**Technical Support – Work Order Specification**

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| **Title: UK HPR1000 Generic Design Assessment – Independent Review of the Verification and Validation of the Computer Codes used for the Design and Safety Analysis** |
| 1. Background to the project

In January 2017 the UK Government formally asked ONR and EA to begin the GDA of the UK HPR1000. The UK HPR1000 is a reactor design proposed for deployment at Bradwell-on-Sea, Essex. General Nuclear System LTD (GNS) is a UK-registered company that was established as the Requesting Party (RP) to implement the GDA on the UK HPR1000 reactor on behalf of three joint requesting parties, i.e. China General Nuclear Power Corporation (CGN), EDF and General Nuclear International (GNI).The GDA process calls for a step-wise assessment of the RP’s safety and security submissions with the assessments increasing in detail as the project progresses. Step 1 of the UK HPR1000 GDA commenced in January 2017 and Step 2 finished in November 2018. Step 3 is due to commence thereafter and last for approximately 13 months. Step 4 is currently planned to last for 24 months, starting in December 2019.The RP for the UK HPR1000 are proposing to use a suite of in-house computer codes for the design justification and (design basis) safety analysis in the areas of reactor physics and transient analysis and a mixture of international and Chinese codes for Severe Accident Analysis (SAA). The computer codes that will be used by the RP in each area are listed in Table 1, below. A number of these codes are new to the UK and ONR have no prior experience with their use. In addition to a thorough and detailed assessment of the safety analysis, ONR will assess the applicability of the computer codes, and their adequacy, in terms of validation, verification, uncertainty, and user proficiency. This will enable ONR to make a robust regulatory judgment regarding the validity of the calculated results, and ultimately – considering the identified safety margins - whether the level of risk is reduced to As Low As Reasonably Practicable (ALARP).To support this, ONR requires a meaningful review of the functionality, validation and actual applicability of the codes in the UK HPR1000 GDA. Considering the number of codes, the multitude of relevant knowledge areas and the timescale for assessment, ONR needs to be supported by external contractors of suitable qualification and experience in the relevant disciplines (Fuel and Core, Fault Studies, Probabilistic Safety Analysis (PSA) and SAA). Separate to this contract, ONR will consider user proficiency through other regulatory activities.The purpose of this contract is therefore to provide ONR with an independent view on the adequacy, or otherwise, of the verification and validation of the identified computer codes for UK HPR1000 against relevant ONR and international standards and guidance. This is expected to be undertaken in 2 phases:* Phase 1: Based on the RP’s submitted information, responses to regulatory questions and the contractors’ own knowledge and experience and a comparison against relevant standards conduct, an initial review of the uses, safety significance, potential gaps in justification or uncertainties for all of the identified computer codes; and
* Phase 2: Undertake a detailed review of a smaller number of computer codes (as agreed by ONR) of the detailed verification and validation evidence. This should provide a balanced view of the codes, and the adequacy for GDA, as well as identifying any gaps or omissions and providing views on their significance.
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| 1. SCOPE OF THE SERVICES REQUIRED

Scope of workThe computer codes identified by the RP to date are listed in Table 1, below:**Table 1 List of the computer codes that will be used by the RP**

