NATIONAL NUCLEAR REGULATOR

For the protection of persons, property and the environment against nuclear damage

REGULATORY GUIDE

Guidance on the Verification and Validation of Evaluation and Calculation Models used in Safety and Design Analyses

RG-0016

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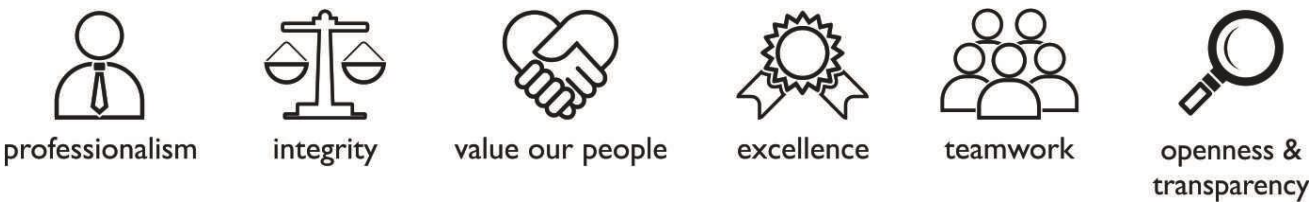

APPROVAL RECORD				
	Name	Designation	Signature	Date
Prepared	P Bester	Special Nuclear Project Coordinator		
Reviewed	Ian Korir	Senior Specialist		
	Andy Graham	Principal Specialist		
	Henriette van Graan	Senior Specialist		
	Jean Joubert	Principal Specialist		
	EXCO			
Recommended	O Phillips	Senior Manager: SARA		
Approved	Dr. MB Tyobeka	Chief Executive Officer		

Note: The original, signed document is retained by the Record Management.

Contributors:
The following persons contributed to the preparation of the document:
Peter Bester
Ian Korir
Andy Graham
Jean Joubert

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1 BACKGROUND

Regulations are mandatory and set down specific requirements to be upheld by the authorisation holder or an applicant for a nuclear authorisation. Guidance documents are developed to assist authorisation holders or/and applicant for authorisations in meeting the regulatory requirements. In general guidance documents have to be adhered to by the holder/applicant. Any deviation from NNR guidance has to be justified.

Section 5 of the draft General Nuclear Safety regulations includes a requirement that states:

> *All calculation models and/or evaluation models used in safety analyses are designed, developed, verified and validated, implemented, used and controlled in accordance with recognised nuclear industry standards and/or practices;*

Analysis of plant design and operation using computer software forms an important part of a modern safety case. Although the use of computer software programs are the main calculation method employed in nuclear plant design and analysis, occasionally calculations by hand are performed. The verification and validation procedures described here are equally applicable to either route. Unless otherwise stated references to calculation methods may be taken to encompass both computer software and calculation procedures carried out by hand. For the purpose of this document spreadsheets and similar calculation tools shall be considered in the same manner as other Commercial Off The Shelf (COTS) software.

The NNR will not provide a general approval for specific computer software, but will only state its acceptance of the software for specific or similar types of applications in the safety analysis under specific conditions as justified in the verification and validation report. For specific applications an independent assessment involving separate calculation models and software programs may also be required.

This RG supersedes the following regulatory documents:

1. RD-0016: Requirements for authorisation submissions involving computer software and evaluation models for safety calculations; and
2. LG-1045: Guidance for Licensing Submissions Involving Computer Software and Evaluation Models for Safety

2 PURPOSE

The document provides guidance on the implementation of the above-mentioned requirement from Section 5 of the draft General Nuclear Safety regulations and consolidates all regulatory requirements and guidance in the area of verification and validation of evaluation and calculation models used in safety and/or design analyses.

The guidance is applicable to all facilities and activities regulated by the NNR in terms of the provisions of the NNR Act and associated regulations, including applicants, holders of authorisations and suppliers of products and service important to nuclear safety as appropriate.

3 SCOPE

This document provides guidance on the verification and validation of evaluation and calculation models used in both safety and design analyses and should be used by applicants, authorisation holders, designer of nuclear facilities as well as service providers performing important to safety analyses and designs.

This guidance is not directly applicable for software used directly for plant operational control and protection. International guidance for this type of software is given for example in [9] and [10].

4 TERMS, DEFINITIONS AND ABBREVIATIONS

In this RG any word or expression to which a meaning has been assigned in the National Regulator Act (NNRA) or the Regulations promulgated in terms of the NNRA, shall have the meaning so assigned. Only additional terms, definitions and abbreviations are provided.

4.1 Terms & Definitions

"**alternative calculation**" means a calculation that is made with alternative methods to verify correctness of another original calculation;

"alternative calculation method" means a calculation method that is developed with alternative and independently developed methods to verify correctness of another original calculation method;

"**best estimate calculation"** means a calculation that employs modelling that attempts to describe realistically the physical processes occurring in the plant;

"blind calculation" means a calculation carried out after an experiment or test being done without knowledge of the experiment or test results. Starting and boundary conditions of the actual experiment or test are employed. A 'double- blind' calculation is a more restricted blind calculation on a facility for which the user has no prior modelling experience;

"**calculation method**" means the methodology used to perform a calculation and refers to the model, software, data or manual approach used;

"calculation" means manual or computer computation used for design, analysis, or to demonstrate the adequacy of a design. The term calculation may also be used to describe a series of calculations performed using variations to the inputs, model parameters, etc;

"calculation method" means the methodology used to perform a calculation. The term calculation method refers to the model, software, data or manual approach used;

"calculation model" means an analytical representation or quantification of a real system and ways in which phenomena occur within that system, used to predict or assess the behaviour of the real system under specified conditions. Where a software product is used the calculation model is the combination of the system model and software product;

"evaluation model" means a calculation framework consisting of one or more calculation models and specific inputs used to model specific system behaviour under certain conditions and linked to specific safety case assessment and/or objective;

"figure of merit" means a numerical quantity based on one or more characteristics of a system or device that represents a measure of efficiency or effectiveness;

"high importance to nuclear safety" means products or services whose failure would directly lead to an accident condition considered in the design of the nuclear facility, or whose failure would lead to a release of radioactive material that exceeds the regulatory dose limits or risk criteria as authorised, or cause the values of key physical parameters to challenge or exceed acceptance criteria for accident conditions considered in the design of the nuclear facility;

"important to nuclear safety" means products or services whose failures or malfunction could compromise safety and lead to radiation exposure of persons and/or the environment and includes products or services categorised as either high importance to nuclear safety as well as products or services whose malfunction or failures could result in low or medium consequences to persons or the environment;

