt PSHA Project will be a probabilistic assessment of the hazard at the site in terms of vibratory ground motion, which will be used as the basis for license application, engineering design of the plant and auxiliary structures, input to other hazard analyses, and risk analyses. In order to cover all of the multiple requirements, the hazard output will be expressed in several different forms. The basic definition of the vibratory ground-motion will be the acceleration response spectrum, conforming to the following criteria:

- The basic parameter will be spectral ordinates of pseudo-acceleration response at 5% of critical damping, using the geometric mean definition of the horizontal component of motion.
- The range of spectral ordinates will be for response periods from 0.01 second (the response period at which the acceleration response is equivalent to PGA) up to 2.0 seconds. These will cover the seismic loading for all the main systems, structures and components at each plant. Estimates of the spectral ordinates at longer response periods, up to at least 5 seconds and preferably extending to 10 seconds, will also be provided for checking the response of elements of the plants that may be sensitive to longer-period motions, such as the spent fuel pools and other liquid storage facilities.
- The spectral accelerations and PGA values will correspond to the shear-wave velocity horizon that will be established as the foundation level for the plant, which may be used as the input to structural analysis and soil-structure interaction analysis. The target horizon at each site will be established through discussion with Eskom.

The basic output will be seismic hazard curves for the site:

- Seismic hazard curves for PGA and for spectral ordinates at a range of response periods (at equal logarithmic intervals) up to 2 seconds.
- Separate seismic hazard curves, possibly derived in a somewhat different manner, will additionally be provided for spectral accelerations at longer response periods.
- The hazard curves will be expressed in terms of the mean hazard and the fractiles from 5% to 95%, including the median.
- The hazard curves will extend to annual frequencies of exceedance as low as 10^{-8}; this very wide range of return periods will be considered in case such values are required in the risk calculations, since it is fairly straightforward to extend the hazard calculations to low exceedance frequencies (notwithstanding the wide uncertainty bands that can be expected at these levels).

The horizontal response spectral accelerations will be presented in a number of different formats apart from the hazard curves that fulfil the various requirements for site licensing, engineering design and seismic risk analysis:

- Uniform hazard spectra (UHS) of horizontal motion at the site, for the full range of periods up to 2 seconds, for several selected annual exceedance frequencies, including 10^{-4} and 10^{-5}.
- Extensions of the UHS to periods in the range 5-10 second will also be provided.
- For a suite of exceedance frequencies and response periods agreed during the project with Eskom, reflecting the design basis and the fundamental frequency of vibration of key elements of the plant, disaggregations will be presented in terms of hazard contributions from different bins of magnitude-distance-epsilon, the last term representing the ground-motion exceedance expressed as a normalised standard deviations from the logarithmic mean (see Section A.2).
- For the dominant magnitude-distance scenarios identified through the disaggregation, scenario response spectra will be generated.
- Period-to-period correlations for spectral ordinates will be provided so that the scenario spectra can be generated as conditional mean spectra anchored to the ordinate at the fundamental response period of the structure to be analysed.

- Factors will also be provided to allow the ordinates of horizontal response spectra to be scaled to obtain vertical response spectra from the scenario spectra. These factors will be a function of magnitude, distance and other seismological parameters, as well as of response period (or frequency). This approach to obtaining the vertical response spectrum (rather than performing the hazard calculations using prediction equations for the vertical motion) is chosen because the alternative procedure can lead to the horizontal and vertical spectra being controlled by different earthquake scenarios.

These deliverables will facilitate the selection and scaling of suites of acceleration time-histories for dynamic analyses, which will be provided by the PTI (with input as required from members of the GMC TI Team) to meet requirements specified for Eksom's engineering analyses.

5.2. Overview of Project Work Plan

The steps involved in building the Seismic Source Characterisation (SSC) and Ground-Motion Characterisation (GMC) models for the Thyspunt PSHA are schematically illustrated in Figure 5.1. The figure is necessarily a simplification of the overall process and does not give any real indication of the detailed work involved with each of the individual steps, but it does illustrate the basic sequence of steps and how they contribute to the overall development of the inputs to the hazard calculations in order to obtain the required Ground-Motion Response Spectra (GMRS) in the foundation level at the Thyspunt site.

Since the hazard model is built-up initially as separate component parts, it is vitally important that compatibility and consistency are ensured at all interfaces. The careful consideration of interface issues is also required to ensure both that each element of variability or uncertainty is duly considered within each component of the hazard model, but not accounted for more than once in each instance. Figure 5.2 provides a visualisation of the key interface issues to be considered in conducting the PSHA. The responsibility of ensuring that all interface issues are adequately resolved in the PSHA ultimately resides with the PTI, who as GMC TI Lead will be in continuous communication with the SSC TI Lead to discuss these interface issues. Moreover, at both WS1 and WS2, there will be a common day of joint sessions for the SSC and GMC sub-projects, where the interface issues will be highlighted and discussed.

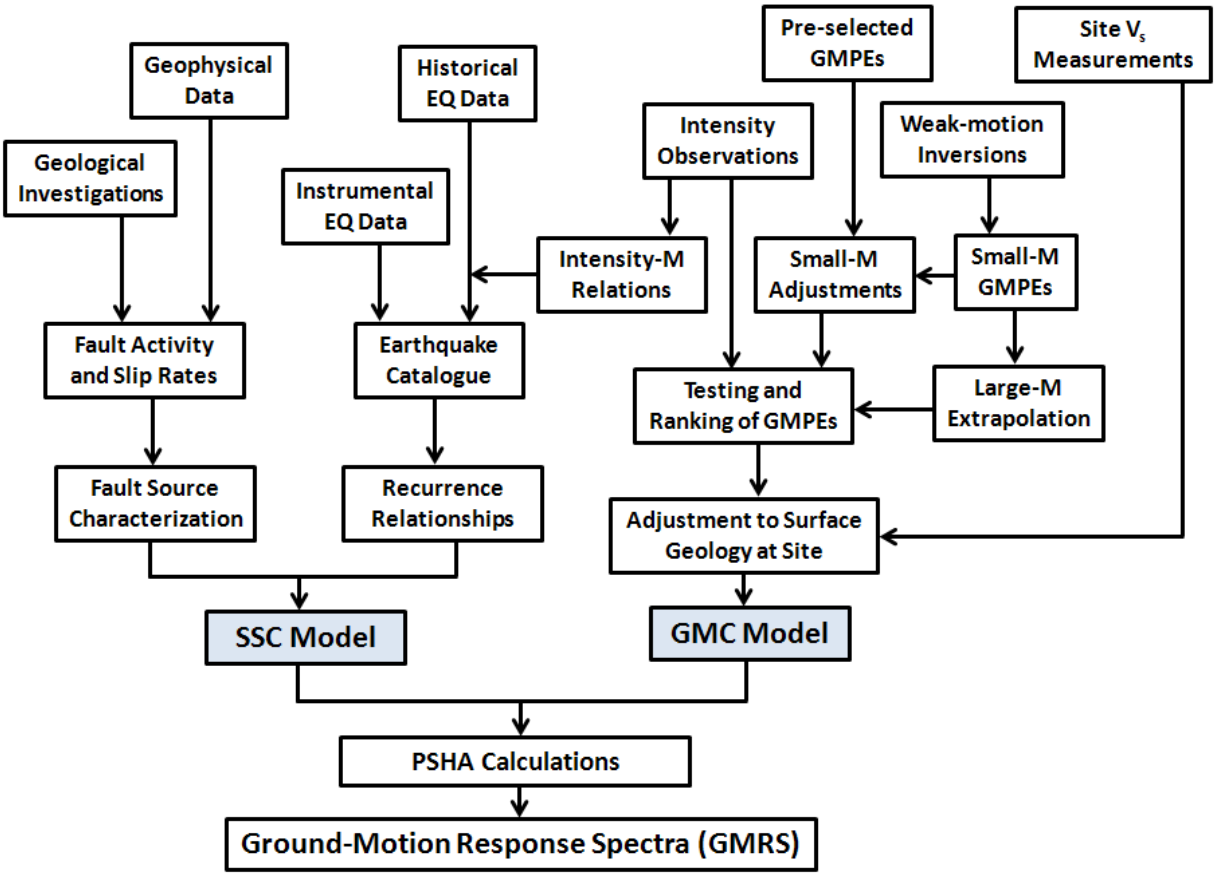


Figure 5.1. Overview of the key steps involved in executing the PSHA for the Thyspunt site.

Some of the interface issues concern the application of the output from the hazard study into the engineering analysis, most notably the definition of the reference horizon for the input motions (whether used directly as input at foundation level or for soil-structure interaction analysis), which in turn is closely related to location of the reactor footprints. These issues, and related matters referred to in Section 5.1 (such as the horizontal component definition and range of target annual exceedance frequencies) will require input from Eskom.

The execution of the PSHA study within the framework of a SSHAC Level 3 process entails a number of distinct tasks, some which will be conducted in parallel and others in series. The specific tasks are summarised below in Table 5.1, with each task being assigned a reference code. These include all of the technical operations indicated in Figure 5.1 plus additional steps that relate to the preparation, execution and documentation of the PSHA specifically within the framework of a SSHAC Level 3 study.

Sub-Project	Interface Issues
Seismic Source Characterization	Homogenised magnitude scale
	Magnitude scale (M), M_{max}, Style-of-faulting classification, 3D rupture geometry, R_{max}, Focal depths
Ground Motion Characterization	Horizontal component definition, response frequencies covered, distance metrics and magnitude scales
	V_{s30}, V_s, kappa (κ), Single-station sigma (σ_{SS}) Depth of sediments
Site Response Characterization	
	Distance metrics (R), Focal depth distribution, M_{min}
Hazard Calculations	

Figure 5.2. Sub-projects of a PSHA study and the interface issues between sub-projects and among components within sub-projects

Figure 5.3 maps the tasks in Table 5.1 on to an expanded version of the flowchart for a SSHAC Level 3 process that was presented previously in Figure 4.1. Some of the tasks (specifically T-10 and T-11) appear more than once because they are performed once for the preliminary hazard input model and then again for the final models defined by the TI Teams for the PSHA calculations. The figure also indicates the different overall phases of the SSHAC Level 3 process, namely Evaluation and Integration (see Section 1.3), followed by Documentation of the results and the bases for all of the technical assessments. The phase prior to the commencement of the Evaluation is preparatory, and includes organization of the project, identification of critical issues to the hazard, data compilation and initiation of the work of collecting additional data.

Table 5.1. Summary of tasks involved in the Thyspunt PSHA

Task	Description of Task
T-1	Prepare Project Execution Plan (PEP)
T-2	Fault Characterization (Geological Investigation)
T-3	Develop Earthquake Catalogue
T-4	Dynamic Site Characterisation
T-5A	Development of SSC Database
T-5B	Development of GMC Database
T-6	Assessment of Hazard-Significant Issues
T-7	**Workshop WS-1: Hazard-significant Issues and Data Needs**
T-8	**Workshop WS-2: Alternative Models and Interpretations**
T-9A	Development of Preliminary SSC Model
T-9B	Development of Preliminary GMC Model
T-10	Development of Hazard Input Document (HID)
T-11	Conduct Hazard Calculations and Sensitivity Analyses
T-12	**Workshop WS-3: Feedback on Preliminary Models and Hazard Impact**
T-13A	Development of Final SSC Model
T-13B	Development of Final GMC Model
T-14	Documentation of Thyspunt PSHA in Draft Report
T-15	Review of Draft Final Report by PPRP
T-16	Finalise and Issue Thyspunt PSHA Report
T-17	Briefing of NNR on Thyspunt
T-18	Review by PPRP

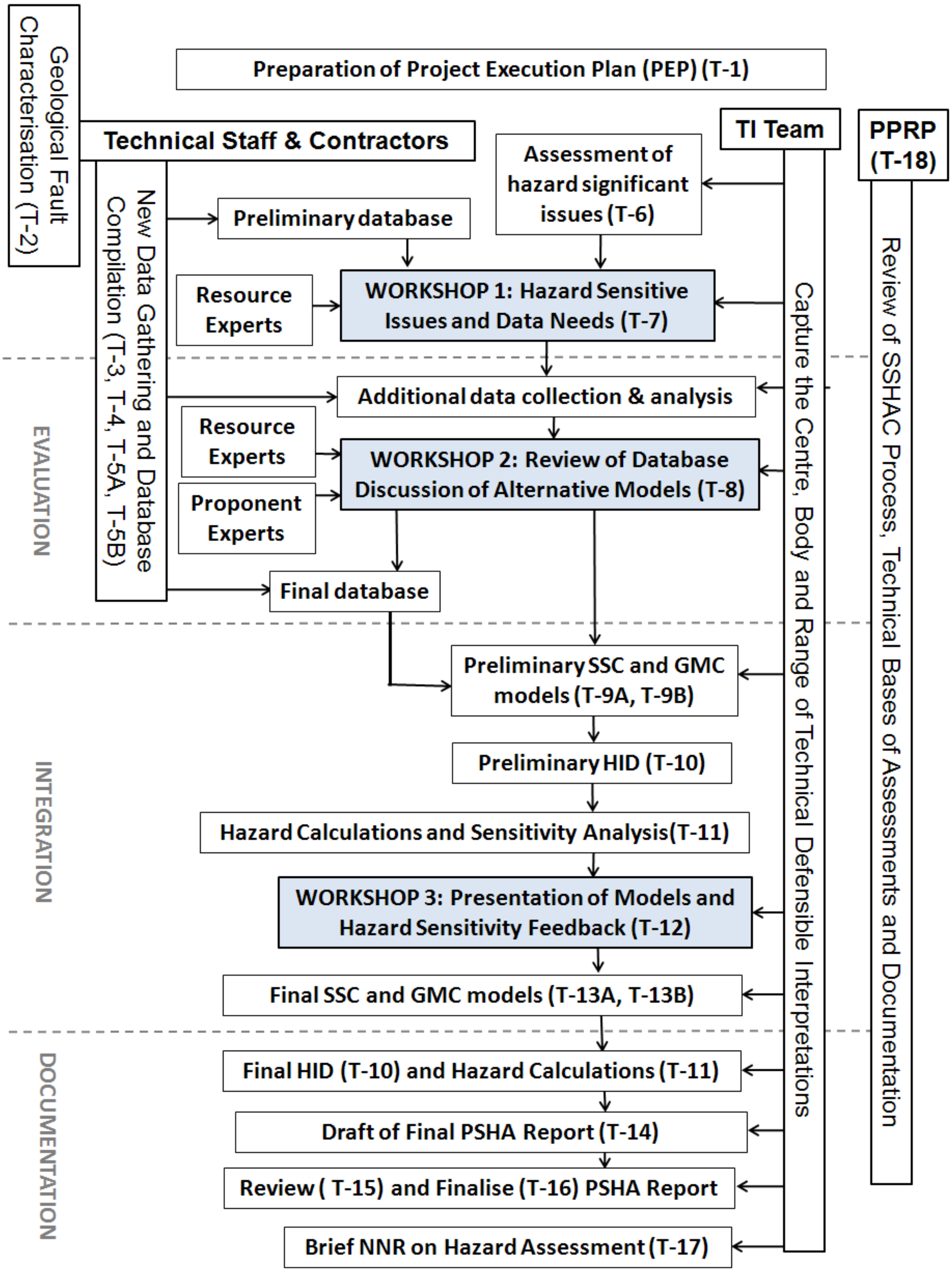


Figure 5.3. Overview of the complete SSHAC Level 3 PSHA for the TNSP, indicating the correspondence with list of tasks as identified in Table 5.1

5.3. Description of Technical Tasks

An overview of each of the tasks listed in Table 5.1 is presented in this section. The work will make full use in each case of the progress made during the first attempt to execute the PSHA for the Thyspunt site, as summarised in Bommer *et al*. (2009). This includes incorporating all of the data collected and analysed between October 2008 and April 2009, as well as the lessons learned regarding the major areas of uncertainty in both the SSC and GMC components of the Thyspunt PSHA, on the basis of which additional work has been identified that should serve to provide additional constraint on the hazard assessment.

Brief notes on Validation and Verification (V&V) are included with each task description; V&V is discussed more fully in Section 5.6.

Task T-1: Development of Project Execution Plan

This task entails the development of this Project Execution Plan (PEP), including review of a preliminary draft by the Project Manager and other colleagues from CGS.

The sponsor may choose to send the Project Execution Plan to the NNR for information.