| **Code name** | **Knowledge/Modelling area** |
| --- | --- |
| Fuel and Core |
| PINE | PINE performs 2-D lattice calculation for single assembly and multiple assemblies of PWR and generates two-group parameter tables. The parameters include diffusion coefficients, macroscopic cross-section, surface dependent discontinuity factors, xenon and samarium microscopic densities, flux shape factor for power reconstruction and kinetic parameters. |
| COCO | COCO is used for nuclear reactor design. The main functions include loading pattern design, critical boron concentration search, evolution calculation, control rod worth assessment, reactivity coefficients calculation, shutdown margin calculation, etc. COCO is also used to perform transient calculations such as Reactivity Induced Accidents (RIA). |
| POPLAR | POPLAR is a 1-D neutron diffusion-depletion code. POPLAR is used to perform bite calculation, calibration calculation, xenon depletion calculation, transient xenon calculation, control rod worth calculation and control rod cross section modification. Furthermore, POPLAR is used for transient calculation. |
| PALM | PALM can calculate the nuclide number density, decay heat, neutron emission rates and photon emission rates for given material. These results are used for safety analysis and radioactive shield design. |
| LINDEN | LINDEN is a sub-channel analysis code which is used for thermal-hydraulic design and safety analysis. It calculates the thermal-hydraulic parameters of coolant in the reactor core under various conditions, including pressure, mass flow rate, quality and void fraction, etc. Based on the calculated thermal-hydraulic parameters, the Departure from Nucleate Boiling (DNB) of reactor core can be predicted by using a specific Critical Heat Flux (CHF) correlation. |
| JASMINE | JASMINE predicts the in-pile performance of the PWR fuel rod duringConditions I and II and provides the initial state data of fuel for safety analysis during conditions III and IV. This includes fuel rod thermal and mechanical analysis, fission gas release, internal pressure, cladding corrosion and hydrogen uptake. |
| Fault Studies |
| GINKGO | GINKGO is a system transient analysis code, which is used to analyse PWR transients under normal operating conditions and accident conditions (Non-LOCA). GINKGO simulates main primary system components, the Nuclear Steam Supply System (NSSS), Engineered Safety System (ESS), Reactor Protection System (RPS), Instrumentation and Control System (I&C) and secondary system components. |
| LOCUST | LOCUST is a system thermal-hydraulic code which has the capability of performing LOCA analysis. It focuses on the analysis of LBLOCA, IB/SBLOCA, SGTR, etc. |
| BIRCH | BIRCH is a fuel rod temperature analysis code, mainly used to analyse the integrity of fuel rods under accident conditions. BIRCH calculates the radial temperature distribution of a fuel rod and the heat flux of cladding surface during transient conditions. In addition, it also calculates energy storage in the fuel pellet, gap heat transfer coefficient and thermal expansion of pellet and cladding, etc. |
| CATALPA | CATALPA is used to calculate the change of pressure and temperature with time inside the containment. It is applied in the accidents that result in significant release of high-energy fluid into the containment, such as Loss of Coolant Accident (LOCA) and Main Steam Line Break (MSLB). |
| Severe Accidents  |
| ASTEC | ASTEC (Accident Source Term Evaluation Code), jointly developed by IRSN and GRS, aims at simulating the behaviour of an entire severe accident sequence in a nuclear water-cooled reactor from the initiating event through the release of radioactive materials out of the containment, including the function of engineered safety systems and procedures of severe accident management. |
| GASFLOW | GASFLOW is a computational fluid dynamics code which is a best-estimate tool to characterize local phenomena within a flow field. GASFLOW can be used to predict the transport, mixing, and combustion of hydrogen and other gases, liquid water droplets, and aerosols in nuclear reactor containments and other Non-nuclear buildings. |
| COM3D | COM3D (Hydrogen Combustion and Explosion Risk Evaluation Computer Code) is a three-dimensional code for turbulent reactive flow simulations in complex 3D-geometries. The Favre averaged Navier-Stokes equations are solved together with different models for turbulence and chemical kinetics. |
| MC3D | MC3D is used for the analysis of steam explosion. The code is developed by IRSN. It is a thermal-hydraulic multiphase flow code mainly dedicated toex-vessel and in-vessel Fuel Coolant Interactions (FCI) studies.  |
| MOPOL | MOPOL (Molten POoL) is a dedicated code used to carry out the sensitive analysis and effectiveness of IVR. Based on research investigations of the molten pool, this code is based on the two-layer molten pool model. The Monte Carlo sampling method is used to sample the different input parameters which have a great influence on heat transfer in the corium pool. The heat flux transfer from the corium pool to the lower head of the pressure vessel is calculated based on the heat transfer model in the molten pool. |

Summary information on code models, correlations, treatment of uncertainty etc. will be submitted to ONR by the RP in “qualification reports” for the identified Fault Studies and Fuel and Core codes, early in GDA Step 3. Detailed evidence supporting the code validation and verification will be presented in the references to the qualification report and in the “verification and validation reports”, which are currently planned to be submitted towards the end of Step 3. Outlines of the contents of these reports, as described by the RP, are presented in Table 2.For the SAA related codes the RP will submit the verification and validation documents (as received from the code developer) at the end of 2018. The report “Applicability assessment on severe accident analysis codes used for UK HPR1000” is scheduled for submission in the middle of Step 3.**Table 2 Outline of the Qualification and Verification and Validation Report contents**