"low consequences" means if the failure of a safety function could at worst lead to an off-site release of radioactive material not exceeding the prescribed limits for normal operation or anticipated operational occurrences, but could lead to dose to workers above the authorised limits;

"medium consequence" means if failure of a safety function could at worst lead to the release of radioactive material below the authorised limits for accident considered in the design but higher than those limits established for anticipated operational occurrences or cause the values of key physical parameters to challenge or exceed acceptance criteria for anticipated operational occurrences;

"legacy software" means software that has been developed in the past for specific applications which may be poorly documented and need substantial V&V efforts;

"mitigation measure" means an approach, justified in detail in the licence submission, which is taken to address a source of weakness in the available validation evidence needed to support a Calculation or Method for use in the safety case**;**

"new software" means software that is under development for a specific application and can therefore be submitted to a full scale V&V process during all stages of development;

"safety analysis" means to demonstrate the attainment of the safety objectives at a nuclear site. In the context of this guidance it is all calculations or other analysis pertaining to application of a Calculation Model or Evaluation model linked directly or indirectly to the justification of the facilities safety case;

"safety case" means a logical and hierarchical set of documents that demonstrates compliance with the Regulatory requirements and criteria and describes the radiological hazards in terms of a facility, site and the modes of operation, including potential undesired modes, and encompasses the

authorisation basis, and safety related documentation applicable during different authorisation stages and will include the safety assessment, operational safety related programmes and supporting documentation;

"s**oftware product**" means the set of computer programs, procedures, and possibly associated documentation and data.

"system model" means the inputs to a Software Product representing the physical properties of a real system. A System Model comprises the spatial and/or temporal model of the system to be analysed and the associated sets of input data.

"system model data validation" means the evidence supporting the System Model data that demonstrates that the achieved calculation using the data is fit for its purpose when applied Mitigation Measures are also taken into account.

"**tuning**" means the process of recalculating the same test case with adjustments, for example, in input parameters, user options or nodalization until the best possible agreement is obtained;

"verification" means process of ensuring that the controlling physical equations have been correctly translated into the software or, in the case of hand calculations, correctly incorporated into the calculational procedures;

"validation" means the evidence that demonstrates that the software is fit for its purpose. When calculating physical processes it may mean showing that the calculation is bounding with a suitable degree of confidence rather than a best estimate.

4.2 Abbreviations

ASME	:	American Society of Mechanical Engineers
COTS	:	Commercial Off The Shelf
EM	:	Evaluation Model
EMDAP	:	Evaluation Model Development and Assessment Process
GUI	:	Graphical User Interfaces
HTR	:	High-Temperature Reactor
IAEA	:	International Atomic Energy Agency
IEEE	:	Institute of Electrical and Electronics Engineers
NNR	:	National Nuclear Regulator
NNRA	:	National Nuclear Regulator Act, Act 47 of 1999
PIRT	:	Phenomena Identification and Ranking Table
QA	:	Quality assurance
RG	:	Regulatory Guidance Document
SAR	:	Safety Analysis Report
SVVP	:	Software Verification and Validation Plan
V&V	:	Verification and Validation

5 PRINCIPAL GUIDELINES

5.1 General

1) Information about computer software and evaluation models for safety calculations and design analyses important to nuclear safety should be comprehensive.

2) The safety case should demonstrate that all models used are robust and have been benchmarked directly or indirectly against experimental data.[1]

3) The applicant should provide for NNR review, a complete description of each evaluation model which is sufficient to permit technical review of the analytical approach, empirical correlations, the equations used, their approximations in difference form, the assumptions made and included in the software products, procedure for treating software input and output information, including specification of those portions of the analysis performed both with and without using software products, values of parameters, and all other information necessary to specify the calculation procedure.

4) Solution convergence should be demonstrated for each calculation, by studies of system modelling or nodalisation and calculation time steps.[2]

5) Sensitivity studies should be performed for each evaluation model, to evaluate the effect on the calculated results of variations in nodalisation, time step size and phenomena assumed in the calculation to predominate. For items for which results are shown to be sensitive, the choices made should be justified.

6) The empirical models and correlations used in the evaluation model should be compared with relevant data. Predictions of the entire evaluation model should be compared with applicable experimental information. If an evaluation model for evaluating the behaviour of the plant system during a postulated accident includes one or more computer programs and other information, overall program behaviour should be checked against results from standard problems or benchmarks.

5.2 Safety Analysis

1) A comprehensive analysis should be performed to determine the functional systems needed to ensure the safety of the nuclear facility.

2) Based on the analysis system performance criteria, specific design criteria and general design criteria should be defined.

3) Safety analysis of complex system behaviour such as nuclear facilities demands use of physical models, as well as computer software models to simulate them. The following six basic principles should be considered in the process of developing and assessing an Evaluation Model (EM) that is used to analyse transient and accident behaviour of a nuclear facility:

   a) Determine requirements for the evaluation model: The purpose of this principle is to provide focus throughout the evaluation model development and assessment process. An important outcome should be the identification of mathematical modelling methods, components,

[1] An indirect benchmark in this sense would be a comparison with an alternate software product which itself is benchmarked against experimental data.
[2] Solution convergence may be influenced by multiple solutions or by discontinuities of physical properties.

phenomena, physical processes, and parameters needed to evaluate the event behaviour relative to the figures of merit linked to general design criteria. The phenomena assessment process is central to ensuring that the EM can appropriately analyse the particular event and that the validation process addresses key phenomena for that event.

b) Develop an assessment base consistent with the determined requirements: Since an EM can only approximate physical behaviour for postulated events, it is important to validate the calculational devices, individually and collectively, using an appropriate assessment base. The database may consist of already existing experiments, or new experiments may be required for model assessment, depending on the results of the requirements determination.

c) Develop the EM: The calculational devices needed to analyse the events in accordance with the requirements determined in principle a) above should be selected or developed. To define an EM for a particular plant and event, it is also necessary to select proper code options, boundary conditions, and temporal and spatial relationships among the component devices.

d) Assess the adequacy of the EM: Based on the application of principle a) above, especially the phenomena importance determination, an assessment should be made regarding the inherent capability of the EM to achieve the desired results relative to the figures of merit linked to the design criteria. Some of this assessment is best done during the early phase of code development to minimise the need for later corrective actions. A key feature of the adequacy assessment is the ability of the EM or its component devices to predict appropriate experimental behaviour. Once again, the focus should be on the ability to predict key phenomena, as described in principle a) above. To a large degree, the calculational devices use collections of models and correlations that are empirical in nature. Therefore, it is important to ensure that they are used within the range of their assessment.

e) Quality Assurance Protocol: Follow an appropriate quality assurance protocol during the Evaluation Model Development and Assessment Process (EMDAP). Quality assurance standards are a key feature of the development and assessment processes. When complex computer codes are involved, peer review by independent experts should be an integral part of the quality assurance process.

f) Provide comprehensive, accurate, up-to-date documentation: This is an obvious requirement for a credible NNR review. It is also clearly needed for the peer review described in principle e) above. Since the development and assessment process may lead to changes in the importance determination, it is most important that documentation be developed early, maintained and updated on regular basis.