Task T-2: Fault Characterisation (Geological Investigation)

This task entails focused geologic studies specifically designed to support characterisation of fault sources for the Thyspunt PSHA. Fault-specific seismic sources will be characterised by their probability of activity, recency of displacement, three-dimensional geometry, style-of-faulting, continuity and segmentation, slip rate, recurrence interval, and recurrence model. All of these characteristics are uncertain and the studies included in this task will focus on characterising and quantifying those uncertainties for faults and/or local seismic source zones that are within sufficient proximity to the Thyspunt site to have a significant contribution to the site hazard. The specific geologic studies that will be carried out for the Thyspunt PSHA have been identified by the SSC TI Lead, in consultation with geologists in the SSC TI Team and in liaison with the PTI. These Geological Investigations are currently underway and the data developed from them will provide input to the PSHA database and seismic source modelling. The oversight of the Geological Investigations by the SSC TI Lead is the primary V&V for this task. Additional V&V for the Geological Investigations is provided by independent reviews of the resulting reports by geologists from South African universities.

All studies carried out require completion within the timeframe and resource constraints of the Thyspunt PSHA, and have commenced prior to the main PSHA study itself under separate contracts. The types of studies that are to be conducted for this task include the following:

- Augment and complement previous studies related to geologic, geomorphic, chrono-stratigraphic studies of key surfaces, their ages, and relation to faults (*e.g.*, marine terraces, alluvial terraces)
- Place constraints on rates of uplift and deformation, such that potential active faults can be identified or precluded within the site vicinity
- Focused tectonic, geomorphic, Quaternary studies of fault behaviour, as appropriate, fault-specific studies constraining recency, M_{max}, and slip rate

For completeness, the specific terms of reference for this task are reproduced herein in full, the task codes identifying individual components of the work being carried out.

Sub-Task A1: Kango Drilling and Enhanced River Exposure

Airphoto reconnaissance and some field data collection have already been completed. AMEC Geomatrix staff will assist CGS staff in logging and sampling from test pits and boreholes along the Kango fault, including a backhoe enhanced exposure along the bank of a river. Assuming that the CGS documentation for Kango studies is provided, AMEC Geomatrix will take primary responsibility for the development of a report on the Kango fault, with assistance from the CGS. The report will incorporate field data, drilling logs and a review of trenching results.

Sub-Task A2: Baviaanskloof Fault Corridor

Airphoto reconnaissance has already been completed. The remaining data collecting in the field will be undertaken by CGS staff, with guidance and support from AMEC Geomatrix as required. AMEC Geomatrix Staff will incorporate field data from the Baviaanskloof fault corridor mapping into a GIS database. Primary responsibility for the report will lie with CGS and AMEC Geomatrix personnel will assist in summarizing the results of mapping investigations and analysis of the subsurface information.

Sub-Task A3: Coega Fault Corridor

This task is subdivided into two sub-tasks.

<u>A3-1: Upper Coega Fault Corridor</u>

AMEC Geomatrix staff will assist CGS staff with data collecting in the field along the upper Coega fault trace (this is the part of the fault trace to the west of the town of Uitenhage). AMEC Geomatrix Staff will incorporate field data from the upper Coega fault corridor mapping into a GIS database. Primary responsibility for the report will lie with GGS and AMEC Geomatrix personnel will assist in summarising the results of mapping investigations and analysis of the subsurface information.

<u>A3-2: Lower Coega Fault Corridor (Coega Harbour Data Compilation)</u>

CGS staff obtained data collected and interpreted for the development of the port of Ngqura (also know as the Coega Harbour) near Port Elizabeth. This task involves incorporating these data sets into the Eskom GIS database. The AMEC Geomatrix staff will assist CGS staff in a desktop investigation to map bedrock relationships and any existing exposures of the Coega fault in the vicinity of the harbour. It is expected that the results of surface mapping and analysis of sub-surface data will also provide information that can be used to identify and map the elevation of the wave-cut platforms across the projected trace of the fault. This information will supplement the information compiled as part of Task A3-1 to evaluate the capability of the Coega fault. Primary responsibility for the report will lie with CGS and AMEC Geomatrix personnel will assist by providing guidance regarding of the mapping investigations and analysis of the subsurface information. AMEC Geomatrix will also review the report.

Sub-Task B1: Mapping stranded Marine Terraces at Cape St Francis and Thyspunt

This activity supports direct costs associated with the mapping and dating marine terraces that are key datums that can be used to evaluate patterns and rates of deformation, at Cape St Francis and Thyspunt. This activity will be carried out using existing sub-surface data, as well as the results of geophysical investigations and a drilling programme. AMEC Geomatrix staff will use existing sub-surface data to establish the best positions for geophysical investigations and drilling programme. The result of geophysical surveys will also be reviewed by AMEC Geomatrix staff, who may propose changes to the drilling programme as new data becomes available. AMEC Geomatrix staff will assist CGS staff in logging and sampling from boreholes and will incorporate existing data, and the result of geophysical surveys and mapping programme. AMEC Geomatrix will take primary responsibility for developing the report of the marine terrace study at Thyspunt and Cape St Francis.

Sub-Task B2: Regional Marine Terrace Investigation (cosmogenic dating)

In May 2009, Professor Paul Bierman of the University of Vermont (in conjunction with staff members of the CGS and AMEC Geomatrix) collected 38 samples from stranded marine terraces between Port Elizabeth and the coastal town of Plettenberg Bay, for cosmogenic nuclide age dating. All these samples have been transported to undergo analysis. AMEC Geomatrix will take primary responsibility for the report, with support from CGS personnel. The report will incorporate the data collected during this trip, as well as the dating report by Professor Bierman on the regional marine terraces.

Task T-3: Earthquake Catalogue Development

The goal of this task is to develop a uniform and up-to-date catalogue of historical and instrumental events in the region of interest (ROI) that can be used for seismic source characterisation at all three sites. Consistent with modern ground-motion models, the catalogue will provide moment magnitudes (M_w) for all events.

The CGS has developed an earthquake catalogue for the region that will serve as the starting point for this task. Due to the sparse nature of the seismicity, it will be particularly important that this task include both the instrumental and historical components of the observed seismicity. Some key tasks that will be required relate to some basic and essential issues faced by the SSC team, including moment magnitude M_w estimates for all instrumental and historical events, uncertainties in magnitude and location, depths of earthquakes and focal mechanisms for well-studied instrumental earthquakes (and associated implications to the tectonic stress regime). There will be interfaces with the GMC sub-project to resolve issues related to the attenuation of intensities, which will be needed to estimate magnitudes for historical (pre-1900) earthquakes that were not recorded instrumentally.

The sub-tasks needed to update this catalogue for use in the project consist of following:

- Add earthquakes that have occurred in the most recent times to the catalogue.
- Conduct specialised studies related to the instrumental record, such as those related to the 1969 Ceres earthquake, to obtain information related to seismic moment, depth, and the relationship between M_L and M_w. These refinements include data on size and location along with quantitative assessments of location uncertainty for the well-studied events.
- Gather new data on historical events that could influence the hazard at the site, and also survey archive records to ascertain, to the degree possible, to what extent the catalogue is likely to be complete in terms of how many events, and of what size, could have occurred without records that would lead to their inclusion in the current earthquake catalogue.
- Examine the results of studies that have identified additional historical events and conduct additional studies as necessary to analyse the macroseismic intensity data in order to develop estimates of moment magnitude, location, and depth. Uncertainties in these characteristics should be quantified for use in the PSHA.
- Review and develop as necessary, relationships to provide estimates of moment magnitude, M_w, for earthquakes as a function of the available size estimates (*e.g.* M_L, other magnitude scales, maximum intensity, felt area). The PEGASOS project in Switzerland provided a mathematical framework for developing a catalogue of uniform magnitudes with uncertainty estimates. With assistance from the seismicity specialty contractor, this framework may be adapted to using M_w as the uniform magnitude scale. Recent studies as part of the CEUS SSC project in the U.S. will also be consulted to discern whether or not the magnitude conversion approaches used in those studies are applicable to the TNSP PSHA.
- Identify dependent events within the catalogue and decluster the catalogue using a variety of accepted declustering algorithms. The EPRI-SOG project in the US provided a mathematical framework and software for performing this analysis. This framework will be adapted to using M_w as the uniform magnitude scale. Alternative approaches will also be examined.

- Assess catalogue completeness using a variety of approaches. The completeness magnitudes – as a function of time and location – will be assessed for the historical record based on a consideration of the patterns of settlement and historical records. If appropriate, a probabilistic approach to assessing catalogue completeness will be considered for use in analysing the instrumental record, in consultation with the seismicity specialty contractor.

The compilation and assessment of primarily historical accounts of earthquake events in the eastern Cape Fold Belt will be conducted by Dr Paola Albini, supported by Dr Fleur Strasser and Nicky Flint of CGS. Dr Strasser and Azangi Amangongolo of CGS will lead the work of compiling the final earthquake catalogue under guidance from specialty contractor Dr Celine Beauval, who will supervise and review each part of the work, providing the first level of V&V. Each completed part of the work will be externally reviewed by Professor Stefan Wiemer from the Swiss Seismological Service (SED) at ETH, Zurich, providing another level of V&V. Oversight by the SSC TI Lead and the PTI will provide additional V&V for this important component of the work.

Task T-4: Dynamic Site Characterisation

The focus of this task is to ensure accurate modelling of the influence of the near-surface geo-materials in the definition of the site-specific Ground-Motion Response Spectra (GMRS) at the Thyspunt site. Eskom has informed the TI Leads that the foundations of the power island of the plant at Thyspunt will be within the bedrock at the site or on an engineered terrace built on the bedrock. This means that all sand cover within the plant footprint will be cleared and that excavations will continue into the bedrock to at least 2-3 m (*i.e.,* through the weathered layer) and the remit for the PSHA project is to define ground motions at the top of the excavated bedrock (any terrace, therefore, at this stage is considered part of the plant construction). However, the definition of the design motions at foundation level will still need to consider the nature of the near-surface geology, which will be classified in terms of the average shear-wave velocity over the uppermost 30 m, in accordance with standard practice. The key objective of the site response work will be to characterise the site in terms of dynamic response, and to ensure that appropriate adjustments are made to the calculated ground motions to account for any difference between the foundation level of the plant and the reference site conditions employed in the predictive equations.

The borehole measurements of shear-wave velocity (PS-logging) will be conducted by Specialty Contractors, and another Speciality Contractor will install instrument arrays at the site for the passive MASW measurements. Dr Artur Cichowicz and colleagues from CGS will conduct the active MASW measurements on site, with V&V provided by on-site supervision from Professor Ellen Rathje.

The non-invasive shear-wave measurements (active and passive MASW) will also be conducted at the Buffelsbos seismograph station, installed by CGS as part of the TNSP (Bommer *et al.*, 2009). The seismic station is close to Thyspunt and located on a rock outcrop that may serve as an analogue for the foundation level bedrock at Thyspunt, so interpretation of the recordings that have been obtained at Buffelsbos may be useful in transforming ground-motion predictions to the specific site conditions at Thyspunt. Measurement of the shear-wave velocity profile at Buffelsbos will facilitate this interpretation.

Professor Rathje, assisted by Dr Adrian Rodriguez-Marek, will interpret the field measurements to develop a model for the dynamic characteristics of the Thyspunt site. V&V of this work will be provided mainly by technical challenge and discussion within the GMC TI Team.

Task T-5: Database Development

The goal of this task is to develop a comprehensive, uniform regional database for use in the SSC and GMC assessments. The database development task is divided between data for SSC (Task T-5A) and for GMC (Task T-5B), each directed and coordinated by the respective TI Lead. For both components of the database, the TI Teams will develop Data Summary Tables and Data Evaluation Tables, as appropriate; these are discussed in Section 7.1.

Task T-5A: Development of SSC Data

This task begins with a decision by the TI Team regarding the region of interest (ROI) that will be used for: (1) data compilation, and (2) defining seismic sources, towards a complete seismic source characterisation for the Thyspunt site

Task T-5A Data Compilation will begin at the time of project authorisation and will continue to the point that the preliminary SSC and GM models are developed. This task entails the compilation of all data that can be used in the characterisation of seismic sources. Where appropriate, data will be placed in a GIS format that is readily usable for SSC model development. The Database Developers will take an active role in identifying data and data sources, including the information made available at the first workshop (Task T-7) and interactions with members of the PPRP and the technical community. Data sources will include, as appropriate, readily available information from the following:

- professional literature,
- data held in the public domain by groups such as the CGS,
- private domain data developed as part of exploration activities, and
- available data in the academic sector.

The database will be designed to include several regional data layers to provide coverage of the ROI, which will extend about 300 km from the three plant sites including in the offshore region (or the edge of the continental slope if it is less). Examples of the types of data that will be compiled are the following:

- Aeromagnetic
- Bouguer gravity
- Free air gravity
- Basement and surface geology
- Tectonic features and tectonic/crustal domains
- Tectonic stress field
- Thickness of sediments
- Crustal thickness
- V_p and V_s at top of crystalline basement
- Seismic reflection data (especially offshore)
- Earthquake Catalogue (developed in Task T-3)
- Quaternary faulting and potential Quaternary features
- Paleoseismology sites
- Topography and bathymetry
- Index maps showing locations of published crustal scale seismic profiles and geologic cross sections

It is anticipated that the TI Team will request additional data sets (regional and local) be incorporated into the GIS database. The scope of this task reflects the incorporation of the above listed regional data sets as well as local data sets for specific seismic sources in the Thyspunt site vicinity. However, given that the database development is designed to support the needs of the TI Team, future decisions by the TI Team will dictate the amount, type, extent, and scale of data required to develop the SSC. New data that are developed as part of Task T-2 Fault Characterisation will also be included in the database.

In addition to the GIS database, a comprehensive bibliography of literature will be compiled for use by the TI Team. Copies of key papers will be provided to the TI Team for their review as required.

In addition to the compilation of data, this task will also include: (1) the management and documentation of data by the CGS Database Developers, and (2) the presentation of data for the TI Team to use in development of the seismic source model. The management and documentation of the data will be done in accordance with the CGS data management procedure. The GIS database will be stored on a server in the CGS offices and updated by the Database Developers. For completeness and transparency, each GIS data layer developed for this project will include thorough metadata information. The data will be presented for the TI Team as directed by the TI Lead. This may involve both map sheets of data compilations as well as real-time plotting of data on screen or projector. A GIS analyst will be present at each of the working meetings and, if requested by the TI Lead, at the workshops to facilitate the display of GIS data.

Validation and verification of this task will occur through review of the Project Report by members of the TI Team.

Task T-5B: Development of GMC Data

There are essentially three components to the database that will be used to define the ground-motion models for application in the Thyspunt PSHA, as indicated in Figure 5.1: (1) a list of the ground-motion prediction equations (GMPEs) available worldwide that could potentially be applicable to the project, together with their characteristics; (2) inversion of weak-motion recordings to determine stochastic source, path and site parameters for the

ROI, and (3) intensity that can be used to constrain the applicability of any equation to the Thyspunt site and to the southern Cape region in general.

In terms of available GMPEs, those derived for subduction-zone earthquakes will be excluded since they are not relevant to the tectonic configuration in South Africa. Since the tectonic regime of the southern Cape region has not yet been unambiguously defined, however, the list of candidate equations will need to include those from active and stable crustal regions, including extensional regimes. The equations will be classified in terms of the date and location of their publication, the dataset on which they are based, their range of applicability in terms of magnitude and distance ranges, the other explanatory variables included in the equation, the functional form of the equation, and the type of regression analysis used to derive the equation. The exact definitions of the predicted ground-motion parameter and each of the independent variables in the equation will also be included.

The usual starting point for deriving, assessing or adjusting ground-motion prediction equations for a region would be the databank of strong-motion (accelerograph) recordings from that area. There are no such recordings available for South Africa, so recourse is necessarily made to the only two data sources that are available, these being the weak-motion recordings (from the Eskom and CGS digital seismograph networks), and intensity data from earthquakes that have occurred in South Africa. The weak motion data will be catalogued in terms of the data, time, magnitude and location of the earthquake, the location and geological/geotechnical classification of the recording site, and the instrumental characteristics (component orientation, sampling rate, etc.). The cataloguing and processing of the weak-motion data up to 2010 will be performed by Professor Andreas Rietbrock, supported by Ian Saunders at CGS and Dr Peter Stafford. The classification of the recording sites through interpretation of the geological site descriptions will be undertaken by Dr Adrian Rodriguez-Marek and Keshav Prasad, supported by the GMC TI Lead, who will provide review for V&V purposes.