| **Chapter**  | **Contents** |
| --- | --- |
| “*Qualification Report*” |
| Limits of application | Applicability of the codes (such as range of water temperature, type of fuel assembly) |
| Models and Numerical Methods | Introduction to key models and key numerical methods, listing the equations |
| Correlations used | Key correlations, including their names, equations, and limits of application |
| Best Estimate calculations and Uncertainty | Overall results of uncertainties (such as the uncertainty of FΔH and soluble boron concentration) |
| User’s proficiency | General introduction to users’ training and qualification (theevidence will be provided to ONR upon request) |
| Quality Assurance | General introduction to RP’s quality assurance system for computer code development (the evidence will be provided to ONR upon request) |
| “*Verification and Validation Report*” |
| Limits of application | Supporting information on how the applicability was obtained. |
| Models, Correlations and Numerical Methods | Supporting information on the verification and validation of the models and correlations. |
| Best Estimate calculations and Uncertainty | Description of the benchmarks, experiments, and operational data of NPPs used; the results, and the conclusions.Evidence of the procedure of obtaining the uncertainties |
| User’s proficiency | N/A  |
| Quality Assurance | N/A  |

In addition to these submissions the contractor can raise technical questions with the RP (via ONR), which can be used to request additional information or documentation to support the review.**WORK BREAKDOWN**Phase 1:During phase 1 the contractor is required to:1. Carry out an initial high level review for each code in Table 1, based upon the early documentation to be submitted by the RP as described above, informed by the contractors own knowledge and experience of relevant good practice in the validation and verification of nuclear safety analysis codes. The review should utilise the contractor’s knowledge of good practice of code development, thermal hydraulics, reactor physics, the identification and ranking of physical phenomena and the modelling of these in reactor safety cases. The purpose of the review at this stage is to identify those codes, or particular aspects of those codes where a detailed review of the verification and validation evidence is considered necessary later in GDA. The documents to be considered at this phase are:
* “qualification reports” for the Fuel and Core and Fault Studies codes
* Verification and validation documents for the SAA codes
1. Raise requests for additional information and documentation from the RP (via ONR), and review the responses. This may require the contractor to attend meetings with the RP to discuss and clarify questions and responses. Such requests for information would be aimed at establishing the quality or availability of V&V information rather than commissioning new work for the RP.
2. Report to ONR this review, including conclusions and recommendations to ONR on areas for follow up when detailed information becomes available.. The review should consider the following factors:
	1. Safety significance of the reviews’ findings and observations (the RP’s transient analysis results will be available to inform judgements on the safety significance of the codes but this contract is to advise ONR on the adequacy of the codes validation and verification, and is not to perform a detailed review of the transient analyses undertaken with the codes);
	2. Complexity of the modelled phenomena;
	3. Novelty of the modelling approaches, correlations and numerical methods;
	4. Compliance with relevant ONR and international standards and guidance.

Phase 2:During phase 2 the contractor is required to:1. Agree with ONR those codes, or particular aspects of codes, where a detailed review is considered necessary. The scope for this review should also be agreed with ONR.
2. Carry out a thorough and detailed review for each code agreed in 4), based upon the full suite of documentation to be submitted by the RP as described above, in addition to the contractors own knowledge and experience.
3. Raise requests for additional information and documentation from the RP (via ONR), and review the responses. This may require the contractor to attend meetings with the RP to discuss and clarify questions and responses. Such requests for information would be aimed at establishing the quality or availability of V&V information. Any findings of major gaps with the validation and verification should be highlighted to ONR for regulatory follow up.
4. Report to ONR this review, including conclusions and recommendations to ONR on the suitability of the computer codes and the adequacy of the verification and validation evidence. The conclusions should include an overall judgement on whether the codes are fit for purpose to support the claims made within the nuclear safety case. The recommendations may include areas for regulatory follow up in GDA, for additional documentary evidence or for investigations using alternative or independent analysis methods. Where the review identifies gaps or omissions, the report should detail the contractors’ views on their significance.