4) The fulfilment of the safety requirements should be demonstrated by the necessary experimental data and analytical methods. Safety analyses evaluate and assess the facility behaviour, potential releases and consequent radiation doses during postulated design-basis and design base extension events. As such, safety analyses resolve the effectiveness of technical resolutions employed to fulfil the safety functions requirements. This should be presented in the Safety Analysis Report.

5.3 Software classification

1) It is required that an authorisation holder shall implement a system to classify structures, systems and components, software, and documentation in a clearly defined classification scheme that is based on their importance to nuclear safety and that the classification system be approved by the Regulator.
2) The software used for evaluation and calculation models must therefore be classified as either high important to nuclear safety, important to nuclear safety or not important to nuclear safety.
3) The level of verification and validation of software should be graded and commensurate with the safety classification of the software.

5.4 Design Analysis

1) The general principles stated in Sections **Error! Reference source not found.**, **Error! Reference source not found.** and 5.3 apply to the design analysis across the life-cycle of the planned system or facility and should be adhered to, as appropriate.
2) Where analyses have been carried out on civil structures to derive static and dynamic structural loadings for the design, the methods used should be adequately validated and the data verified.
3) The approach to validation and verification should consider whether the controlling physical equations have been correctly implemented into computer code, databases or spreadsheets or, in the case of hand calculations, correctly incorporated into the calculation procedures. The safety management arrangements should ensure that calculations are validated to an extent proportionate to their importance to the safety case.
4) It should be done consistent with good engineering practice taking into consideration the latest applicable international standards such as specified by ASME or IEEE.
5) Calculations involving the prediction of extreme physical behaviour often use calculation methods that are consequently often not amenable to rigorous validation. In such cases the results should be reviewed to ensure that they sensibly reflect the expected physical performance in broad terms.

6 MAIN ELEMENTS OF EVALUATION MODEL/SOFTWARE VALIDATION

In the assessment of the computer software verification and validation submissions, the applicant needs to be satisfied in a number of general areas as explained below. The extent of that satisfaction, consistent with the graded approach, depends upon the importance to nuclear safety of the software, the complexity and level of understanding of the phenomena and processes involved, and the degree of extrapolation from experiment or practical experience to the situation being modelled.

The following section lists a number of areas that should form the main elements of verification and validation, although the requirements will vary depending on the structure of the method and its application. For instance software used to carry out fault tree analysis does not model physical processes and would require consideration of only a limited number of the areas below.

6.1 Verification and Validation

6.1.1 Limits of application

1) Calculation methods are often developed to apply to a limited range of plant states. For instance different calculation methods are frequently used to model steady state operations and transient operations.
2) Similarly, in analysing a particular fault situation, different calculation methods may be used for different phases of the fault. In these situations, the calculation method may have been developed to model a definable range of physical phenomena and will not be applicable outside that range. The limits of applicability are often based on an identifiable change in the dominant physical processes which are predicted to take place.
3) The submission should indicate the dominant physical processes that are expected to be simulated by each calculation method and define the limits of application of these calculation methods.

6.1.2 Physical processes and modelling

1) Nuclear facilities and especially reactor systems, are characterised by an interaction of several phenomena which cannot be easily separated. As a first step the applicant should identify physical phenomena and define the governing processes, and the associated calculation method which models the behaviour of the system.
2) The validation submission should identify all changes in the physical processes that make the method no longer applicable.
3) The derivation of the equations used to model the various processes and the simplifying assumptions made should be fully described.
4) Modelling a physical situation requires the development of mathematical equations to describe the processes which are believed to occur. In general a number of simplifications are made to enable a tractable formulation to be made. For example, complex three-dimensional geometries may be reduced to one- or two-dimensional approximations in order to simplify the modelling. The submission should enable the assessor to follow the derivation of the controlling equations and should justify any simplifying assumptions which have been made during their derivation.

6.1.3 Numerical Methods

1) In many cases the physical complexity of the process being modelled means that a mathematical model does not have an analytical solution. Solution of the controlling equations requires numerical approximation techniques, such as finite differences and finite elements methods. The applicant should justify the solution methods used and should demonstrate the accuracy of the numerical approximation.
2) Numerical problems that can occur with such techniques should be listed along with an explanation as to why they will not invalidate the calculations which the method may be used for.
3) The codes should check that any basic conservation laws, such as for mass or energy, are indeed obeyed by the numerical scheme employed.

4) There should be a demonstration that the dimension of the nodalisation used is capable of providing a converged solution. Where such a nodalisation is not practicable, the submission should explain why any lack of convergence does not invalidate the safety argument.

6.1.4 Correlations used

1) In many cases the physical complexity of the process being modelled means that the full set of governing equations is not tractable or that it is not practicable to derive them from first principles. In these cases empirical correlations may be used to represent the essential parts of the physical process and so enable the problem to be 'closed'.
2) The applicant should provide a technical basis and justification for the use of each correlation in the range of interest to safety case calculations. As well as the accuracy of the correlation within its correlated range, it should be explained what steps are taken to prevent the correlation being used outside that range. In order to do that, the important correlation parameters should be stated along with the correlation range for each of them.
3) If a correlation is being used outside the range justified by its database, the submission should provide an assessment of the consequences on the accuracy of the calculation results.
4) When correlations are derived from experiments in scaled-down facilities the validity of extrapolating their use to the full-sized plant needs to be demonstrated by physical arguments based on dimensionless numbers such as Reynolds number, etc. Similarly the empiricism built into the correlation should be from a broad enough database to ensure applicability to all anticipated plant conditions.
5) The accuracy of the fits of correlations to the database should be shown in the submission by graphs or by analogous means
6) If correlations are used in the calculation that do not cover the anticipated plant conditions being analysed, this use should be justified.
7) Where the calculation switches between different correlation ranges or between separate correlations, discontinuities are often introduced. Any modifications required to overcome such computational difficulties should be described.