The inversion of the weak-motion data to obtain suites of stochastic source, path and site parameters will be conducted by Professor Andreas Rietbrock, using the techniques that he has developed (Edwards *et al*., 2008). The dataset will also be passed to Dr Stéphane Drouet to conduct parallel and independent inversions using his own methodology (Drouet *et al*., 2010). The independent determination of the stochastic parameters will both serve as

V&V and provide insight into the epistemic uncertainty associated with the determination of these parameters.

One potentially very important additional data source are recordings from the seismograph that has been installed on a rock outcrop near to the Thyspunt site at Buffelsbos. Spectral analysis of weak-motion recordings from this seismograph will be conducted to determine site-specific characteristics such as the near-surface attenuation factor (kappa) and could also be used as Empirical Green's Functions in the generation of synthetic seismograms for larger earthquakes.

Intensity observations of earthquakes in South Africa, particularly earthquakes for which there are instrumentally-determined magnitudes, will be compiled and catalogued, with as much information about the individual observations sites as can be retrieved. Isoseismal maps will be presented graphically, and also summarised in terms of both equivalent radii and average epicentral distance of the isoseismals. For both individual intensity observations and isoseismal maps, a listing of the key characteristics (date, time, magnitude, depth, etc.) of the earthquakes will be listed, together with any reports of damaging effects of the earthquake shaking. The compilation of intensity data, which has been underway for some time at CGS, most recently being led by Dr Vunganai Midzi, will be completed within the TNSP with support from CGS colleagues. Keshav Prasad will also assist with the production of the intensity database specifically in providing geological classifications of the IDP locations. V&V for the intensity database will be provided by internal review within CGS and review of the final report by the GMC TI Lead.

Task T-6: Assessment of Hazard-Significant Issues

Prior to the first workshop, the TI Team will make a preliminary assessment of the key SSC and GMC issues that would be most important to the hazard at the Thyspunt site. This assessment will be based on the results of exploratory PSHA calculations for the Thyspunt site and associated sensitivity analyses. A preliminary model of the seismic sources and a number of candidate ground-motion prediction equations (GMPEs) will form the basic input to the exploratory PSHA, but additional options for both SSC and GMC inputs will be considered in order to see how they would affect the results should they be included in the final logic-tree.

The sensitivity studies will include the following:

- Disaggregation of the hazard results at various annual frequencies of exceedance and at structural periods of importance to show the contribution of various magnitudes, distances, and seismic sources to the mean hazard
- Analyses to illustrate the contribution of various uncertainties in the SSC and GMC input models to the uncertainty in the hazard results
- "One off" sensitivity analyses to show the impact of various branches of the input logic trees on the hazard results (*e.g.*, the probability that a given fault is active, alternative fault slip rates, impact of a given ground-motion prediction equation)

The results of this task will be presented at the first workshop (see Task T-7) and will provide a sound technical basis for limiting and focusing the scope of the SSC and GMC characterisation activities toward those technical issues that are most important to the hazard results at the Thyspunt site at the mean annual frequencies of interest.

Task T-7: Workshop #1 (WS1): Hazard Significant Issues and Data Needs

The goals of this workshop are: (1) to identify the SSC and GMC issues of highest significance to a PSHA at the Thyspunt site and (2) to identify the data and information that will be required to address those issues. The workshop will assemble the Project Manager, TI Teams, Resource Experts, Specialty Contractors (if appropriate), PPRP, and observers to discuss the significant issues and to identify the existing databases. To assist with identifying hazard-significant issues, the TI Team will present the sensitivity studies conducted in Task T-6 as motivation for identifying important assessment issues in PSHA that should be addressed with the available data. The sensitivity analyses will be supplemented with discussions of hazard sensitivity at other sites, based on experience, and the issues that have generally been shown to be important.

The resource experts present at the workshop will include researchers who have been involved in the development of pertinent databases, such as the CGS and university-based groups. Resource experts involved with the development of seismicity catalogues and ground-motion databases will also participate in the workshop. Discussions will be held regarding all databases that may be available for use by the project, and identification of researchers who should be contacted to gain access to the data.

The workshop will entail five days, with the first two days dedicated to the SSC sub-project alone and the final two days to the GMC sub-project. The third day will be common to both sub-projects and will focus on the earthquake catalogue, tectonic framework and other interface issues. At this session, the results of the hazard sensitivity analyses will be presented and the discussion of important SSC and GMC issues will take place. During the separate SSC and GMC workshop days, the specific components of the PSHA model, and their individual impacts on the hazard estimates at Thyspunt and the associated uncertainty, will be discussed in more detail. At the end of each day of the workshop, the assembled groups will summarise the results of the discussions, the decisions taken and the path forward.

This task includes the workshop planning, identifying and contacting participants, preliminary identification of significant issues, presentations, and documentation of the workshop. The information included in the Workshop Summary is discussed in detail in Section 7.2.

At the end of each day of the Workshop, the TI Leads and Project Manager will meet with the PPRP to discuss issues that have arisen, and for the PPRP to pose questions and raise concerns with the TI Leads. These meetings will be convened by the Project Manager, and the sponsor will be invited to attend.

Prior to the Workshop, the PPRP shall meet for up to a full day in order to discuss the Project Execution Plan and other issues, and immediately after the Workshop the Panel will again convene to produce their consensus report.

Task T-8: Workshop #2 (WS2): Alternative Models and Interpretations

The goals of this workshop are: (1) to present, discuss, and debate alternative viewpoints regarding key SSC and GMC issues; (2) to identify the technical bases for the alternative hypotheses and to discuss the associated uncertainties; and (3) to provide a basis for the subsequent development of preliminary SSC and GMC models that consider these alternative viewpoints. The workshop will also provide an opportunity to review the progress being made on the database and seismicity catalogue activities and to elicit additional input, as needed, regarding these activities.

A key attribute of this workshop is the discussion and debate of the technical merits of alternative viewpoints regarding key technical issues. Proponents and Resource Experts will present their interpretations and the data supporting them. Alternative viewpoints will be juxtaposed and facilitated discussion will occur with a focus on implications to SSC and GMC for hazard analysis (not just on scientific viability) and on uncertainties (*e.g.*, what conceptual models would capture the range of interpretations and the degree of technical support for each model). Because not all potentially applicable models and proponents will be available to attend the workshop, additional interpretations and proponents will be identified who will be contacted by the TI Team after the workshop, so that all viewpoints are ultimately considered.

This workshop will last 7 days, three days each for the SSC and GMC sub-projects and a day off between the sessions. Each day will conclude with the relevant TI Lead making a presentation summarising the key points discussed and outlining the path forward.

This task includes preparation for the workshop, identification of appropriate Proponents and Resource Experts, facilitation of discussions, presentations, and documentation of the workshop. Documentation of the workshop will be identical to that for WS2 (Task T-7), which is discussed in detail in Section 7.2.

As for WS1, the PPRP may convene prior to the Workshop and will definitely assemble for a day after the Workshop in order to write their consensus report.

Task T-9: Construct Preliminary SSC and GMC Models

Based on the results of the first two workshops (which identify the key issues, available data, and alternative interpretations) as well as the database and earthquake catalogue, preliminary SSC and GMC models will be developed for the Thyspunt PSHA. A key component of the models will be the quantification of uncertainties in alternative conceptual models as well as in parameter values. This task is divided into two components: Task T-9A development of the preliminary SSC model and Task T-9B development of the preliminary GMC model.

Task T-9A: Construct Preliminary SSC Model

The preliminary SSC Model for the Thyspunt PSHA will include the spatial distribution of future events, maximum magnitudes, and recurrence, as discussed below.

Spatial Distribution

The spatial distribution of future earthquakes will include the following: (1) definition of the locations of future earthquakes using area zones, spatial smoothing, combinations of both zones and smoothing, faults, etc.; (2) identification of alternative conceptual models regarding spatial distribution (*e.g.*, alternative source zone boundaries due to different interpretations of tectonics or structure) and assignment of weights to the alternatives, including the probability that particular tectonic features are seismogenic in the present tectonic regime; (3) assessment of parameters required to exercise the spatial models such as smoothing operator, smoothing distance, nature of zone boundaries, etc.; and (4) assessment of characteristics of future earthquakes including rupture orientations, magnitude-dependent rupture dimensions, depth distribution and magnitude dependency, styles of faulting, and geometries of specific fault sources. Due consideration will be given to the criteria for identifying and characterising seismic sources (seismogenic sources, capable tectonic sources) given in NRC Regulatory Guide 1.208. An important assessment will be classification of the regional tectonic regime according to whether it is analogous to other stable continental regions or to more active plate boundary environments.

Maximum Magnitude Assessment

A first task will be to take stock of recent studies that have been conducted to update the EPRI maximum magnitude data and associated regressions for stable continental regions (SCR) (Johnston *et al*. 1994), which allow for a Bayesian approach to be used to evaluate maximum magnitudes. These updates incorporate studies of large SCR events that have occurred over the past 15 years and will provide prior distributions of maximum magnitude for various source types, which will then be updated using likelihood functions based on the observed seismicity associated with a seismic source of interest. The results and methodologies developed in the CEUS SSC (Seismic Source Characterisation for Nuclear

Facilities in Central and Eastern United States) Project for the evaluation of M_{max} in the central and eastern US will be considered as part of this task.

If data are available, constraints on maximum magnitude may also be developed based on maximum fault rupture dimensions. Consideration will also be given to the use of updated empirical models between fault rupture dimensions and magnitude.

<u>Earthquake Recurrence</u>

The earthquake catalogue will have been prepared for recurrence analysis as part of Task T-3 (including completeness, de-clustering, and magnitude uncertainty analysis). This task will entail the assessment of recurrence models and calculation of recurrence parameters and associated uncertainties for identified seismic sources. It is anticipated that computer codes will be utilised for the estimation of seismicity rates and *b*-values that allow various smoothing functions (e.g., of *a*- and *b*-values) that can be estimated even in the presence of low historical rates of activity. Where data are available, paleoseismic recurrence and fault slip rates will be incorporated and merged with constraints on recurrence from observed seismicity. Consistency between the recurrence models and spatial distribution of sources, and the observed seismicity will be checked.

Task T-9B: Construct Preliminary GMC Model

The main objective in the development of the ground-motion model is to construct a suite of weighted logic-tree branches for the prediction of median values of the required ground-motion parameters and their associated aleatory variability. The aim is to define a suite of equations that can capture the expected range of possible ground motions for all relevant earthquake scenarios in the target region. The relevant earthquake scenarios will be defined by the ranges of magnitude and source-to-distance, together with the styles-of-faulting, corresponding to the SSC models developed in Task T-9A. The final suite of equations must be adjusted if there any incompatibilities in terms of the definitions of predicted or explanatory variables and they may also be adjusted for applicability to the target region and the site.

The process of selecting and adjusting the final suite of equations will essentially follow the recommendations of Cotton *et al*. (2006) and Bommer *et al.* (2010). This begins with the comprehensive list of potentially applicable equations compiled in Task T-5B, and then rejecting from this collection those considered inappropriate in terms of quality, derivation or applicability. Starting from the selected suite of candidate models, three main components of the preliminary GMC model need to be defined, as discussed below.

Median Ground Motions

The first step will be to extrapolate the median predictions to smaller magnitudes to check their consistency with the median values obtained from the inversion of weak-motion recordings in South Africa, adjusting the models as necessary. The resulting equations and their predictions will then be analysed to assess their applicability through qualitative or numerical criteria based on capability to predict the observed intensity data, depending on the quantity and quality of the final catalogue of intensity values.

Stochastic source, path and site parameters obtained by inversion of the weak-motion data will used to generate ground-motion predictions based on stress drop scaling models selected by the TI Team to capture the centre, body and range of defensible models for South Africa. Comparisons will be made between these extrapolated stochastic models and the selected and adjusted models discussed above.

Branch weights will be applied to the median predictions of the final suite of predictive equations, reflecting the collective views of the GMC TI Team regarding the centre, the body and the range of ground motions from potential future earthquakes in South Africa. Since some equations may be better suited than others for particular earthquake scenarios, the weights may vary with magnitude, distance and response frequency.

All of the models in the logic-tree will be adjusted so that the predicted median motions are calibrated to the near-surface profile at the Thyspunt site, as determined from the shear-wave velocity measurements (Task T-4) and from the inversion of the weak-motion recordings from the Buffelsbos station (Task T-5B).

Additional insight into nature of ground motions in South Africa, and in particular the similarities and differences with ground motions from Stable Continental Regions such as Eastern North America and Australia, may be obtained from the NGA-East project, which is a SSHAC Level 3 project currently underway with sponsorship from USNRC, US Department of Energy (DOE) and the Electric Power Research Institute (EPRI). The NGA-East project is charged with developing the next generation of GMPEs for seismic hazard assessments at nuclear power plant sites in Central and Eastern United States, to be used in conjunction with the source models produced by the CEUS SSC project referred to earlier. CGS, in common with other seismological agencies in low-seismicity regions, has responded to a request from the NGA-East project by contributing records to the database, which will be analysed and compared with data from other stable regions.

Ground-Motion Variability

The GMC TI Team will consider two options for constructing the ground-motion logic-tree, one being to include the published measure of ground-motion variability (sigma) with each model. An alternative approach is to develop separate logic-trees for the median motions and for the ground-motion variability. The advantage of the latter approach is that advantage can be taken of recent work that has looked at the decomposition of sigma into components, some of which are repeatable and therefore can be separated from the genuinely random components and modelled instead as an element of epistemic uncertainty (Al Atik *et al*., 2010). If the site profile is sufficiently well characterised, then the repeatable site amplification effects can be calculated through site response analysis, and the so-called single-station sigma (Atkinson, 2006) can be invoked, which is markedly smaller than the ergodic sigma values generally associated with GMPEs. Since detailed shear-wave velocity measurements will be made for the Thyspunt site, there is a potentially-supportable basis for adopting the single-station sigma model for the PSHA. Developments regarding single-station sigma models likely to emerge from both the PEGASOS Refinement Project and the NGA-East Project will be taken advantage of for the Thyspunt PSHA.

Vertical-to-Horizontal Ratios

Since vertical ground motions will be part of the required output, as well as the horizontal component of motion, the GMC sub-project will also develop V/H (vertical-to-horizontal) ratios as a function of response period, magnitude, style-of-faulting, distance and site class. The correct approach to obtaining vertical response spectra from PSHA is now accepted as being to apply V/H ratios to the horizontal spectrum. If separate PSHA calculations are performed in terms of the vertical component of motion, then disaggregation of the horizontal and vertical hazard at a particular response period will often identify different earthquake scenarios; this creates problems of inconsistency for cases where 3-dimensional input is required to dynamic analyses. Since the full range of uncertainty in the horizontal motions will already be captured, the logic-tree for V/H ratios is not expected to include a wide range of options but some epistemic uncertainty must be captured.

Task T-10: Develop Hazard Input Document

Based on the assessments made in Task T-9, a hazard input document (HID) will be developed that documents and summarizes the key elements of the SSC and GMC models including logic trees, parameter distributions, and derived parameters.

The HIDs will be developed by the TI Leads, and then reviewed by all the members of the relevant TI Team for V&V. Additional checks on the HIDs will be provided by those conducting independent spot-checks on the hazard calculations (Task T-11).

This task includes two rounds of HID development: (1) following the development of the preliminary SSC and GMC models (Task T-8), and (2) following finalisation of the SSC and GMC models (Task T-13), a final HID will be developed, and it will be included in the Project Report. The HID documentation is discussed in Section 7.4.

Task T-11: Perform Hazard Calculations and Sensitivity Analyses

Using the HID developed in Task T-10, the preliminary SSC and GMC models will be used to develop sensitivity studies on seismic hazard, presenting means and fractal hazards at the Thyspunt site. To support Workshop #3 Feedback, several sensitivity studies will be conducted of intermediate results using the preliminary SSC and GMC models. These will include importance of various parameter values to maximum magnitude and recurrence distributions and their uncertainty, summed moment rates based on recurrence models, comparison of predicted and observed seismicity rates, and predicted spatial intensity maps. Sensitivity to catalogue analysis (*e.g.*, completeness) will also be considered. For the GMC models, the sensitivity analyses will explore the choice of predictive equation, the influence of the aleatory variability (sigma), and any adjustments made for parameter compatibility, style-of-faulting influence, and source, path and site characteristics of the target-versus-host region.