**INPUTS**The following documentation will be available to the contractor:**Table 3 Relevant RP Submissions**

| **Report Title** | **Intended Submission Date to ONR** |
| --- | --- |
| UK HPR1000 GDA, Pre-Construction Safety Report Chapter 5, Reactor Core | 15/11/18 |
| UK HPR1000 GDA, Pre-Construction Safety Report Chapter 12, Design Basis Condition | 15/11/18 |
| UK HPR1000 GDA, Pre-Construction Safety Report Chapter 13, Design Extension Conditions and Severe Accident Analysis | 15/11/18 |
| UK HPR1000 GDA, Pre-Construction Safety Report Chapter 14, Probabilistic Safety Analysis  | 15/11/18 |
| SA codes V&V Documents | 30/12/18 |
| PINE - A Lattice Physics Code: Qualification Report | 30/03/19 |
| COCO - A 3-D Nuclear Design Code: Qualification Report | 30/03/19 |
| POPLAR - A 1-D Core Calculation Code: Qualification Report | 30/03/19 |
| PALM - A Burn-up Calculation Code: Qualification Report | 30/03/19 |
| GINKGO - A System Transient Analysis Code: Qualification Report | 30/03/19 |
| LINDEN - A Sub-channel Analysis Code: Qualification Report | 30/03/19 |
| BIRCH - A Fuel Temperature Analysis Code: Qualification Report | 30/03/19 |
| LOCUST - A Thermal-hydraulic System Analysis Code: Qualification Report | 30/03/19 |
| CATALPA - A Thermal-hydraulic Containment Analysis Code: Qualification Report | 30/03/19 |
| Applicability assessment on severe accident analysis codes used for UK HPR1000 | 30/04/19 |
| PINE - A Lattice Physics Code: Verification and Validation | 30/12/19 |
| COCO - A 3-D Nuclear Design Code: Verification and Validation | 30/12/19 |
| POPLAR - A 1-D Core Calculation Code: Verification and Validation | 30/12/19 |
| PALM - A Burn-up Calculation Code: Verification and Validation | 30/12/19 |
| GINKGO - A System Transient Analysis Code: Verification and Validation | 30/12/19 |
| LINDEN - A Sub-channel Analysis Code: Verification and Validation | 30/12/19 |
| BIRCH - A Fuel Temperature Analysis Code: Verification and Validation | 30/12/19 |
| LOCUST - A Thermal-hydraulic System Analysis Code: Verification and Validation | 30/12/19 |
| CATALPA - A Thermal-hydraulic Containment Analysis Code: Verification and Validation | 30/12/19 |
| JASMINE – A code for fuel rod thermal and mechanical analysis, fission gas release, internal pressure, cladding corrosion and hydrogen uptake: Verification and Validation | 30/05/20 |

In addition, the contractor can raise technical questions with the RP (via ONR) to request additional information or documents. The response time to the questions is at the discretion of the RP and will depend upon the complexity and number of queries. However, a minimum response time of 6 weeks should be assumed.ONR expect the review to be undertaken principally against ONR standards and guidance, in particular the Safety Assessment Principles (SAPs), AV.1 to AV.8, and the associated Technical Assessment Guides, in particular NS-TAST-GD-042 (Rev. 3) - Validation of Computer Codes and Calculation Methods. These are available at www.onr.org.uk. The contractor may also utilise other relevant standard and guidance (such as industry guidance, IAEA guidance or other international guidance where relevant), and its own experience and knowledge as part of the review.**DELIVERABLES**The contractor should provide one report upon completion of phase 1, and a further report (or update to the phase 1 report) upon completion of phase 2. The report(s) should contain full details of the work undertaken, discussion and summary, conclusions and a full reference list. The report(s) should be provided in draft, to allow for one round of ONR comments, before issue. Draft and final versions of all reports should be prepared according to the contractor’s quality system.During the review the contractor is expected to raise any requests for additional information or documents. These should be sent to ONR in a manner that can be forwarded to the RP with minimum changes necessary, and should include details of the background to the question(s), relevant standards and guidance which the response will be judged against (where relevant) and the questions themselves.**TIMESCALES**The following timescales can be assumed:* Start of contract: 02/19
* Phase 1 review: 02/19 until 30/06/19
* Draft report for Phase 1: 01/07/19
* Final report for Phase 1: 31/08/19
* Phase 2 review: 01/09/19 until 30/06/20
* Draft report for Phase 2: 01/07/20
* Final report for Phase 2: 31/08/20