6.1.5 Comparison with experiments

1) One way of testing the combined effect of the various elements of the mathematical modelling is to compare the predictions against experimental results. Experimental comparisons tend to be of two types: 'separate effects' tests are designed to examine at the most a few phenomena which the calculation is attempting to model, while 'integral' tests are designed to enable most of the phenomena of interest to the state of the system to occur in an interactive way. These experiments should be as well instrumented as practicable so that as much as possible is known about the conditions being studied
2) Both types of test can be carried out at various scales but integral tests are usually limited to fairly small scales by considerations of cost and complexity. Both types of test should be used to validate the predictive capabilities of the computational method.
3) Exclusion of experiments which seem particularly relevant to the validation exercise should be justified.

4) Wherever possible, comparisons should be made with integral experiments at a range of scales and the ability of the calculation method to extrapolate from small scale tests to the system situation should be discussed in relation to such integral experiments

5) Many calculation methods are 'tuned' to a greater or lesser degree to results from a specific experimental facility. A calculation method that has been gradually tuned to a succession of slightly differing test cases may show excellent agreement with results from a particular facility. This excellent agreement does however not indicate its predictive capability for a range of different facilities. The verification and validation plan should therefore contain, where appropriate, 'pre-test', 'blind' or 'double-blind' calculations. A 'pre-test' calculation should be carried out prior to the test being done and has to assume appropriate test starting and boundary conditions.

6) A 'blind' calculation should be carried out after the test and should employ starting and boundary data from the actual test. A 'double-blind' calculation is a more restricted blind calculation on a facility for which the user has no prior modelling experience.

7) For comparison of software products and/or calculation models against experiment a range of well instrumented experiments is required, starting with simple representations and leading to more complex situations which try to represent the actual conditions experienced. Otherwise a justification should be presented giving the reasons why such a range is not necessary or can be otherwise limited in extent.

8) The experiments should be conducted at:

   a) a scale close to the intended application; or

   b) a range of scales to allow the appropriate scaling factor methodology and values to be determined; or

   c) a robust justification should be presented to specify why the adopted scale is satisfactory for the method under consideration.

9) The validation package should include an assessment showing that the applied experiments provide information which is significant for the validation of the respective calculation method.

10) When analysing separate effects tests, the correlations that are being tested should be identified and reference to the accuracy claimed should be made.

11) A distinction should be drawn between any database that was used to develop the correlations and that which is being used as input data for the validation exercise itself.

12) The ability of the calculation method to extrapolate from small scale tests to the plant situation should be discussed in relation to integral experiments.

13) The validation package should include comparison calculations for a range of different facilities or robust justification for the absence of such a range should be presented.

14) For both types of experiments the following basic requirements should be satisfied:

   a) The experiments should be well instrumented;

   b) They should be designed at a scale close to the conditions of the facility or otherwise be conducted at different scales suitable to allow for a meaningful extrapolation;

   c) The respective calculations should preferably be ‘pre-test’ or ‘blind’ calculations; and

d) If adjustments are made in numerical method, input parameters or calculation model in order to obtain sufficient agreement of experiment and calculation, the general applicability of these adjustments, especially for the intended design calculations, should be discussed.

6.1.6 Comparison with plant data

1) Whenever possible, calculation predictions should be compared with actual plant data.

2) Tests carried out in full-sized plants during commissioning or start-up procedures, as well as operational transients or accidents, can be a useful source of data and should, where possible, be included in the validation submission. In general plants are not as well instrumented as specially designed experiments and measurements taken from them may be too coarse to allow quantification of calculation accuracy. Such data may however be used to check the validity of computed trends as the boundary or initial conditions are parametrically varied.

3) Plant tests normally do not provide the physical conditions that occur in more severe transients and consequently any conclusions based on plant data comparisons should be drawn very carefully for such areas.

4) Any plant data comparisons included to provide calculation validation evidence should be documented in detail. This should include detailed descriptions of data uncertainties and calculation uncertainties in particular.

6.1.7 Comparison with Analytical Solutions

1) Where appropriate the submission should compare calculations with analytical solutions to benchmark problems.

2) Certain well defined problems may have established analytical or numerical solutions. Also asymptotic analytic solutions may be available for limiting cases. In the areas of structural mechanics and neutron physics for instance, numerical 'benchmark' problems already have a long tradition. The use of numerical benchmark problems will provide information on the mathematical solution ability of the calculational method rather than on the physical modelling and their value may be limited. Nonetheless it is important to ensure that numerical solution errors are small compared with modelling errors and benchmark problems may be a way of establishing bounds on these errors, albeit for limited types of problems. A numerical benchmark problem requires:

   a) the model equations to represent a well-posed mathematical problem with a unique solution;

   b) every term in the equations to be defined and written down explicitly; and

   c) the initial and boundary conditions to be defined explicitly.

3) Although these requirements limit the types of problem that can be considered, a validation submission should incorporate such comparisons or else explain why it is not appropriate to do so.

6.1.8 Comparison with alternative calculation methods

1) The applicant should, if possible, compare calculations carried out with the safety case calculation method against those obtained using alternative, independently developed methods.

This applies particularly in those areas of severe accident modelling which cannot be covered sufficiently by experiments or commissioning tests.

2) The comparison calculational method should have been developed independently of that used in the safety case and should be sufficiently different from it in either numerical methods or physical modelling to make the comparison worthwhile.

3) When the safety case is based on a proprietary computer code then comparisons should preferably be made with non-proprietary codes as these will have generally been subject to more wide-ranging scrutiny and use. If the safety case is made with a calculational method that contains gross simplifications then, where possible, more advanced methods should be used in the comparison to demonstrate that the simpler method is taking adequate consideration of the dominant physical phenomena.

4) The alternative calculation method used for comparison should include or reference a statement about its validation, since comparisons against a demonstrably unreliable calculation would be pointless.

6.1.9 Biased Calculations

1) Uncertainties in the representation of important physical processes may be such that pessimistic models of these processes are deliberately built into the calculation procedure. Any claim to conservatism in such modelling should be justified.

2) Unless otherwise stated, conservatism should mean that the calculated relevant safety parameters (e.g. temperature, pressure, radiation field, strain etc.) are biased on the conservative side throughout the calculation for the whole spectrum of operational or fault conditions being modelled.

3) The validation of biased methods against experiment can raise particular difficulties since the pessimisms may introduce features into the calculations which do not correspond with what is seen in the test. In order to make meaningful comparisons with experiment, sensitivity studies should be necessary in which calculations are made with any deliberately pessimistic bias removed from selected parts of the modelling.

6.1.10 Best estimate calculations

1) The modelling should provide a realistic calculation of any particular phenomenon to a degree of accuracy compatible with the current state of knowledge of that phenomenon.