This task will use the updated earthquake catalogue, and will compare hazard results with the updated catalogue with hazard results presented in Workshop #1 (WS1). Disaggregation analyses and sensitivity analyses will be conducted to identify important sources and source characteristics such as M_{max} and source boundaries, contributions to uncertainty, and the effect of impact of alternative competing hypotheses. For WS3 (Task T-12), the hazard results will be presented in terms of absolute rather than normalised acceleration values, since these values will be based on SSC and GMC models developed and fully owned by the TI Teams. The key features of the presentations of hazard estimates at WS3 will be clear demonstration of the influence of individual logic-tree branches.

Task T-11 will be repeated following Task T-13, in which the final SSC and GMC models are developed and distilled into the final HIDs. In this case, the hazard calculations will be executed directly to generate hazard curves (means and fractiles), uniform hazard spectra for various annual exceedance frequencies, and disaggregations to identify contributing scenarios to the hazard at response periods and exceedance frequencies agreed with Eskom. Using the V/H ratios defined in Task T-9B, vertical response spectra will also be generated from the horizontal spectra, either as UHS or as scenario spectra (see Gülerce & Abrahamson, 2010).

The main hazard calculations with be performed at CGS by the Hazard Calculation Team, using the software FRISK88. There will be several steps taken to provide V&V for this central activity. The coding of the final selected and adjusted GMPEs will be checked by Dr John Douglas, and independent spot-checks of the hazard calculations will be conducted by Dr Marco Pagani of the GEM (Global Earthquake Model) Secretariat, supported by members of the GEM Model Facility, using the *OpenQuake* software, for sample runs selected by the PTI. Additionally, some of the hazard calculations will be repeated at CGS using alternative hazard calculation packages that are freely available; although these runs would not be expected to produce identical results, since each program works in different ways, the exercise will provide additional assurance that the calculations have been performed correctly.

Task T-12: Workshop #3 (T-WS3): Feedback

The goal of this workshop is to present and discuss the preliminary SSC and GMC models in a forum that provides the opportunity for feedback to the TI Teams on the hazard consequences of components of their models. Feedback will be given in the form of hazard results and sensitivity analyses (Task T-11) to shed light on the most important technical issues. The feedback gained at this workshop will ensure that no significant issues have been overlooked and will allow the TI Teams to gauge the impact of the SSC and GMC models, uncertainties, and assessments of weights. No proponent experts will be present at this workshop, and resource experts and specialty contractors will only be invited if their presence is required for the discussions that will take place. Whereas the PPRP attend WS1 and WS2 as observers, in WS3 they are provided the opportunity to directly cross-examine the TI Teams on the technical bases of their decisions and on the extent to which these have taken full account of the full range of available data, models and methods. The feedback and sensitivity analyses, and the technical challenge and defence of the TI Team assessments, will provide a basis for the finalisation of the SSC and GMC models.

The workshop will last for 5 days (plus additional days for the closed meetings of the PPRP), and will have a common session with the SSC and GMC participants on the 3rd day. The approach planned for each session will begin with the TI Leads presenting the preliminary SSC and GMC models, with particular emphasis on the manner in which alternative viewpoints and uncertainties have been captured. The technical bases for the assessments and weights will be described to allow for a reasoned discussion of the constraints provided by the available data. Presentation of the hazard calculations and sensitivity analyses will provide a means of focusing the discussions on those SSC and GMC issues having the greatest hazard significance, including the largest contributors to uncertainty. For each day of the workshop, it is envisaged that the mornings will be occupied by discussions within the TI Teams, possibly involving some resource experts and/or specialty contractors, and will then open up to interrogation of the TI Teams by the PPRP each afternoon. Following the separate sessions, the entire group will meet in a common session at which the results of the SSC and GMC discussions will be summarised and the path forward will be described.

This task includes preparation for the workshop, facilitation of discussions, presentations, and documentation of the workshop. Documentation of the workshop will be similar to that described for Tasks T-7 and T-8, as described in Section 7.2.

Task T-13: Finalise SSC and GMC Models

In light of the feedback discussed in Workshop #3 (WS3) and using the final database and seismicity catalogue, the TI Team will finalise the SSC and GMC models as part of this task, with these carried out as separate tasks T-13A for the SSC model and T-13B for the GMC model. Uncertainties will be fully characterised using logic-trees (for alternative conceptual models) and probability distributions (for continuous parameter distributions). Alternative models will be weighted and the technical basis for relative weights developed. Finalisation of the software used for developing seismicity parameters will occur in this task.

Although presented in Table 5.1 and Figure 5.3, they must be considered under one heading herein because this is the final opportunity to ensure that all interface issues (Figure 5.2) have been adequately and effectively addressed.

Task T-14: Document Thyspunt PSHA Study in Draft Report

Following the finalisation of the SSC and GMC models, the final hazard calculations will be performed, subject to external and independent checks (Task T-11), to produce all of the required products identified in Section 5.1. The TI Team will then draft a comprehensive report presenting the databases employed, the discussions and deliberations at the Project Workshops, and the assumptions, technical bases and rationale underlying the final model definitions. The report will also document in detail the hazard results and present interpretation of their significance and the main sensitivities and unresolved uncertainties. The final report on the PSHA is discussed in Section 7.5.

Task T-15: Review of Draft Report by PPRP

The draft report on the Thyspunt PSHA project will be submitted to the PPRP for review and comments. At this stage, the review will be focused on the completeness and clarity of presentation of the SSC and GMC models, documentation of the process followed throughout, and interpretation of the hazard calculations, since these will be final. The purpose of the technical challenges and questions posed by the PPRP to the TI Team at WS3 (Task T-12) is to pre-empt any major issues arising at the time of reviewing the draft final report. The PPRP comments will be provided in writing and discussions between the TI Teams and the PPRP will occur as necessary to ensure that the intent of comments is understood.

Task T-16: Finalise and Issue Thyspunt PSHA Report

Taking account of the feedback and observations from the PPRP, the TI Team will produce the final version of the Thyspunt PSHA report. The report will be submitted to the PPRP as a basis for them to confirm that all of their comments have been addressed and to provide a basis for the Panel to write its letter of concurrence. Once that letter of concurrence has been received, the report will then be submitted to the Project Manager for presentation to Eskom, together with the concurrence letter from the PPRP (Task T-18).

Task T-17: Brief NNR

In coordination with Eskom, the TI Leads will meet with National Nuclear Regulator (NNR) to present and discuss the results of the Thyspunt PSHA, and to respond to any questions that the regulator may wish to raise regarding the study and its conclusions. The PTI will also be available for meetings with the NNR, at the request of Eskom, during the course of the project to discuss any technical or procedural issues, and the relationship of the study to regulatory requirements in South Africa.

Task T-18: Participatory Peer Review Panel (PPRP)

The PPRP will participate in the project primarily through attendance at the three Workshops, for which they will be provided material to review prior to the meetings. At the end of each day of the Workshop and then again at the end of each Workshop, they will present their observations and suggestions to the Project Manager and the TI Team in discussions. Following each Workshop, the PPRP will submit to the Project Manager a consensus report giving observations on technical assessments and procedures, which will be forwarded to the TI Leads. The latter will be required to produce a written response to the PPRP report, and both the report and the TI Team response will form part of the project documentation (see Section 7.3).

Upon receipt of the PPRP comments and observations on the draft PSHA report, the TI Team will revise the report to take the PPRP feedback into account. There is no need to respond to the PPRP review comments because at this stage the technical issues will have been dealt with during the course of the project, and comments from the PPRP on the draft report will be dealt with by revising the report directly. If necessary at this stage, the TI Team will liaise directly with the PPRP (primarily through the Chairman and with the knowledge and participation of the Project Manager) for clarification and resolution of any issues.

Once the final report is issued, the PPRP (through the coordination of the Chairman) will issue its concurrence letter, summarising its view of the entire PSHA both in terms of technical assessment and procedure. This concurrence letter will be appended to the final Project Report.

5.4. Workshops and Working Meetings

The main work in developing the inputs to the PSHA, and also executing and documenting the hazard calculations, occurs outside of the formal Workshops. The three formal Workshops provide an opportunity to present the development of the work, and the process, to observers, including the PPRP. The first two Workshops (WS1 and WS2) mainly serve to allow the TI Team to discuss the critical issues, review the available data, methods and models, and interrogate resource and proponent experts. At the final Workshop (WS3), the TI Team discuss the preliminary models in view of the hazard feedback and sensitivity analyses in order to ascertain if additional work is required and where the models most need refining.

WS3 additionally provides an important opportunity for the PPRP to directly question the TI Team on the decisions it has made and the technical bases for these decisions, in accordance with USNRC (2012). Together with the feedback provided at the end of each day of WS1 and WS2, and the written reports submitted at the end of all three Workshops, this defines the ‘participatory’ nature of the PPRP review; Hanks *et al*. (2009) proposed that a more suitable adjective might be ‘continuous’. The objective is to ensure that all concerns regarding factors such as the consideration of all available data, models and methods from the broader technical community, and the provision of the centre, body, and range of technically defensible interpretations as represented by the SSC and GMC models. The PPRP will ensure that the technical bases for the inclusion or exclusion of each element in the final logic-tree (and the associated weights for those included), are raised in time to be addressed during the course of the project. If this process works well, the PPRP should not encounter any issues of major concern when reviewing the draft final report.

In between the Workshops, the TI Teams will conduct working meetings as needed to execute the work. Some of these may be very informal and involve only a sub-set of the relevant TI Team, for work to be conducted on reviewing or developing models for subsequent presentation to the full TI Team. For example, such meetings may take place among the geologists in the SSC TI Team and among the members of the SSC TI Team producing the earthquake catalogue. Similarly, meetings will take place among the members of GMC TI Team working on the inversions of weak-motion data and among those working on the characterisation of site response and the adjustment of predictive models to the site-specific characteristics at Thyspunt, amongst other examples. Such informal meetings may be called at short notice and will be held wherever is most convenient with respect to the base locations of the participants. Specialty Contractors may also be invited to these meetings if required, such as Céline Beauval for meetings related to the earthquake catalogue, and Andreas Rietbrock and Stéphane Drouet when weak-motion inversions are being discussed.

However, more formal Working Meetings of the TI Teams will also be organised, not least because of the importance of all members of the TI Team sharing fully in the ownership of the final logic-tree (see Sections 4.1 and 7.5). Some of these meetings will be held in South Africa and others at the base of the respective TI Lead (*i.e.*, London or San Francisco area), and will be scheduled in advance (see Schedule in Section 5.5). All members of each TI Team will be expected to be present at such formal Working Meetings if this is possible. The PTI may attend one or more Working Meeting of the SSC TI Team for the purpose of discussing interface issues and discussing input to the hazard calculations.

Although in some SSHAC Level 3 and 4 projects PPRP members have been invited to attend Working Meetings as observers, the geographical distribution of the project participants and the budgetary consequences of such attendance preclude it from the TNSP SSHAC Level 3 PSHA. At the same time, it is noted that views on this issue vary, and while some see advantages in the PPRP becoming more informed as a result of observing working meetings, there is also a real danger of PPRP members losing their objectivity if they become too close to the inner workings of the TI Teams. Moreover, some evaluator experts feel that the Working Meetings are more effective if the TI Team members can thrash out issues without any sense of inhibition because of the presence of reviewers.

5.5. Project Schedule

The detailed schedule for all of the tasks listed in Section 5.3 is presented in the form of a Gantt chart in Appendix C. Table 5.1 summarises the most important dates and milestones in the project.

Table 5.2. Summary of tasks involved in the Thyspunt PSHA

ACTIVITY / MILESTONE	DATES
Formal re-start of project	1st February 2011
Kick-off meeting	31st Jan – 4th Feb 2011
Workshop #1 (WS1) (SSC sub-project) (GMC sub-project)	11th-15th April 2011 (11th-13th April) (13th-15th April)
Workshop #2 (WS2) (SSC sub-project) (GMC sub-project)	15th-21st January 2012 (15th-17th January) (19th-21st January)
Workshop #3 (WS3)	27th-31st August 2012
Final draft report to PPRP for review*	14th February 2013
PPRP comments to TI Leads	1st April 2013
Draft final report (with TI responses) to PPRP	1st May 2013
Final report, and PPRP concurrence letter, to Eskom	1st June 2013

* *Simultaneously submitted to Eskom for information*

All of the project participants have been informed of the meeting dates and have committed to attending the relevant meetings. Should the start date of the project be delayed, all of the dates would need to be moved, which could result in very significant delays since new dates would need to be found when all key participants (many of whom moved other commitments to accommodate these meetings) were available.

The launch meeting scheduled at the very start of the project will serve several purposes, including discussions between the project leaders (Project Management Team and TI Leads, accompanied by the Chairman of the PPRP) and Eskom to discuss how the project will proceed and to air any concerns. If Eskom deemed it appropriate and useful, meetings could also be arranged with the NNR to discuss the study and its relation to their regulatory requirements in terms of seismic safety.

During the same visit, the TI Leads will visit CGS to discuss the immediate work tasks with staff members, including data gathering activities and the execution of exploratory hazard analyses to identify critical issues for the Thyspunt PSHA for presentation at WS1.

The dates and locations of the formal Working Meetings are listed in Table 5.3.

Table 5.3. Dates and locations of formal Working Meetings; PPRP observers in parentheses

Meeting	SSC Meetings	GMC Meetings
WM1	Pretoria, 26-30 September 2011 (Dr Hilmar Bungum)	San Francisco, 8-10 October 2011 (Dr Gabriel Toro)
WM2	Pretoria, 27-30 March 2011 (Dr Roger Musson)	Potsdam, 19-22 March 2012 (Dr Gabriel Toro)
WM3	San Francisco, 29 May - 1 June 2011 (Dr Richard Quittmeyer)	London, 6-8 June 2012 (Dr Roger Musson)
WM4	San Francisco, 9-11 October 2012 (Dr Richard Quittmeyer)	London, 1-3 October 2012 (Prof. Fabrice Cotton)

5.6. Validation and Verification

As noted in Section 5.3, in the detailed descriptions of the tasks that collectively make up the SSHAC Level 3 study, Validation and Verification (V&V) exercises will conducted, and recorded, at various stages of the project.

The V&V measures are intended to ensure accuracy at all stages of the model building and hazard calculations, and include independent external checks, internal checks using alternative procedures and software, and sample calculations to reproduce published figures or values. V&V in data gathering and interpretation includes on-site supervision of measurements, internal and external review of reports, and cross-checking within the TI Teams.

Figure 5.4 provides an overview of the main components of the project and the review that provides the Verification and Validation by different individuals or groups.

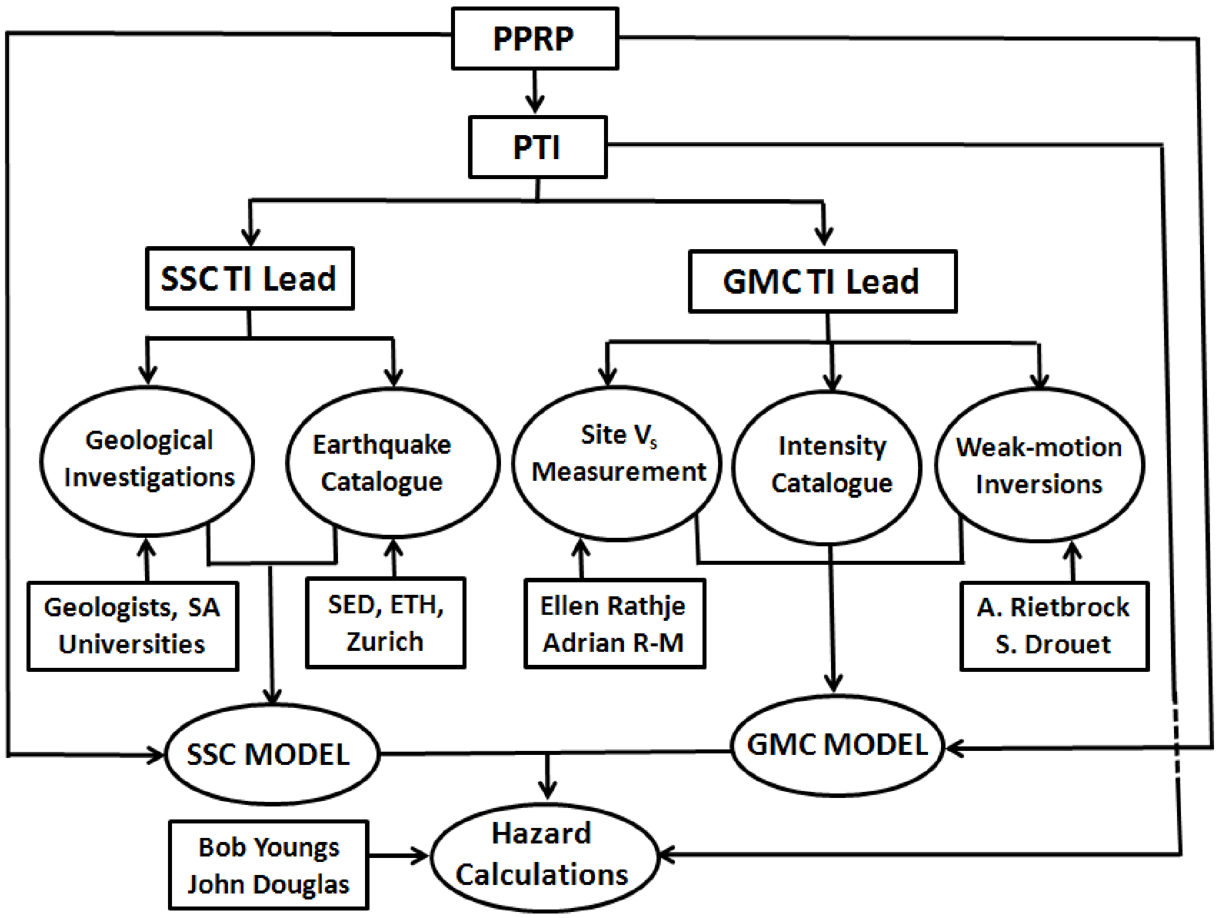


Figure 5.4. Schematic view of V&V for key elements of the TNSP SSHAC Level 3 PSHA study. The deliverables are identified by ellipses, whereas the rectangles identify those who will provide the V&V; in the case of the weak-motion conversions, the two Specialty Contractors will effectively cross-check each other's work through parallel inversions using alternative techniques.