The key project milestones and delivery dates for the various reports will be agreed and fixed when the contract is awarded.**MEETING REQUIREMENTS**ONR expect a kick-off meeting to be held between ONR and the Contractor on contract award. This should include an introduction of the Contractor’s team, background in codes validation, software and hardware availability. This meeting will take place either at the ONR offices in Bootle, or the contractor offices. During the course of the review there may be the need to attend meetings with the RP. This could be face-to-face, either in Liverpool or London, or via videoconference. For planning purposes assume four separate half-day meetings with the RP during the course of the contract.Brief monthly progress meetings should also be assumed for the duration of the contract. For planning purposes two further separate half-day meetings with ONR will also be required during the course of the contract. These should be assumed to be by teleconference or videoconference. A close-out meeting will be held upon completion of the contract. This meeting will take place either at the ONR offices in Bootle, or the contractor offices. Videoconference facilities are also available if necessary. |
| 1. OBJECTIVES

In summary, the required outcomes of this work are for the contractor to provide a report which presents the observations and conclusions from an independent technical review of evidence presented by the RP in relation to the verification and validation of the computer codes used as part of the safety analysis. Ultimately the contractor should provide their view on whether the use of these codes is fit for purpose as part of the UK HPR1000 safety case. |
| 1. CONSTRAINTS

The following constraints will apply:* The work is expected to start and conclude in accordance with the overall timescales given above, and a project programme will be agreed with the contractor upon contract award.
* ONR will provide the latest versions of any relevant documentation submitted by the RP. Further information will need to be identified and requested by the contractor through technical questions (via ONR). The timescales for both of these processes are largely outside of ONR’s direct control and therefore delays to the receipt of information may occur. Similarly the quality of any response cannot be guaranteed. A pragmatic and flexible approach will need to be adopted by the contractor to deal with this, both technically and contractually.
* It is expected that the successful contractor will also draw upon their experience, resources and publically available information to perform this work.
* All information received from the RP will need to be treated in accordance with the ONR Technical Support Contact Framework agreement and non-disclosure agreement. The information or a certificate of destruction will need to be returned to ONR at the end of the contract.
* The arrangements for security vetting and IT security established in the Technical Support Contract framework agreement will need to be followed. No information with a security marking above UK OFFICAL - SENSITIVE is anticipated as part of this contract. Most information will carry the RP’s commercial marking.
* The contractor and where applicable, its sub-contractors, will need to provide assurances that it has, or is able to obtain, all necessary export control licenses, where required to transfer relevant information out of the UK and return it.
* The transmittal of all documents between ONR and the contractor will be through ONR's Joint Programme Office (JPO). This will be through encrypted DVDs, regardless of the security marking (unless the documents are publically available on the internet).
* Any conflict of interest should be declared. Where a potential conflict exists, the contractor should describe how this will be managed.
* The aim of this work package is to inform and advise ONR. However, it is ONR’s intention to brief the RP on the conclusions of the work. The RP will be provided with copies of any reports produced for information and will be invited to comment on their factual accuracy.
* It is not ONR’s intention to publish the reports produced through this contract. However, it is likely they will be referenced in publically available reports and therefore subject to freedom of information requests. This should not constrain or limit the produced reports but should be taken into account with the style and format.
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| 1. CONTRACT MANAGEMENT

ONR will require to be kept updated about progress and delivery of the required work in accordance with the Framework arrangements. This should include monthly meetings, to include a contract start-up meeting at ONR’s offices at Bootle, or the contractors’ offices.  |
| **TECHNICAL RESPONSE** |
| 1. Response

The Technical Response should demonstrate a clear understanding of the work required.Please provide: * a description of how you will deliver the scope of work (methodology) and the proposed delivery team you will use, clearly signposting to relevant sections within your Capability Prospectus where appropriate/relevant;
* a description of the standards that you will use for the reviews;
* a description of the expertise and experience of the teamsin a range of disciplines relevant to thermal hydraulics, core physics and severe accident codes *(for example coding development experts, code users, subject matter experts in validation and verification);*
* a demonstration of up-to-date knowledge of relevant research programmes and international benchmarks;
* an overview of any prior experience of conducting peer reviews of computer codes validation and verification for safety analysis;
* an overview of any prior experience with the HPR100 design or computer codes;
* a description of proposed deliverables and/or outputs;
* an outline of anticipated engagement (project meetings & management);
* details of proposed cost and associated effort assumptions;
* a project delivery plan showing activities and milestones;
* a planned invoice schedule;
* details of any assumptions or constraints.
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