2) The neglect or simplification of any phenomenon should not be treated by including a deliberate pessimism or bias but should form part of an assessment of the overall modelling uncertainty.

3) Deriving the overall uncertainty for a best estimate calculational method may be a difficult undertaking. The combined uncertainty from all the individual models within the procedure is not necessarily the total uncertainty for the calculation. Uncertainties also come from applying models derived from small scale experiments to the full-sized plant (scaling uncertainties) as well as from the uncertainties associated with the input boundary and initial conditions. In arriving at the overall calculational uncertainty all such sources should be taken into account.

4) The methodology used to combine the various sources of calculational uncertainty should be described and justified.

5) For complex calculational methods a rigorous derivation of an uncertainty 'response function' (i.e. the response of the calculation to arbitrary uncertainty variations in the constituent models) would usually involve excessive numbers of sensitivity studies and alternative approaches will generally involve judgement of which 'dominant phenomena' or 'key models' may need to be considered. The bias for any such judgements should be clearly stated.

6) The methodology used to combine the various sources of calculation uncertainty should be described and justified.

7) For each parameter that is judged to be of relevance to the derivation of the overall uncertainty, justification should be provided for the assumed uncertainty distribution of that parameter.

6.2 Quality Assurance

6.2.1 General

1) There is a need to establish that the computer code correctly represents the physical model by ensuring that a systematic approach has been adopted for designing, coding, testing and documenting the computer program. In this respect relevant industry standard should be adopted as a guide against which the degree of assured quality can be judged.

2) All activities related to verification and validation of software products and input data should be carried out by suitably qualified and experienced staff who are sufficiently independent of the software developers and the persons who compiled the input data.[3]

3) Independent staff may be an independent team / department of the user's organisation or an external organisation. In this guidance both of them will be subsumed under the term 'V&V team'.

4) Involvement of the software developers themselves in the V&V activities is permissible but it is recommended that:

   a) The V&V plan and results of V&V efforts are reviewed independently;

   b) Checking of calculation/analyses should be performed by competent independent staff. (It is recommended that the bulk of V&V analysis is performed by independent staff since this also re-enforces the desire for comprehensive software documentation);

   c) The Software configuration management is independently checked and

   d) The V&V work management is not the responsibility of any of the developers.

5) Where a multi-level software classification scheme is applied the amount and type of V&V should be justified with respect to the importance classification of the program. For QA-purposes the division of responsibilities between software developers/users and the V&V-team should be specified in the V&V Plan.

6) The efforts to verify and validate software products should be documented adequately. Elements of a comprehensive documentation are V&V plans, interim V&V reports where appropriate, and final V&V reports. All this documentation should be available to the NNR.

[3] Sufficient independence is given if the persons are not the same and the V&V process is managed independently and is not distorted by resource or other constraints arising from undue pressure for completion.

6.2.2 Computer software quality assurance

1) All computer codes should be verified and validated for a particular hardware and software configuration as well as a particular engineering application.
2) The submission should contain a Validation and Verification report for the particular hardware and software configuration used.
3) This should list details of the hardware on which the code was run and version numbers for the supporting software such as compiler, linker, loader, library routines and operating system.
4) Evidence that the hardware and software have been suitably verified and validated should be provided.
5) For a high level of assurance, the computer programming language should conform to the appropriate national and international standards.
6) The computer programming language used and its extensions should conform to the appropriate national, international or de-facto standards. Exceptions which may be made for COTS or Legacy Software should be justified. New coding added to Legacy Software should conform to the addressed standards unless it is a very limited alteration to existing routines and thereby avoids an extensive amount of recoding for cases where this would carry a greater risk of introducing errors or undesired numerical results changes.
7) The algorithms used should maintain the required numerical precision and should preferably be free of numerical instabilities. If any known numerical instabilities are present the approach taken should be justified.
8) User manuals should be suitable for their purpose and of an appropriate standard.
9) Evidence that the software has been produced and maintained to the required standard for the application should be recorded to allow for potential inspection by third parties.
10) It should be demonstrated by the applicant that the sections of software used in the generation of the results have been adequately tested.
11) In the case of non-trivial validation schemes a validation matrix linking the diverse calculation models and the applicable experiments should be included.

6.2.3 Data quality assurance

1) The procedures for the derivation of the input data for the computer codes should also follow rigid validation procedures and should be auditable so as to assure their quality.
2) Each item of data should have a clearly defined origin within the plant documentation or else its source should be identified and justified. Details and justification should be given of embedded data.
3) Since it is often impossible to check manually the integrity of input data, there should be suitable measures, where feasible, within the computer code to trap input data errors and erroneous results.
4) When analyses are performed with Evaluation Models employing individual programs consecutively or together, special care should be taken to document and ensure a correct and

transparent transfer of data at the interfaces between the individual programs. Wherever possible, such transfer should be automated.

5) Initial conditions and boundary conditions imposed on the calculation should be assessed to demonstrate their suitability and the related documentation should be made available to the NNR.

6) If safety analyses are performed by means of software using Graphical User Interfaces (GUI), the program(s) should automatically record the program version details, all input used to control the program's operation, all data used for the calculation and a copy of significant output in log file(s) to be kept for the QA trail. The required content items for this file are analogous to those for non-GUI programs. GUI programs which cannot record these details should not be used for safety analysis.

6.2.4 User Proficiency

1) The applicant should demonstrate the competence of the users to model adequately the plant and to analyse the results produced by the calculation method.

2) Any initial deficiencies in software user experience level and knowledge should be addressed by suitable training and experience development and such experience or knowledge should be maintained to allow for any later required additional analysis work.

3) The licensee's validation submission should contain sufficient information to enable the NNR to make a judgement on the proficiency of the user

4) Analysts and users of computer codes should have a good knowledge of the:

   a) plant systems;

   b) phenomena addressed, applicability of the models, and their limitations; and

   c) meaning and significance of the input and output variables.

5) It is also very important that the applicant's organisation is set up to support the proficient users. There should be adequate procedures for reviewing calculation methods and data used in them by suitably qualified experts. The licensee is expected to establish suitable peer review groups with relevant experience in interpreting experimental and plant data. These groups should endorse the codes, their application to the problem in hand and the competence of the users.

6.3 Configuration Management

1) Evidence should be included that adequate procedures are in place to control the production and maintenance of the software products, in particular change control and issuing of correct versions. Collectively these procedures are known as Configuration Management. Calculations performed to support the safety case should only use software products following such procedures.