6. MONITORING

This Chapter briefly describes the way in which the work will be monitored at different levels, and the acceptance criteria that will be applied to each part of the work.

6.1. Monitoring

Monitoring is required at all levels throughout the duration of the project, in terms of all of the following areas of activity:

- Geological, geophysical and geotechnical data collection
- Data retrieval and compilation
- Identification of available data, methods, models and views in the technical community
- Data processing and interpretation
- Conduct of SSHAC Level 3 workshops
- Calculations of seismicity parameters, site response and probabilistic seismic hazard
- Documentation of all assessments and their technical bases

The monitoring is provided in several different ways, the first being review, oversight and interrogation by members of TI Teams, including interactions within the groups. In some cases, this will mean suitably qualified individuals overseeing certain activities, such as *in situ* measurements of shear-wave velocity, which will be done by the person within the TI Team who has the most extensive experience in this specific activity (Prof. Ellen Rathje).

For several key activities, Specialty Contractors will be engaged who in effect provide a level of internal review and therefore monitoring. Examples include oversight (by Dr Céline Beauval) and review (by Prof. Stefan Wiemer) of the work to develop and analyse the earthquake catalogue for the ROI.

At the next level, the key responsibility for the work resides with the appropriate TI Lead, depending on whether the activity is related primarily to SSC or GMC issues. The TI Leads will be supported by members of their teams and will call on those with particular expertise for the monitoring of each activity; for example, Prof. Frank Scherbaum will be expected to assist in monitoring the weak-motion inversion work conducted by Prof. Andreas Rietbrock and Dr Stéphane Drouet. However, the ultimate responsibility for monitoring lies with the TI Lead.

The overall technical work, and specifically also the work related to the seismic hazard calculations and the independent checks on these calculations, will reside with the PTI.

At a higher level, the project is ultimately monitored by the PPRP, which has responsibility to monitor the conduct of the project in terms of adherence to the principles of a SSHAC Level 3 process, and also in terms of the technical assessments. The importance of the monitoring role by the PPRP in a SSHAC Level 3 project cannot be over-emphasised: acceptance by the PPRP that a proper SSHAC Level 3 process was followed and that defensible technical assessments have been made is fundamental to a successful outcome.

There may additionally be occasional audits and surveillances.

6.2. Acceptance criteria

Acceptance by the TI Leads for the completion of the various technical tasks will be submission of a report by the responsible individual or team, which is complete and comprehensive, including all references and other pertinent supporting material. Ultimately, the criterion that the TI Leads will apply for the acceptance of these reports will be that they conform to the highest standards of presentation and that they are sufficiently complete to facilitate reproduction of the work were this to be required. If any submitted report is deemed insufficient in this respect, the TI Lead will request revisions and additions to bring it up to an acceptable level.

Acceptance by the PTI of calculations will be based on demonstration of the use of appropriate software, with recording of the input specified and the output obtained. Additionally, for calculations to be accepted, it will be necessary to show that independent checks and verifications have been obtained, and that these agree with the main results to within tolerable limits. The PTI will also repeatedly request for feedback and sensitivity analyses to be prepared for review by the TI Teams showing the impact of calculations in terms of predicted seismicity rates, predicted distributions of ground-motion amplitudes, and seismic hazard estimates.

For the final acceptance by the PPRP of the overall project, there will be three criteria applied, consistent with SSHAC Level 3 framework outlined in Section 1.3, namely:

- The project has been conducted in accordance with the requirements of a SSHAC Level 3 framework, particularly with regards to the conduct of the Workshops, performance of participants in accordance with the responsibilities and attributes relevant to their role (see Chapter 4), and the assumption of intellectual ownership by the TI Teams
- The evaluations by the TI Teams has given adequate consideration to all available data, models and methods relevant to the assessment of ground shaking hazard at the Thyspunt site, and that the integrated distribution adequately captures the centre, the body and the range of technically-defensible interpretations
- The documentation of the study is complete and comprehensive, and provides defensible bases for all of the technical assessments by the TI Teams

7. RECORDS

This Chapter discusses the different levels of documentation through which the complete record of the project will be developed. As the project progresses, the documentation will be made available to all participants through a secure data portal maintained at CGS in Pretoria, with password-controlled access for project participants. The portal address is:

http://196.33.85.22:8080/SSHAC

The database portal will be maintained primarily by Magda Roos, who will be assisted in the design of the portal by Dr Serkan Bozkhurt from AMEC Geomatrix; input and review will be provided by the TI Leads. This will ensure that all participants have full access to all of the documentation and data collected, retrieved and produced by the project, which in turn will facilitate internal review.

Spatially-referenced data, particularly relating to geological information and to the earthquake catalogue, will be systematically entered into a GIS format for ease of query and presentation. The GIS databases will be created and maintained by the GIS database team at the CGS, with support from Dr Serkan Bozkhurt.

The following sub-sections briefly describe specific forms of documentation that are of central importance as elements of the overall project record.

7.1. Data Summary and Evaluation Tables

The evaluation phase of the SSHAC Level 3 hazard assessment includes an exhaustive review of all available data, models and methods relevant to earthquake-induced ground shaking at the Thyspunt site. In order to provide an accessible and manageable summary of the published and unpublished reports reviewed, and other data sources that are retrieved and reviewed, the SSC TI Team will create Data Summary and Data Evaluation Tables. These essentially form catalogues that provide a summary of all sources on information that were reviewed by the TI Teams, highlighting what is relevant in them for SSC modelling at the site, in the Summary Tables. An example of an extract from a Data Summary Table for an SSC project is shown in Figure B.1 in Appendix B.

The Data Evaluation Tables are reserved for those data sources that were actually included in the SSC models, thus they provide a succinct summary of the TI Team's evaluation of the source in terms of its quality and extent. Importantly, the Data Evaluation tables also provide an assessment of the degree of reliance that the TI Team has given to that data source in making their assessments. The Evaluation Table will also indicate whether a copy of the reference is actually in the database, whether the data is relevant to the SSC model, if the information has been considered for the integration phase, and if so how the data has been or could be used. An example of an extract from a Data Evaluation Table for an SSC project is shown in Figure B.2 in Appendix B.

The goal of the Data Summary and Data Evaluation Tables is to provide a written record to users of the PSHA regarding all of the data that were reviewed by the TI Teams, their evaluation of the quality and usefulness of the data, and their degree of reliance on particular datasets. In this way, future users or reviewers of the PSHA will know what was available to the Teams at this snapshot in time and how the data were used.

For the GMC TI Team, a slightly different approach will be adopted but it serves exactly the same purpose. For the limited datasets that the TI Team will have at its disposal (shear-wave velocity measurements at the site, weak-motion recordings and their stochastic inversions, and the database of intensity observations), there will be Data Summary Reports. For other generic elements of the GMC model-building exercise (including published GMPEs, sigma models for the aleatory variability, reviews of existing relationships between intensity and ground-motion parameters) the GMC TI Team members will develop 'white papers' summarising the current state-of-the-art.

7.2. Workshop Summary Reports

A very important component of the project documentation is the summary reports from the Workshops. The summary reports will include sufficient information for a third party who did not attend the workshop to understand the key topics discussed and the resolutions reached that have implications for the TI Teams' work to be done after the conclusion of the workshops. One element of the summary report will be summaries by the TI Leads of the key actions and agreements made during the workshop. The approach that will be used has worked very well in other projects, such as the PEGASOS Refinement Project. At the end of each day the TI Lead produces, in PowerPoint for clarity of display, a summary of the main discussions and decisions. This is done on-screen with the TI Team participating and in the presence of all observers. This provides an immediate check for completeness while the events of the day are still fresh in the minds of the participants, which is lost when someone reviews a summary report a few days after the workshop. These summaries are then all reviewed on the end of the last day, and another PowerPoint is interactively produced in the same way summarising the way forward. These PowerPoint files, produced by the TI Leads in their respective sessions and by the PTI in the common sessions, will constitute the Workshop summaries.

Following each workshop, the PPRP will be provided with a private meeting space for a day (or more, if required) to write their report on the Workshop, including comments on procedure and on the execution of the technical work, posing questions, making suggestions and raising any concerns. It is expected that this will be a consensus report of all members of the PPRP present at the Workshop. Since the PPRP members reside in three different countries (and the US members are located in widely distributed cities), the consensus report should be written while the PPRP is gathered together. At WS1, the PPRP is likely to meet before and after the Workshop, the first meeting being to discuss their operation as a Panel and related matters. For WS2, the PPRP may choose to forfeit their pre-workshop meeting to allow slightly longer for report writing after the Workshop.

As soon as the TI Leads receive the PPRP report from the Project Manager, they will immediately begin work on a joint response to the Panel's comments. This will be discussed with the Project Manager, and then when finalised sent by the Project Manager to the PPRP for information. On the basis of the PPRP report and the TI response, the TI Leads and the Project Manager will work together to draft an Action Tracking List (see Section 7.3 below).

The Project Manager, in consultation with the TI Leads, will also draft a 'Lessons Learned' document from each Workshop, regarding organisational and procedural issues, as well as safety matters.

Within two weeks of the Workshop, the workshop summary will be completed and then either distributed on CD-ROM (or made available through the project portal) to all participants and observers. The complete workshop summary for each Workshop will include the following:

- Workshop agenda and list of participants
- Copies of all presentations
- Summaries by TI Leads
- PPRP consensus report
- TI response to PPRP report
- 'Lessons Learned' report

7.3. Action Tracking Lists

The Action Tracking Lists specifically summarise the decisions taken at the Workshops as well as the issues raised by the PPRP and the actions formulated by the TI Leads and the Project Manager to address these concerns. The purpose of the list is very simply to ensure that these are recorded, together with a clear indication of who will be responsible for executing each action, who will verify that the action has been executed, and the date by when this must be completed. The tracking list is a tool for use by the PM and TI Teams to assure themselves that actions are being taken within the project to address PPRP concerns and to follow through on decisions taken at the Workshops; however, there is no direct involvement by the PPRP. The PPRP's conclusion that their concerns have been addressed will occur as they witness the project (if they have raised process issues) or as they review project documentation.

Since the PPRP reports to the Project Manager (PM), the PM will maintain the Action Tracking Lists and update them as actions are executed. The PM will also alert the TI Leads to actions whose due date is approaching if the issue is as yet unresolved. When completed, the final version of each tracking list will record the date when each action was completed, and also indicate where the evidence of this action is located.

7.4. Hazard Input Documents (HID)

The concept of a Hazard Input Document (HID) was first developed in the PEGASOS Project in Switzerland, a SSHAC Level 4 PSHA for four nuclear power plant sites (Abrahamson *et al*., 2002). The purpose of the HID is to summarise succinctly but unambiguously the input to the PSHA as defined by the logic-tree produced by the TI Teams. The HID is intended to enable the hazard analyst to execute the PSHA calculations by clearly communicating the details of the SSC and GMC models, the logic-tree structure and the corresponding branch weights or probability distributions. In order to be succinct and to facilitate interpretation by the hazard analyst – including those contracted to carry out sample hazard calculations (spot-checks) for verification purposes – the HID contains no justification or explanation for the choice of models or their associated weights. However, the HID must contain sufficient explanatory text and illustrations to be self-contained and unambiguous to a hazard analyst.

The HIDs are produced for the SSC and GMC models by the respective TI Leads, with summary notes on any compatibility issues provided by the PTI, with each HID being reviewed and approved by all members of the relevant TI Team. This internal review serves several purposes, including ensuring that the HID is a complete and accurate summary of the TI Team's model, as well as reinforcing the critical issue of intellectual ownership of the integrated model by the full TI Team.

This is a very important issue in a SSHAC Level 3 project (see Section 1.3), as noted in the original guidelines by Budnitz *et al*. (1997): "*It is absolutely necessary that there be a clear definition of ownership of the inputs into the PSHA, and hence ownership of the results of the PSHA*." The study and its output are, of course, owned by the project sponsor, Eskom; what is referred to hear is ownership in intellectual terms, which in effect means the ability and willingness of each and every member of the TI Team to explain, justify and defend the final models. Although the TI Leads and PTI will usually act as the spokespersons for the PSHA model, it is vitally important that the models are accepted and approved by the complete TI Team. This collective view is achieved through interactions within the TI Team and discussion of all technical issues, with members – encouraged and facilitated by the TI Lead – challenging each other's views and providing technical defence of the proposed models. Ultimately, the TI Leads have responsibility to ensure that the SSC and GMC models represent the views of the complete TI Teams and that each member of the team is prepared to defend the complete model.

Two sets of HIDs will be produced during the project, one summarising the preliminary SSC and GMC models produced after WS2, and another after WS3 to summarise the final models. The second, and final, set of HIDs will be appended to the final PSHA report.

7.5. PSHA Final Report

The final deliverable of the PSHA project is a report documenting the full SSC and GMC models and their technical bases, and the resulting hazard estimates. This report is produced by the TI Leads, with ultimate responsibility for quality and completeness residing with the Project TI. The final version of the PSHA report should be accompanied by the final concurrence letter of the PPRP, which would be expected to confirm that the report conforms to the required standards in terms of quality and completeness.

The main PSHA report will summarise all of the components of the hazard input models and the hazard output, but for reasons of length, it is likely to make extensive reference to reports on individual elements of the hazard study. These reports will be produced by Specialty Contractors, resource experts, and members of the TI Teams, and each of them will require formal acceptance and approval by the corresponding TI Lead or the PTI before being finalised. The acceptance criteria for these reports will that they are complete (to the point of permitting reproduction of the model, where applicable) and conform to high standards of presentation and clarity. Some of these reports, such as those related to the earthquake catalogue and the inversions of weak-motion recordings, may additionally be supported by electronic data files. The individual reports, once approved and accepted, will be produced as CGS reports, with each assigned a sequential reference number.

The final report on the Thyspunt PSHA may include some of these CGS reports as annexes, or will otherwise simply reference them where appropriate. However, although supporting data and information may be provided in these annexed reports, the main report will be written to provide a complete overview and summary of the PSHA model, including defence and justification of the TI technical evaluations and the final integrated model. Although the report will be drafted by the TI Leads, the various chapters will undergo extensive internal review by members of the TI Teams, both to ensure completeness and to ensure collective ownership of the hazard model by the complete team of evaluator experts.

8. DEVELOPMENT TEAM

This Project Execution Plan has been developed by Dr Julian J Bommer and Dr Kevin J Coppersmith.

Dr Julian Bommer, who is PTI and TI Lead for the GMC sub-project in the Thyspunt PSHA project, is an independent consultant and also currently Visiting Professor of Earthquake Risk Assessment in the Department of Civil & Environmental Engineering at Imperial College London. Dr Bommer graduated from Imperial College with a BSc in Civil Engineering in 1985, a Masters degree in Geotechnical Engineering in 1986, and a PhD in Engineering Seismology in 1991.

Dr Bommer has been actively engaged in research in the fields of earthquake ground-motion characterisation and prediction, seismic hazard analysis, and seismic risk assessment for over 20 years, and has published almost 100 papers on these topics in international peer-reviewed journals as well as numerous other papers in conference proceedings as well as many reports and articles. He has conducted post-earthquake field reconnaissance studies in Algeria, Armenia, California, Colombia, El Salvador, Greece, Italy, Japan, Mozambique, Peru, Turkey and the UK.

Dr Bommer has always been engaged in engineer practice as well as academia, particular with regards to the specification of seismic design loads in the form of response spectra and acceleration time-histories, both for design codes (including being part of the drafting committee of Part 1 of Eurocode 8) and for site-specific assessments for major engineering projects. With regards to the latter, Dr Bommer has served as a consultant for seismic design issues of major dams and bridges around the world, and he has also served since 2003 as a member of the Seismic Advisory Board for the Panama Canal Authority.

In the field of nuclear engineering, Dr Bommer has served as a member of the ground-motion expert panel in the ongoing SSHAC Level 4 PEGASOS project for PSHA at NPP sites in Switzerland, and has been involved in studies related to seismic hazard assessment at nuclear sites in the UK, where he now serves as a n advisor to the regulator, HM Nuclear Installations Inspectorate. He served on the review panels for the PSHA studies conducted for new nuclear power plants in Abu Dhabi and Romania, and since 2008 has been a member of the Seismic Advisory Board for PG&E's Diablo Canyon NPP in California. Dr Bommer now serves as chairman of the PPRP for the NGA-East project, a SSHAC Level 3 project being conducted to develop new ground-motion prediction models for nuclear installations in Central and Eastern United States. He is also a co-author of the forthcoming US NRC NUREG providing practical implementation guidance for SSHAC Level 3 and 4 studies.

Dr Kevin Coppersmith is the TI Lead for the SSC sub-project. Dr Coppersmith received his BS degree in Geology from Washington & Lee University in 1974 and his PhD from the University of California at Santa Cruz in 1979. He has more than 30 years of consulting experience, with primary emphasis in probabilistic hazard analyses for design and review of critical facilities within regulated environments. Dr Coppersmith has pioneered approaches to characterising earth sciences data, and their associated uncertainties, for probabilistic seismic hazard analyses for a range of critical facility sites including nuclear power plant sites, high-level waste repositories, dams, offshore platforms, pipelines, and bridges. His consulting experience has focused on the characterisation of seismic sources for probabilistic seismic hazard analysis, including quantification of uncertainties in earth sciences data. In most cases, these projects have been subject to considerable regulatory review as part of licensing or safety reviews.

Dr Coppersmith was a member of the Senior Seismic Hazard Analysis Committee (SSHAC), which provided methodology guidance on probabilistic seismic hazard analysis to the NRC, DOE, and EPRI. As a co-principal investigator, he recently completed a study for the NRC on reviewing lessons learned from the application of SSHAC Study Level 3 and 4 methodologies over the past ten years. He is lead author on the NUREG-series document on detailed implementation guidance for SSHAC Level 3 and 4 studies currently being drafted with NRC staff.

Dr Coppersmith has extensive experience in leading SSHAC Level 3 and 4 studies for nuclear facilities and other critical facilities. He served as seismic source characterisation (SSC) Technical Facilitator/Integrator (TFI) for SSHAC Level 4 seismic hazard studies at the Yucca Mountain high level waste repository, and he was SSC TFI for the PEGASOS SSHAC Level 4 study for four nuclear power plants in Switzerland. He was also the TFI for the Probabilistic Volcanic Hazard Analysis conducted for Yucca Mountain in 1996 as well as for the update to that study completed in 2008. He is currently the Technical Integrator (TI) Lead for the SSHAC Level 3 *CEUS SSC for Nuclear Facilities* project, sponsored by EPRI, NRC, and DOE. He currently chairs the Participatory Peer Review Panel for BC Hydro's SSHAC Level 3 Seismic Hazard Analysis for 41 sites in the service area in British Columbia, Canada.

APPENDIX A

Overview of Probabilistic Seismic Hazard Analysis (PSHA)

This Appendix is designed only to provide a brief overview of the essential elements of a PSHA study (Figure A.1), not least to identify and explain the concepts of aleatory variability and epistemic uncertainty in the specific context of seismic hazard assessment rather than as generic concepts. For more detailed discussion of the issues discussed in this Appendix, the reader is referred to the various cited references and also the textbooks of Reiter (1990) and McGuire (2004).

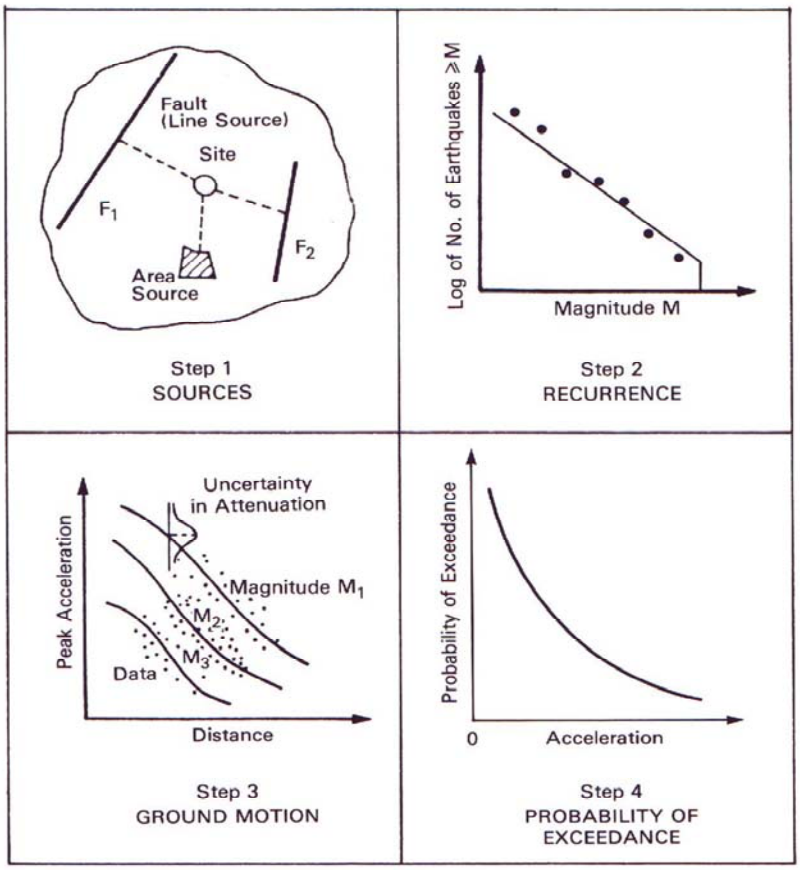


Figure A.1. Overview of the steps in a probabilistic seismic hazard analysis (Reiter, 1990).

Figure A.1 summarises the essential components of a PSHA study, with the upper two boxes collectively representing the Seismic Source Characterisation (SSC) model and the lower left-hand panel the Ground-Motion Characterization (GMC) model. These are explained in greater detail in Sections A.1 and A.2; section A.3 briefly discusses the influence of the near-surface geo-materials on the resulting ground motions, which is really a component of the GMC model. Section A.4 then describes the hazard calculations in PSHA that integrate these models of aleatory variability into a seismic hazard curve (the lower right-hand panel in Figure A.1) that shows the annual frequency or probability of exceedance of different levels of a given ground-motion parameter. The final section of this Appendix discusses epistemic uncertainty and use of logic-trees that lead to multiple hazard curves whose spread reflects the uncertainty associated with the final hazard assessment.

A.1. Seismic Source Characterisation (SSC) Models

The first step in conducting an assessment of possible levels of future ground shaking at a site is to develop a model for earthquake activity in the region around the site. The model needs to specify the potential locations of future earthquakes, and also the magnitudes (up to the maximum) of these events. For a probabilistic analysis of hazard, it is necessary to also define the rates at which these earthquakes are expected to occur; the rates of recurrence of earthquakes is the primary control on the level of seismic hazard at a site.

Earthquakes are caused by the sudden displacement on geological faults, which releases strain energy accumulated in the Earth's crust. Therefore, locating active geological faults and determining their activity (usually in terms of their recency of slip, geometry, slip rates, etc.) is the primary aim of seismic source characterisation. However, for various reasons it is rarely, if ever, possible to unambiguously associate all seismic activity with known geological faults (faults may not reach the surface; moderate-magnitude events are associated with fault rupture only a few kilometres in length; epicentral locations are invariably associated with uncertainties of a few kilometres, etc.) whence general area sources are defined to capture 'floating' earthquakes.

In addition to seismic source zones, the assessed spatial distribution of future seismicity can also be represented in a PSHA by a direct consideration of the locations of past (observed) earthquakes. Approaches such as spatial "smoothing" of seismicity can express the assessor's degree of belief that the future spatial distribution will follow the observed pattern of earthquakes, including the uncertainty associated with that assessment. Once the geographical location of sources, whether faults or areas, are defined, the key step is to then define their activity rate. Typical models for seismic source activity rates are shown in Figure A.2.

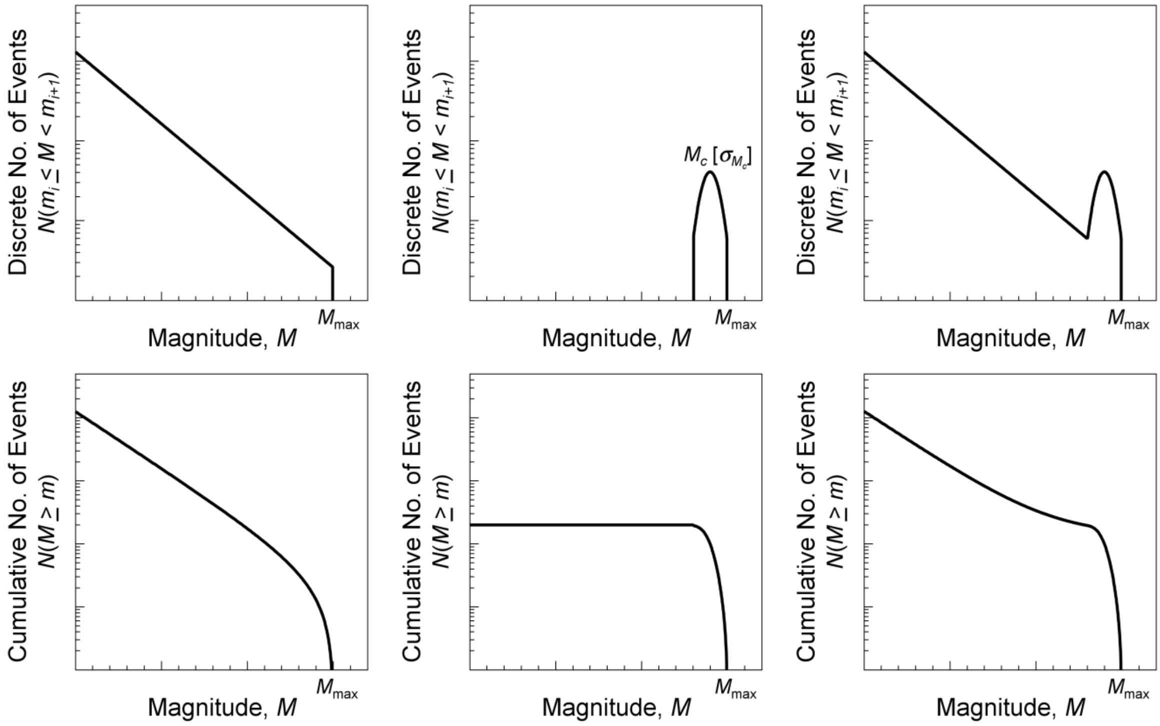


Figure 3.2. Typical forms of earthquake recurrence relationships, shown in non-cumulative (*upper row*) and cumulative (*lower row*) formats. *From left to right*: Gutenberg-Richter model, maximum magnitude model, and characteristic earthquake model.

The activity of fault sources is estimated from paleoseismological and geomorphological investigations, whereas for area sources the activity is determined by statistical analysis of the instrumental and historical catalogue of earthquakes in the region. The probability distribution of magnitude is often assumed to follow a doubly-bounded exponential distribution for area sources (Cornell & Vanmarcke, 1969), which is a modified form of the famous Gutenberg-Richter equation (Gutenberg & Richter, 1944). For fault sources, it is more common to use a characteristic distribution (Schwartz & Coppersmith, 1984), a special case of which is the maximum magnitude model.

The largest magnitude of the earthquake recurrence distribution (M_{max}) is usually highly uncertain, except in the most highly active regions. A variety of tools can be brought to bear in estimating M_{max}, including approaches that consider the maximum rupture dimensions that the source might entail (*e.g.*, Wells & Coppersmith 1994), or approaches that consider the largest earthquakes that have been associated with tectonically-analogous sources in other parts of the world (*e.g.*, Johnston *et al.*, 1994).

The seismic source model essentially defines earthquake scenarios to be considered in the hazard analysis. The scenarios are defined by magnitude, M, and location, which in turn determines the distances, R, from the site. The style-of-faulting of each earthquake scenario may also be specified in seismic source characterisation (SSC) model, as can other attributes of expected source behaviour (*e.g.*, hypocentral depth distribution, magnitude-dependent rupture dimensions, and strike and dip of ruptures).

A.2. Ground-motion Characterization (GMC) Models

For each earthquake scenario considered in the SSC model, the hazard analysis needs to estimate the resulting ground motions at the site. This is achieved using ground-motion prediction equations, sometimes called attenuation equations, which predict the value of a specified ground-motion parameter as a function of magnitude, M, distance, R, and a parameter representing the nature of surface geology as well. Most modern equations also consider the influence of the style-of-faulting. The most abundant ground-motion prediction equations are for peak ground acceleration (PGA) and for ordinates of acceleration response spectra (SA).

These prediction equations are usually derived from regression analyses on datasets of recordings from accelerographs. The equations are very simple models that attempt to represent a very complex process, including only a few of the features of the earthquake source, the travel path and the nature of site in the model (and moreover using rather simple parameterisations of these features). Moreover, there is probably an inherent randomness in ground motions that could not be predicted regardless of the complexity of the model. As a consequence of all of these factors, there is always a large scatter of the data about the curve fitted through the regression analysis (Figure A.3). The residuals of the observed data with respect to the model predictions are generally found to conform to a log-normal distribution, whence the scatter is represented by the standard deviation (sigma, σ) of this distribution.

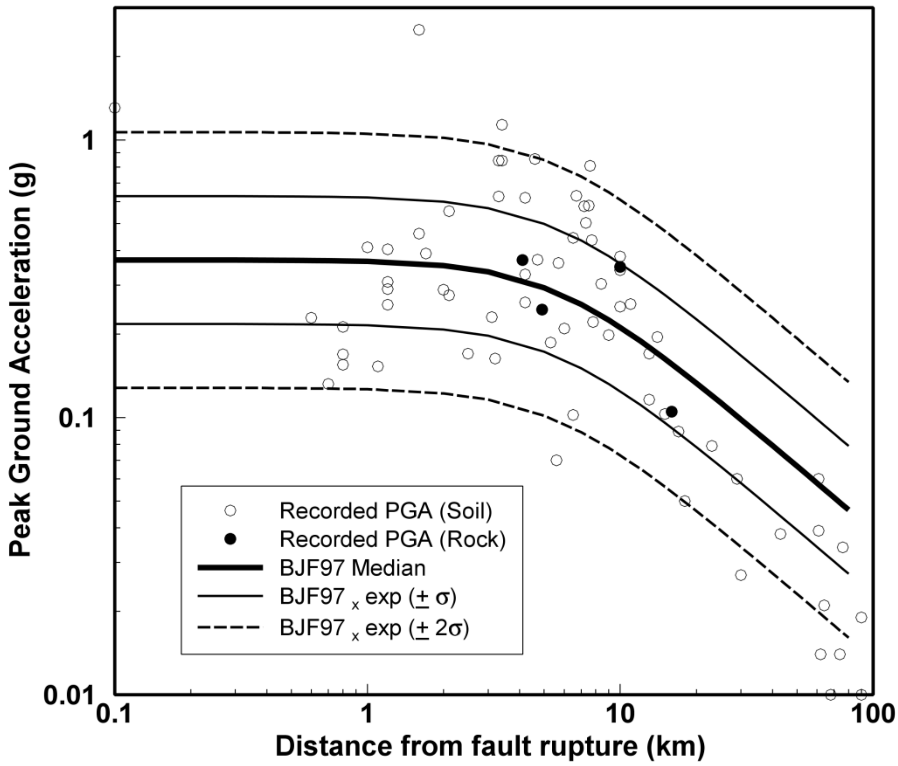


Figure A.3. Recorded values of PGA from the 2004 Parkfield earthquake compared with predicted ground motions at different exceedance levels obtained from the equation of Boore *et al.* (1997); from Bommer & Abrahamson (2006).