2) Main elements of a software configuration management are:

   a) It should be ensured that a software system and its components, specifications, verification evidence and descriptive documentation are all mutually identified and at a known status (defined by issue/revision/version identifiers) and are contained in a suitable database.

b) A software configuration control system should be established with a datum defined as a configuration baseline from which all amendments and/or changes should be controlled.

c) The physical security of source codes should be assured in order to prevent unauthorised changes.

d) Software configuration should be checked against hardware configuration to ensure mutual compatibility.

e) Controls should be established to record changes of the configuration status.

f) The configuration system should only permit sanctioned program versions to be used.

g) Provisions should be made for informing all personnel of the latest changes to the software and/or documentation.

h) A master configuration list should be established containing all configured items together with their current configuration status and identification of all associated documentation. In order to limit the scope for inadvertent changes that list should be prepared automatically from the database.

7 V&V METHODOLOGY

7.1 General

1) The scope of the measures for V&V depends on the level of confidence already established for the respective software and should be based on the following items:

   a) Status of program documentation;

   b) Current level of documented V&V status;

   c) Past experience;

   d) Comparability of application; and

   e) Difference between the level of importance and the level of established V&V status.

2) The level and type of V&V activities depend on the type of software to be validated and the application of the software. It is important to note that the V&V activities should cover all of the EM safety analysis calculation applications.

7.2 Scope of V&V measures

1) The scope of V&V measures should cover the following aspects in particular:

   a) The description of the considered physical/chemical phenomena should be reviewed and their range of applicability evaluated.

   b) The adequacy of the mathematical model for the class of problems to be analysed and any justification of idealisations and simplifications should be evaluated.

   c) Any claim to conservatism of the mathematical model should be justified and possibly be quantified in order to allow for a meaningful analysis of uncertainties of a given calculation. It has to be kept in mind that, in complex calculations, conservatism in the modelling of a single

phenomenon might well lead to misleading sequences of events, unrealistic transient time-scales being predicted and some physical phenomena being missed.

d) The adequacy of the solution algorithms and numerical models for the class of problems to be analysed should be evaluated with special attention to convergence and stability of solution.

e) If empirical correlations are used, the methods used to prevent or notify use of the correlation outside its definition range should be described. For complex correlations flow charts should be provided showing their implementation in the calculation. Where the calculation may switch between different correlation ranges, discontinuities may be present. Any modifications to overcome such computational difficulties should be described.

f) Sensitivity studies should be performed with the software in order to clarify important parameters and more generally to seek evidence about any cliff edge effects.

   i) If identified cliff edges remain in the software being used in the safety analysis then justification for this approach should be presented

   ii) Sensitivity analysis can also be used to provide information as part of an Uncertainty Analysis to determine best estimate plus uncertainty results to the required confidence level.

g) The source code should be programmed according to good programming practices in order to ease understanding of the code and to allow its portability to other operating systems and compilers as well as to other hardware environments.

h) The Program Documentation should be verified to ensure that it has been completed, conforms to established standards, and is a clear and correct description of the completed computer program.

i) The software should be designed in a way to allow effective user control of input processing. It should be furnished with suitable measures to trap input data errors.

j) The software should check basic conservation laws globally as well as locally and issue warnings should violations occur. Relevant output data should be processed to easily understandable formats, additional output should be available to facilitate review and plausibility checking. It is important that the program output should include run time/date and particularly code version information.

k) It should be assured that the software is compatible with the hardware and the operating system (and version) of the computer installation on which it shall be run. The algorithms used should maintain the required numerical precision and should preferably be free of numerical instabilities. If any known numerical instabilities are present the approach taken should be justified.

7.3 Verification – General Methodology

1) In order to verify whether the software is programmed in a way that satisfies the specified requirements, program tests should be performed.
2) The verification activities for software should include the verification of the selected numerical algorithm and the verification of the coding itself, i.e. proof that it is to a reasonably achievable degree free from programming errors.
3) Software testing methods should include static analysis and dynamic testing methods where the former analyse the form, structure, and consistency of the program without executing it while the latter involve execution of the program.

7.4 Validation – General guidance

1) Software programs that model physical processes should be validated in order to prove that they predict these processes correctly.
2) There are several options for performing this validation and the combinations of options yielding the desired level of validation should be chosen and these documented and justified in the V&V documentation. The particular options are described in paragraphs 6.1.5, 6.1.6, 6.1.7 and 6.1.8.
3) In cases where a satisfactory validation is not achieved or not achieved in time for particular licensing stages, additional margins have to be introduced into the respective safety relevant calculations. These margins should be justified dependent on the degree of validation achieved.

7.5 Development of new software

1) The application domain for the modeling and simulation capability should be well understood and carefully defined, and the accuracy requirements should be known for the applications of interest.
2) A validation tier hierarchy, including the validation pyramid, should be carefully constructed using a systems engineering approach.
3) A Phenomena Identification and Ranking Table (PIRT) should be constructed to identify and rank the importance of physical processes and interactions of processes for all tiers and faces of the validation pyramid.
4) Code verification activities should be defined and prioritised, schedules set, and needed resources allocated.
5) Software quality assurance procedures should be defined, implemented, consistently adhered to, and documented.
6) Using the results of the PIRT, model validation activities, both computational and experimental, should be defined and prioritised, schedules set, and needed resources allocated.
7) Validation metrics should be carefully defined with requirements stated, and clearly connected to modeling and simulation requirements for the application domain.
8) Statistical data for both computational and experimental results should be used for the validation metrics to precisely quantify the accuracy of the model for all validation experiments.

9) For software which is still to be developed, it is advantageous to perform verification (in particular) and validation (if possible) of software components as they are created throughout the overall development process.

10) The plan for software development and associated V&V should typically include the following phases:

   a) Initiation Phase

   b) (functional) Requirements Definition Phase

   c) Design Phase

   d) Coding Phase

   e) Integration and Testing Phase

   f) Installation Phase

7.6 V&V of Legacy software

1) The scope of V&V efforts for Legacy Software should be based on an assessment of already existing V&V documentation. The following sub-sections detail recommendations for such an assessment.

7.6.1 Verification

1) A summary of all program tests carried out by the developers or by users and the test results should be compiled, and be available for use in the verification process. The summary should be reviewed to determine the adequacy of test coverage. The test coverage may be considered adequate if:

   a) A sufficient number of tests has been carried out to test all program requirements

   b) Sufficient tests representative of anticipated program applications are included

   c) Important design features and major logical paths are tested

   d) The results of the tests are satisfactory

2) Depending on the specifications in the V&V plan, the V&V team may decide to repeat some of the developer and user tests, and to conduct additional ones if the test coverage is found to be inadequate. These decisions should be justified and documented in the V&V documentation.

3) The test results should be reviewed to determine that all program requirements have been tested and that no significant discrepancies exist between results obtained by the V&V team, the developers or the users.