Although it is common to plot the predicted median values of acceleration against distance for a given magnitude (such as the thick black line in Figure A.3), the equations actually predict a probabilistic distribution of the ground-motion parameter for any given magnitude-distance-site combination. The median value of motion has a 50% probability of being exceeded in the event of a given earthquake scenario (M-R) occurring; the median-plus-one-standard deviation value has a 16% probability of being exceeded, and the median-plus-two-standard deviations value has a 2.3% probability of being exceeded. The ultimate objective of a seismic hazard analysis is to estimate ground-motion levels at a site, whence the analysis considers scenarios that are defined by both the earthquake (M-R) and the number of standard deviations above or below the median prediction, usually specified by epsilon (ε).

In regions of low-to-moderate seismic activity, where there are not large databanks of strong-motion records, ground-motion prediction equations are often derived through stochastic simulations using parameters determined from inversions of weak-motion recordings obtained from seismographs (Boore, 2003). Several such equations have been published, for example, for ground-motion prediction in the Central and Eastern United States (*e.g.*, Atkinson & Boore, 2006). The sigma value is more difficult to determine reliably for such equations but the inherent variability in the ground-motion prediction must still be included when the equations are employed in seismic hazard analysis.

A.3. Site Response Analysis

As seismic waves travel upwards toward the Earth's surface, they are modified as they are transmitted through the upper layers as a result of changes in the wave propagation velocity. If there are soil layers overlying the bedrock at a site, the ground motion can experience significant amplification as a result of the impedance contrast between the soil and the underlying rock. As well as increasing the amplitude of the shaking, soil layers can also modify the frequency content of the motion and increase the duration of the ground shaking.

Most ground-motion prediction equations include a term to account for the effect of the near-surface geology at the site, sometimes based on simple site classes and sometimes using the explicit value of the average shear-wave velocity over the uppermost 30 m, V_{s30}. In both cases, the amplification modelled will be that corresponding to a generic site in this class or with this value of V_{s30}, rather than the specific conditions at the site. For this reason, for critical facilities such as nuclear power plants the influence of the near-surface geology is modelled using more sophisticated approaches (*e.g.*, Bazzurro & Cornell, 2004). The first stage is to characterise the profile at the site by developing a model of the site as horizontal layers, each of which is characterised by its density and shear-wave velocity. The effect of these layers on the upwards travelling waves can then be computed in time domain using accelerograms to represent the bedrock motions (Figure A.4) or else in the frequency domain, for example using Random Vibration Theory (*e.g.*, Rathje & Ozbey, 2006). Site amplification effects can occur even when there is no soil layer overlying the rock at the site (which will be the case at Thyspunt where all overburden will be excavated in order to provide a foundation horizon for the nuclear island within the bedrock), if there is a decrease is shear-wave velocity as one approaches the ground surface, due to weathering or the presence of softer formations. The influence of such variations will be greater if there is a marked contrast in shear-wave velocities between rock layers below the site.

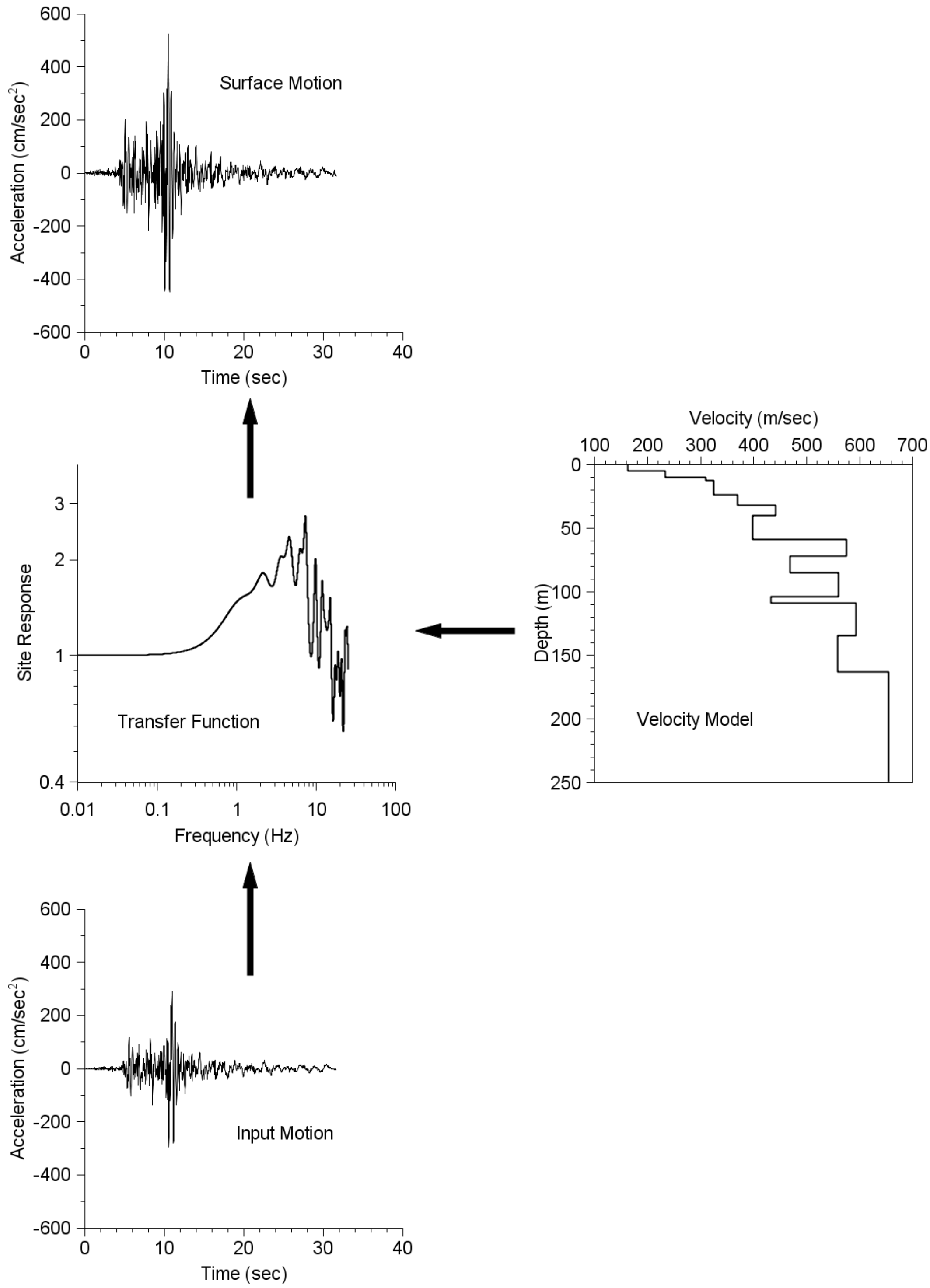


Figure A.4. Illustration of site response analysis; adapted from Bommer & Boore (2004). The acceleration time-histories are shown as time-domain signals whereas the transfer function is defined in the frequency domain, whence it can inferred that a transformation of one or other of these is necessary in order to apply the site response adjustment to the bedrock motion

A.4. The PSHA Integration Process and Aleatory Variability

The historical development of probabilistic seismic hazard analysis (PSHA) has been summarised by McGuire (2008). The main motivation for introducing PSHA as an alternative to the approach of assessing ground motions from a single earthquake scenario was the fact that earthquake occurrence is a random process. Deterministic seismic hazard analysis (DSHA) essentially requires the magnitude and location of the controlling design earthquake to be selected by judgement, which in practice will be to some degree arbitrary. Cornell (1968) made the following eloquent argument in support of the probabilistic approach:

> "*In the determination of the distribution of maximum annual earthquake intensity at a site, one must consider not only the distribution of the size (magnitude) of an event, but also its uncertain distance from the site and the uncertain number of events in any time period*."

Even in the very unusual case of a site at which the hazard is entirely dominated by a single fault producing characteristic earthquakes with very little seismicity between quasi-periodic large-magnitude events, a DSHA would still involve making a decision regarding the ground-motion level: should it be the predicted median acceleration or the median-plus-two-standard-deviation level? The latter is about 20 times less likely to occur but the motions would be about 3 times greater.

Instead of arbitrarily selecting the values of M, R and ε, PSHA considers all possible combinations of these three variables, by considering all the earthquakes that could occur within the defined seismic sources and the levels of ground motion that each could produce at the site. The frequency of exceedance of each M-R-ε scenario is calculated as the product of the frequency of occurrence of earthquakes of this magnitude and greater, and the frequency of exceedance of the ground-motion level; the latter is equal to 0.5 for the median motion. The total frequency of exceedance of a given level of motion is then found by summing the frequencies of all the M-R-ε combinations producing that acceleration at the site. A plot of the different levels of acceleration against their associated annual exceedance frequency is a known as a hazard curve, and this is the fundamental output from a PSHA. A full PSHA study will usually repeat the hazard calculations for response spectral ordinates at a range of response periods covering all of the structural analyses that may need to performed for the design of the facility. For the selected annual frequency of exceedance (which is often expressed as its reciprocal, which is known as the return period and is reported in years), the corresponding spectral acceleration can then be read from the hazard curves and used to construct a uniform hazard response spectrum (UHS) period-by-period.

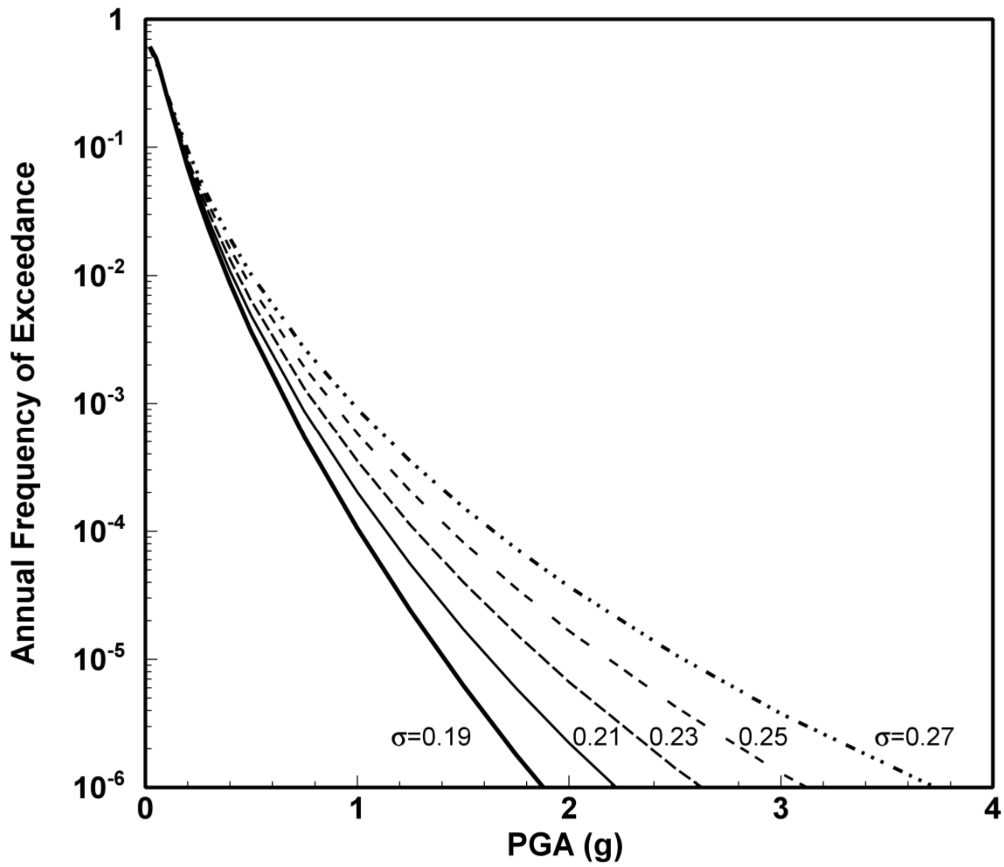


Figure A.5. Hazard curves derived using the prediction equation of Boore *et al*. (1997) with the published value of sigma (0.23) and modified values (Bommer & Abrahamson, 2006)

The level of the hazard curve, in other words how frequently different levels of motion are expected to be exceeded at the site, is controlled mainly by the seismic sources, both in terms of their proximity to the site and their level of activity. For a site dominated by a single seismic source, the hazard curves scales directly with the recurrence rate of earthquakes within the source: if the activity rate in the source is doubled, the hazard increases by a factor of two. The shape of the seismic hazard curve is determined by the nature of the recurrence rates and also the variability associated with ground-motion prediction equation; Figure A.5

shows how the value of σ influences the shape of the hazard curve. The variability in the near-surface geological profile can also be incorporated into the probabilistic hazard calculations (Bazzurro & Cornell, 2004).

The aleatory variability associated with ground-motion prediction equations (which is usually one of the strongest influences on the shape of the seismic hazard curve) is theoretically irreducible, since it reflects the inherent randomness in ground motion. However, the value of σ is actually defined with respect to a particular prediction equation, and so it can be thought of as ‘apparent aleatory variability’, since developing more sophisticated predictive models can result in modest reductions of its value. However, despite a hugely expanded global strong-motion database and the development of predictive models with many explanatory variables and complex functional forms, the resulting values of σ have remained in the same range for several decades (Strasser *et al*., 2009). More promising avenues for reducing the value of σ associated with ground-motion predictions have been opened up by the decomposition of the ground-motion variability into its component parts, some of which are repeatable (such as the average amplification effect at a specific site) and can therefore separated and constrained by site- or path-specific data leading to a reduction in the aleatory variability (*e.g*., Al Atik *et al*., 2010).

A.5. Epistemic Uncertainty and Logic-trees

The definition of inputs to a PSHA inevitably involves a large degree of judgement on the part of the analyst, because it is almost always the case that the most appropriate model or parameter value for each component is not known unambiguously. This arises because of our incomplete knowledge of earthquake processes in any given location, and as a result there can be several models that appear to be feasible alternatives for the analysis. This is now referred to as epistemic uncertainty, and unlike the random (or aleatory) variability that can usually be measured or inferred from observations, epistemic uncertainty can only be judged. Rather than try to determine which is the ‘correct’ model, which generally it is not possible to do unambiguously, it has become standard practice to consider various options for each model or parameter value that is uncertain, the models being selected to represent the range of possible interpretations.

The tool that is commonly used to handle these alternative models is the logic-tree (Kulkarni *et al*., 1984; Bommer & Scherbaum, 2008), in which the alternative models are assigned to branches emerging from a node, and assigned weights reflecting the relative confidence of the analyst in each of the branches representing the most appropriate choice. Figure A.6 shows an example of a logic-tree for PSHA.

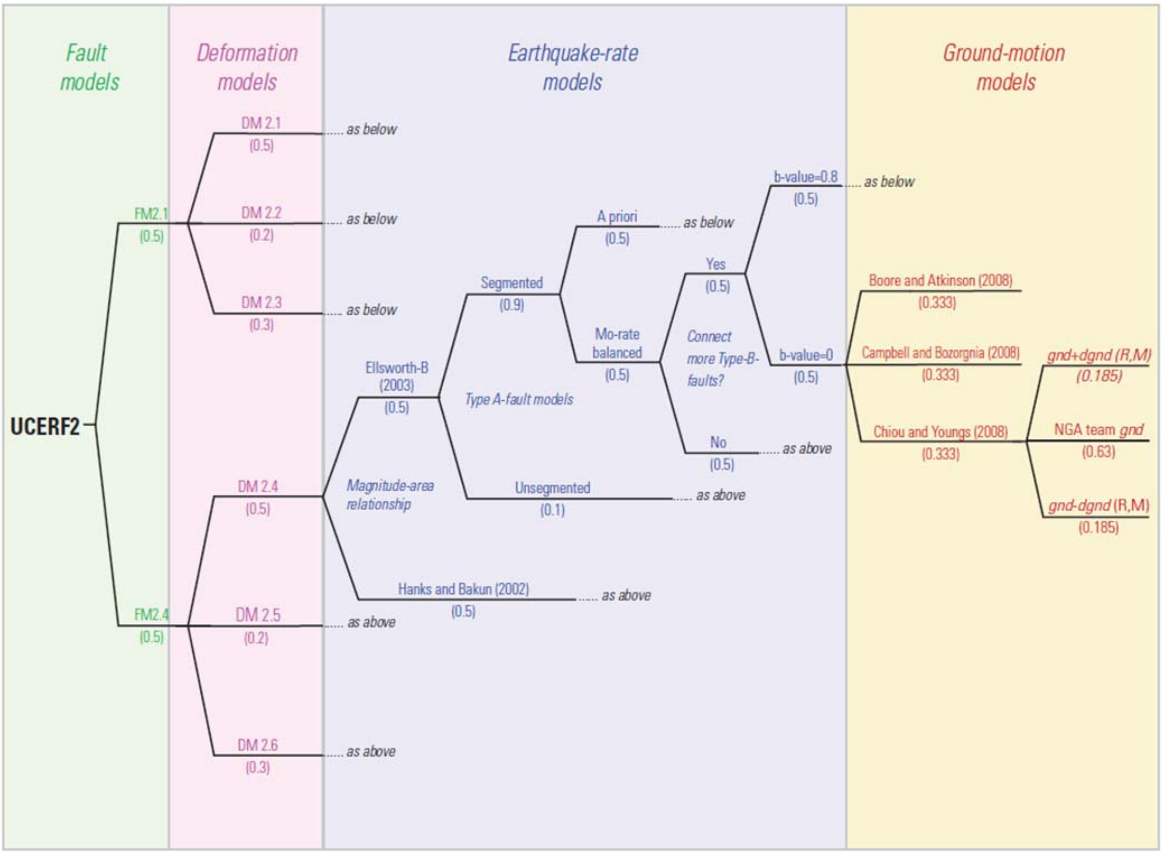


Figure A.6. Logic-tree for UG Geological Survey PSHA for western United States as part of the national seismic hazard mapping exercise (Petersen *et al*., 2008).

The branch weights coming from a single node are invariably set to sum to unity. There is ongoing debate regarding the exact interpretation of the weights on logic-tree branches (*e.g*., Abrahamson & Bommer, 2005; McGuire et al., 2005; Musson, 2005), but the fact is that in downstream calculations the weights are treated as probabilities. Therefore, regardless of one's philosophical view of their meaning, it is worth bearing in mind the treatment of logic-tree weights as probabilities when they are being assigned to the branches.

Once the logic-tree is fully set up and weights assigned to all branches, the hazard calculations are then performed following each possible route through the logic-tree. Each branch-tip produces a separate hazard curve, the total probability of which is the product of the weights on all the branches adopted for its calculation. Therefore, whereas the aleatory variability determines the shape of an individual hazard curve, the epistemic uncertainty results in a family of hazard curves. The statistics of the annual frequencies of exceedance for each ground-motion level allow different hazard curves to be constructed representing the median and other fractiles, as well as the mean hazard curve (Figure A.6), which is the basis for specifying seismic design loads in most nuclear regulatory environments.

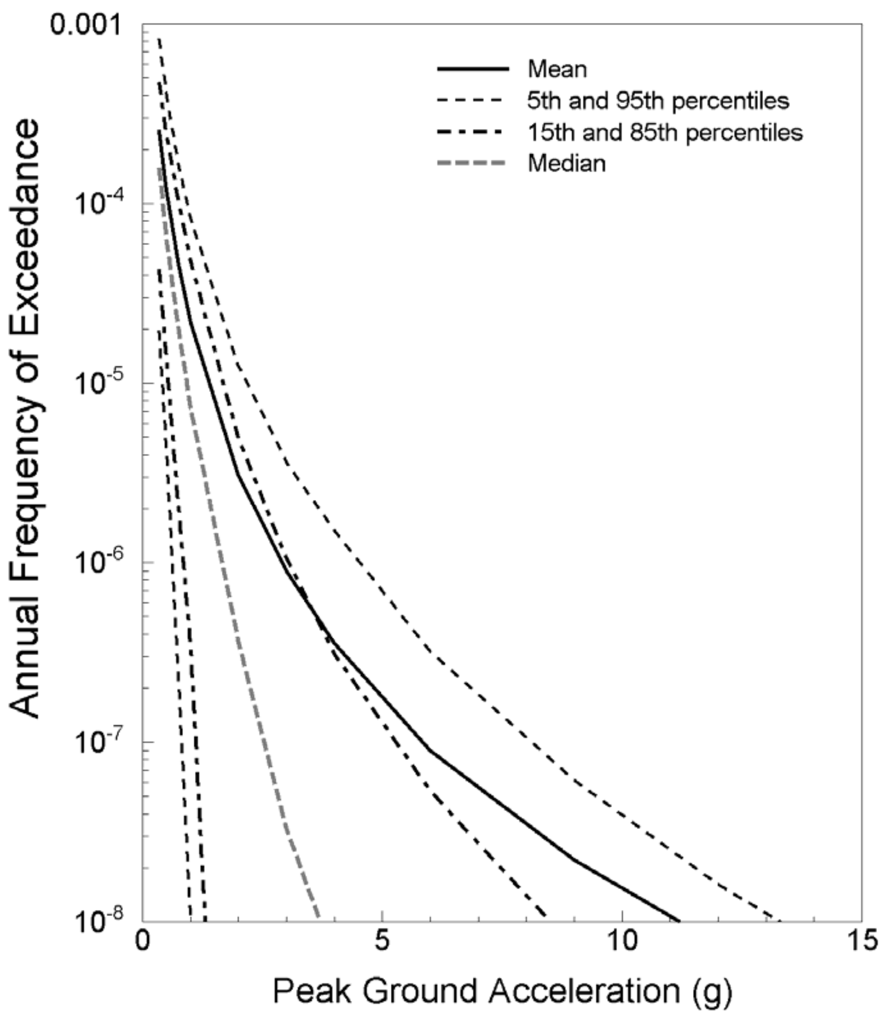


Figure A.7. Hazard curves for Yucca Mountain obtained from a PSHA performed within a logic-tree framework (Abrahamson & Bommer, 2005).

A logic-tree can be set up either with discrete branches at a node or with a distribution at a node; the former will always be applied to alternative models but for parameter values either of the options can be adopted. In the SSHAC Level 4 PSHA conducted for Yucca Mountain (Stepp *et al*., 2001), distributions were used, whereas in the Level 4 PEGASOS for NPP sites in Switzerland (Abrahamson *et al*., 2002), most of the nodes were represented by logic-tree branches.

In attempting to ensure that the full range of uncertainty on all elements of the hazard model are captured, a logic-tree can become very complex with large numbers of branches, leading to enormous numbers of hazard runs if every single branch combination is to be sampled. In some SSHAC Level 4 projects, such as PEGASOS, the number of branch-ends has actually become prohibitively large, resulting in the decision to reduce the number of branches actually considered by the hazard analysts. This may be done, if unavoidable for practical reasons, but the onus then rests on the hazard analysts to demonstrate to the satisfaction of the evaluation/integrations teams that these changes have not appreciably changed the hazard estimates that would be obtained from the complete logic-tree. Should it be the case that a logic-tree continues to have an unavoidably large number of branches, it is possible to obtain good approximations of the distribution of hazard estimates by careful sampling of the branch combinations instead of following each path through the logic-tree to every single branch end. The logic-trees produced by the TI Teams must represent the full range of technically-defensible interpretations of the available information; branches should not be eliminated during the integration phase on the basis of being of low hazard impact.

APPENDIX B

Examples of Data Summary and Data Evaluation Tables

Data Summary Table
Illinois Basin-Wabash Valley Region

Citation	Title	Relevance to SSC
		GENERAL FOR REGION
		BASEMENT STRUCTURE
Kolata and Nelson (1991)	Tectonic History of the Illinois Basin	Illinois basin is a polyhistory basin that formed primarily during the Paleozoic Era. The basin began as a failed rift concurrent with the breakup of a supercontinent during latest Precambrian or Early Cambrian time. Following the rift basin phase, which lasted from Early to Middle Cambrian, the tectonic setting changed to a broad cratonic basin centered over the rift. Plate tectonic interactions along the eastern and southern margins of North America have repeatedly reactivated the rift and have influenced basin subsidence, sedimentation, formation of geologic structures, migration of subsurface fluids and contemporary earthquake activity.
Pratt et al (1992)	Widespread Buried Precambrian Layered Sequences in the U.S. Mid-Continent: Evidence for Large Proterozoic Depositional Basins	Seismic reflection data in the Illinois region show a Precambrian layered assemblage extending 320 km in an E-W direction and 200 km in a N-S direction. The assemblage is approximately 12 km thick. Apparent sequence boundaries (onlap, downlap) within the assemblage suggest they are part of a large depositional basin with diffractions and dipping strata due to faulting. The layered sequence correlate with regions of relatively long-wavelength and low-amplitude magnetic anomalies; the extent of this magnetic signature suggests that about 200,000 km² of Illinois, Indiana, and western Ohio may be underlain by similar Precambrian strata.
Hildenbrand and Ravat (1997)	Geophysical Setting of the Wabash Valley Fault System	Analyses of gravity and magnetic data have been used to evaluate the geologic framework of the northern Mississippi embayment and Illinois basin regions. Inversion of high-resolution aeromagnetic data shows that interpreted ultramafic dikes closely follow mapped faults; their abundance suggests that the Wabash Valley fault system (WVFS) contains more faults than those mapped. Both dike pattern and mapped WVFS terminate near the Reelfoot–Rough Creek–Rome rift system. The Grayville graben (~20 km wide, ~700 m maximum basement relief, and <40 km long) underlying the Wabash Valley developed during rifting, perhaps in response to stress concentrations generated by a bend in the rift system. The Wabash Valley faults are interpreted to be minor tectonic structures (relative to the Reelfoot rift and Rough Creek graben) and probably do not represent a failed rift arm. There is a lack of any obvious relation between the WVFS and the epicenters of historical and prehistoric earthquakes. Five prehistoric earthquakes lie near structures associated with the Commerce geophysical lineament.

Figure B.1. Example of Data Summary Table from the CEUS SSC Project

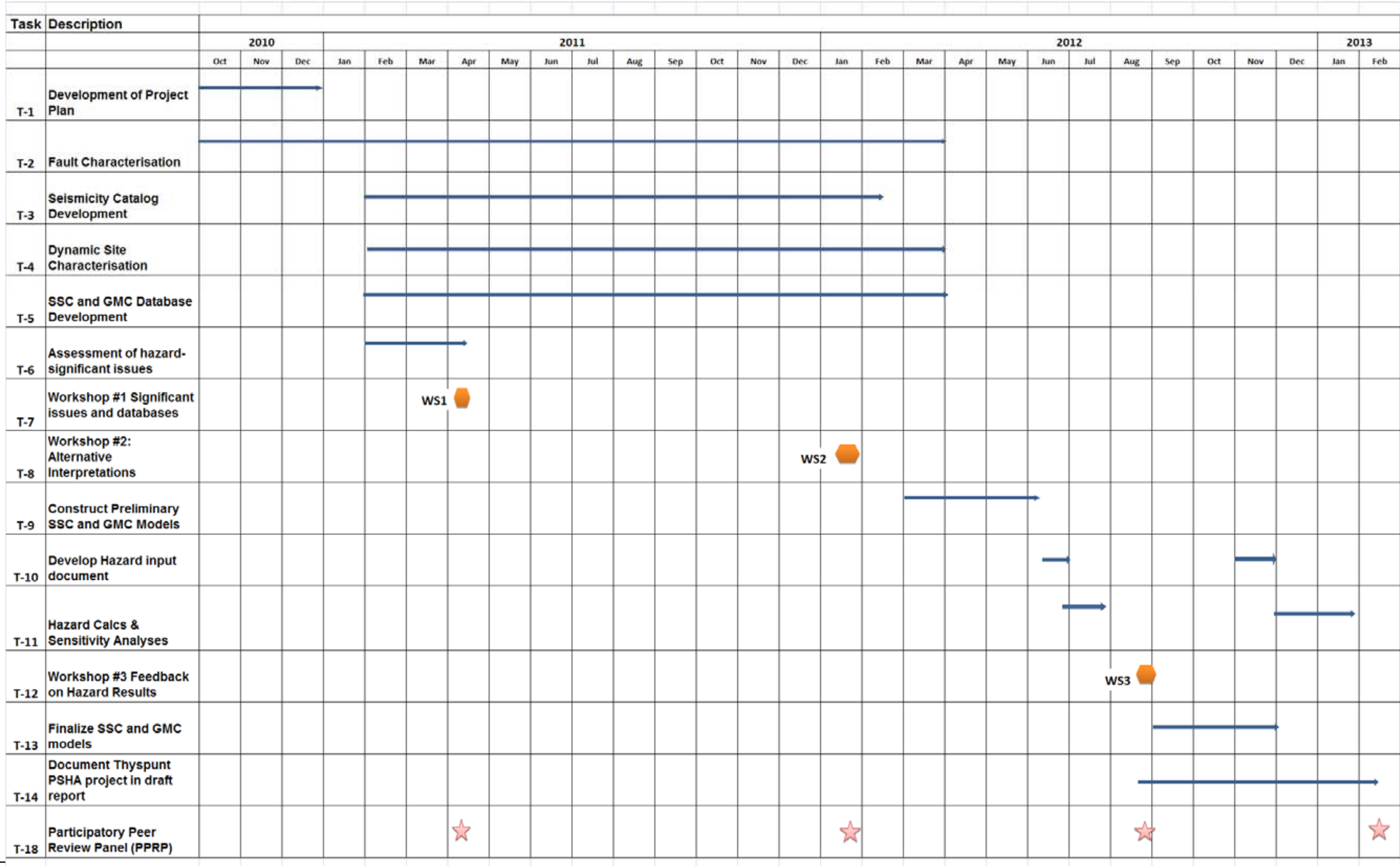
Data Evaluation Table
Illinois Basin-Wabash Valley Region

Data Type / Reference(s)	Quality (1=low, 5=high)	Notes on Quality or Data	Source Considered (e.g., A, B)	Used in SSC and Reliance Level (0=no, 5=high)	Discussion of Data Use	In Database
Instrumental Seismicity						
CEUS-SSC earthquake catalog	5		IBEB	5	Used to evaluate recurrence parameters.	Y
Hamburger et al. (2008)	3	Abstract	IBEB	4	Reactivation of structures in contemporary stress regime— Magnitude 5.4 earthquake, 04:30 , , located near New Harmony fault at depth of ~14 km.	Y (eq. cat.—event size and location)
Withers et al. (2009)	3	Abstract—citing preliminary analysis	IBEB	4	Reactivation of structures in contemporary stress regime—, M_W 5.2 (M_W 5.4 GCMT [http://www.global cmt.org]) , earthquake. Largest event in 20 years in WVSZ.	Y (eq. cat.—event size and location)
Yang et al. (2009)	3	Abstract—citing preliminary analysis	IBEB	5	Analysis of aftershocks using sliding-window cross-correlation () technique and double-difference relocation algorithm give a best-fit plane having a nearly E-W trend with an orientation of 248 and a dip angle of 81. The fault is nearly vertical down to ~20 km. Provides constraints on seismogenic width.	N

Figure B.2. Example of Data Evaluation Table from the CEUS SSC Project

APPENDIX C

Thyspunt PSHA Project Schedule



Task
Description
2010
2011
2012
2013
Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb
T-1 Development of Project Plan
T-2 Fault Characterisation
T-3 Seismicity Catalog Development
T-4 Dynamic Site Characterisation
T-5 SSC and GMC Database Development
T-6 Assessment of hazard-significant issues
T-7 Workshop #1 Significant issues and databases
WS1
T-8 Workshop #2: Alternative Interpretations
WS2
T-9 Construct Preliminary SSC and GMC Models
T-10 Develop Hazard input document
T-11 Hazard Calcs & Sensitivity Analyses
T-12 Workshop #3 Feedback on Hazard Results
WS3
T-13 Finalize SSC and GMC models
T-14 Document Thyspunt PSHA project in draft report
T-18 Participatory Peer Review Panel (PPRP)