7.6.2 Validation

1) The V&V team should also compile a summary of all available validation calculations which have been performed by the developers and users and their results.

2) The summary should be reviewed to determine whether it covers adequately the scope and range of application of the physical processes to be considered. The results of the available

validation calculations should be evaluated with respect to their significance and the degree of agreement between calculation and experiment, benchmark or analytical solution.

3) Depending on the results of the review/evaluation of existing validation efforts and depending on the specifications in the V&V Plan, additional validation efforts may be required and should then be specified accordingly.

7.7 V&V of COTS Software

1) V&V efforts for COTS software should be similar to those for legacy software. In both cases the software exists and related documentation should also be available.

2) As with legacy software, V&V activities for COTS software should start with a clarification of the software V&V status and the proposed use of the software. The results of this clarification and emerging requirements for additional V&V efforts should be incorporated in the V&V Plan and subsequent V&V documentation.

3) If the existing Program Documentation including documentation of software verification and of validation test calculations is judged to be sufficient with regard to the intended application of the software, V&V may focus mainly on applicability of the system model, input, and user qualification.

4) The use of spreadsheets could be justified for simple evaluation and calculation models and where it can be demonstrated with high confidence that human error is eliminated. Spreadsheets should be avoided where practical for routine calculations and complex evaluation models.

7.7.1 Verification

1) Typically no source code is available for COTS software.

2) In this situation verification activities independent of the software supplier are restricted to black box testing and those types of algorithm testing which do not depend on source code access. As the capability for independent software verification is typically limited, an assessment of the documented QA measures undertaken by the software supplier is appropriate.

3) Depending on the verification documentation provided by the software supplier, the V&V team should decide and justify in the V&V documentation which parts of the verification testing should be performed or repeated independently.

4) Subject to their importance for the safety case, COTS Software without sufficient confidence in their verification process should be excluded from safety analyses.

7.7.2 Validation

1) The review of existing validation documentation should lead to the identification of those items which are not adequately covered by the existing validation calculations and which therefore require additional validation test calculations.

8 DOCUMENTATION

8.1 General

1) In order to assess the verification and validation of software used in design and/or safety analyses the submission (validation package) should cover:
   a) limits of application;
   b) details of models used;
   c) details of numerical methods;
   d) correlations used;
   e) details of comparisons with experimental data;
   f) details of comparisons with plant data;
   g) comparison with analytical solutions;
   h) details of comparisons with other calculational methods;
   i) biased calculations;
   j) quality assurance;
   k) user proficiency and support;
   l) shortcomings and proposed sensitivity analyses.

8.2 Clarification of V&V Status

1) For existing software the first step should involve the identification and assessment of the available documents linked to software development such as:
   a) Program Documentation based on the guidance listed in references [10] and [12];
   b) Functional Requirement Specifications;
   c) Design Specification; and
   d) Test Plan and Test Results.
2) If formal documents on development and V&V are not available, they should be reconstructed where possible.
3) Based on the assessment results and the requirements of current application, complementary measures should be defined to bring the V&V up to the appropriate standards.

8.3 V&V Plans

1) V&V Plans, interim and final V&V Reports are identified as elements of the appropriate comprehensive documentation.
2) Having clarified the status of the software to be verified and/or validated, a Software V&V Plan (SVVP) should be produced addressing the following items:
   a) Identification and classification of the software to undergo V&V
   b) Reasons why retrospective V&V is to be performed
   c) Scope and objectives for the level of V&V selected

d) Existing documents on software development to be used for review

e) Availability and use of user experience

f) Actions to be taken to supplement missing or unavailable development products

g) Time schedule of V&V activities and milestones

h) V&V project organisation

i) V&V project management

3) For documentation of the results the following information should be included in V&V Reports:

a) Summary of V&V performed

b) V&V results

4) Any recommendations and requirements for additional efforts should immediately be fed back into the SVVP by issuing a revised SVVP version.

5) For QA-purposes the results of the V&V process should be reviewed by the V&V-team and the review should be documented in a Final V&V Report. The review documentation should include the following issues:

a) Completeness of the V&V Plan, especially of the identified or reconstructed program requirements

b) Verification efforts: Test coverage and evaluation of test results

c) Validation efforts (comparison to analytical solutions, benchmarks, other software, experiments, or plant data) and evaluation of validation results

6) The V&V-Plans (prior to execution and if necessary, also revised versions) and the Final V&V-Reports should be submitted to the NNR at the appropriate stage of authorisation or as required for modifications.

9 GUIDELINES FOR AUTHORISATION STAGES

9.1 General

The above guidance is applicable to all computer codes used in important to safety design and safety analyses. However, it is recognised that in special cases such as new nuclear facility projects a stage licensing process could be applied and the demonstration of conformance to this guidance can be spread across licensing stages as indicated in this Section 9. This is also consistent with Item (6) in Part 5, Section 2 of the draft NNR General Nuclear Safety regulations, which states:

“(6) Where an applicant adopts a multi-stage approach to licensing for nuclear facilities, each stage of licensing shall be supported by a safety case addressing the aspects important to safety …”

Similar to such levels of maturity of the safety case associated with each stage of licensing, there are corresponding levels of maturity of V&V associated with each stage of licensing, as is indicated in Sections 9.2 to 9.5 below.

In general the scope and depth of analysis will increase with each licensing stage as the required level of design detail increases. This implies in particular that system models to be applied to safety analysis during an early licensing stage usually cannot provide the level of detail and input data

accuracy that is achievable at later licensing stages. The usual approach to cope with these uncertainties is to introduce additional margins or other mitigation measures. The verification and validation of system models required for the individual licensing stages will take the individual levels of detail into account and consider margins and mitigation measures. This is addressed by the use of the particular definition given for 'System Model data Validation' in Section 4.1.

Note: *It should be borne in mind that the guidance in Sections 9.2 to 9.5 is written for the case of a stage licensing process of a new nuclear facility project where the design of the new nuclear facility is considered to be quite novel or deviating significantly from a design associated with a previously authorised nuclear facility. In case the design of a new nuclear facility does not deviate significantly from a design associated with a previously authorised nuclear facility, much of the guidance in Sections 9.2 to 9.5 could be simplified, for example, by viewing many of them in a checklist fashion instead of an exercise wherein such compliance/adherence activities have to be unnecessarily repeated.*

9.2 Stage 1: Nuclear Licence to Site or Authorisation to Design

1) For the acceptance of the safety case associated with the nuclear licence to site or an authorisation to design, the process should include information focused on the software used for demonstration of the safety case. Reference can be made to past experience if justification of applicability can be given based on the criteria below.
2) For all calculations included in the safety case, the following activities should have been performed:
    a) The governing phenomena should have been identified and documented as discussed in Section 6.1.2;
    b) Appropriate mathematical formulations should have been selected;
    c) Selection (and potentially classification) of appropriate software should have been performed;
    d) If the phenomena constituting a physical process have been analysed separately then the separation of phenomena should be justified, the interfaces should be discussed, and increased safety margins should be applied which have to be documented and justified;
    e) The following steps of software V&V should be performed:
        i) Clarification of the V&V status;
        ii) Production of a V&V plan (including a validation matrix for non-trivial validation schemes)
        iii) The V&V plan should have been executed at least to the following degree:
            (1) Software Documentation should exist in at least a basic form;
            (2) the software should be verified at least in those aspects used in the safety case calculations;
            (3) the status of existing validation calculations (e.g. of HTR-applications in the past) should be clarified. At least basic validation efforts should exist or should be performed. If the existing validation calculations have been judged insufficient regarding scope, accuracy and coverage, then higher safety margins have to be

introduced into the calculations. The extent of any such margins or biases should be described and justified.

f) V&V of used system models should have been performed;

g) V&V of the output processing should have been performed:

i) Basic output written by software should be verified as representing the correct quantity with correct units; and

ii) Post-processing software applied to software results and related input and output should be verified to ensure correct operation of all interfaces;

h) In case of insufficient validation status of the software higher safety margins should be introduced. These higher margins should be fully documented and justified;

i) Documentation should be issued for all of the activities associated with the above guidance and be available to NNR;

j) Qualification of the software users should have been performed; and

k) For software models classified as important to nuclear safety and where only a subset of the models are being verified, validated, and used, details of how it is ensured that other models do not affect any safety analysis results should be presented.

9.3 Stage 2: Construction and Installation or Authorisation to Manufacture (Preliminary Safety Assessment)

1) In order to allow issue of a stage 2 licence the following guidance should be followed:

a) The guidance for Stage 1 should have been met;

b) All software products to be applied in the safety and design analysis process should have been determined;

c) The identification of governing phenomena should have been finalised and reviewed;

d) The selection of appropriate mathematical formulations and selection of appropriate programs should have been completed for all software to be used for safety analysis calculations;

e) Satisfactory V&V should be presented for all software to be used for safety and design analysis calculations;

f) Where a V&V plan was not executed completely, for example because required validation experiments could not be performed in time, the particular V&V status should have been assessed and correspondingly increased safety margins should have been introduced into the safety analysis calculations. Such extra margins should be fully documented and the chosen levels justified;

g) Where the extent of the V&V completed is less than that planned the safety case submission should clarify the following factors:

i) The missing V&V evidence;

ii) The reasons why the evidence is missing;

iii) The expected timescale for this evidence to become available;

iv) The expected evidence that will be obtained from the additional V&V when it is completed;

v) The impact on the safety case of this missing evidence;

vi) Clarification of the alterations made to the safety case to handle the absence of this additional V&V evidence;

vii) Clarification and justification for additional margins or other measures made to satisfy the safety criteria for the current safety case;

h) In all cases the safety case presented should be self-consistent so that the V&V evidence presented is sufficient to underwrite all of the modes of plant operation considered;

i) The following activities should have been extended to all safety analysis calculations:

i) V&V of used system models should have been performed; and

ii) V&V of output processing should have been performed:

(1) Basic output written by software should be verified as representing the correct quantity with correct units; and

(2) Post-processing software applied to software results and related input and output should be verified to ensure correct operation of all interfaces.

j) Related documentation for all of the above guidance should have been issued.

k) Qualification of software users should have been performed. All users should have adequate levels of experience or training to enable the analysis to be performed to a satisfactory standard.

9.4 Stage 3: Fuel on Site, Fuel Loading, Testing and Commissioning (Preliminary Safety Assessment)

1) In order to allow issue of a stage 3 licence the following guidance should be met:

a) The guidance for the stage 2 licence should have been met.

b) The validation efforts should have been completed and Final V&V Reports should have been issued for all software used for safety and design analysis calculations.

c) However, additional subsequent system data validation efforts are allowed if it is wished to reduce or remove certain mitigation measures included in earlier submissions. These will be reviewed on a case by case basis and should be performed to the same overall standards and requirements as earlier submission work (or any higher standards that are then in force).

d) Any new calculations performed after a stage 2 licence to provide new validation evidence should have been submitted to the same V&V efforts regarding all aspects of the relevant Evaluation Models (including software V&V) and user qualification as discussed for stages 1 and 2 licensing.

9.5 Stage 4: Plant Operation (Final Safety Assessment)

1) It is expected that all aspects of Evaluation Model V&V should have been completed at earlier licensing stages.
2) However where V&V programmes were not fully completed in the earlier Stages and extra safety margins were introduced for the safety case to address the deficiency, further V&V evidence may now be available either from extra experimental test facilities or from plant commissioning data in particular.
3) Consideration will be given to proposals in the Stage 4 SAR to reduce or eliminate the extra margins introduced earlier based on new validation evidence.
4) New V&V evidence should meet equivalent V&V content guidance to those applied in the earlier licensing Stages.

10 REFERENCES

The following references were consulted during the compilation of this document:

[1] Act No. 47, 1999, National Nuclear Regulator Act

[2] Regulations in terms of section 36, of the National Nuclear Regulator Act, 1999 (Act no. 47 of 1999), on Safety Standards and Regulatory practices (GN R388).

[3] Verification, Validation, and Predictive Capability in Computational Engineering and Physics, William L. Oberkampf et al., Foundations for Verification and Validation in the 21st Century Workshop, October 22-23, 2002

[4] Portability of Scientific and Engineering Software, ANSI/ANS-10.2-2000

[5] Documentation of Computer Software, ANSI/ANS-10.3-1995

[6] Guidelines for the Verification and Validation of Scientific and Engineering Computer Programs for the Nuclear Industry, ANSI/ANS-10.4-1987 (R1998)

[7] Manual on Quality Assurance for Computer Software Related to the Safety of Nuclear Power Plants, IAEA Technical Reports Series No. 282, Vienna 1988

[8] Software for Computer Based Systems Important to Safety in Nuclear Power Plants, IAEA Safety Standards Series No. NS-G-1.1, Vienna (2000)

[9] USNRC, “Verification, Validation, Reviews, And Audits For Digital Computer Software Used in Safety Systems of Nuclear Power Plants”, Regulatory Guide 1.168, September 1997

[10] Documentation of Computer Software ANSI/ANS-10.3-1995