NUCLEAR SAFETY DIRECTORATE - BUSINESS MANAGEMENT SYSTEM		
TECHNICAL ASSESSMENT GUIDE **CONTAINMENT: VALIDATION OF COMPUTER CODES AND CALCULATIONAL METHODS**		**T/AST/042** ISSUE 001
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1. Purpose and scope

1.1 This Technical Assessment Guide (TAG) provides advice to assessment inspectors on the interpretation of the Safety Assessment Principles **[1]** covering the validation of computer codes and other calculational methods used by the licensees to perform plant analysis in support of their safety cases. This guide expands the principles so as to give guidance on what the NII assessor should expect to see in a validation statement which a licensee produces in support of a code or calculational method used within a nuclear safety case.

1.2 This assessment guide is intended to apply primarily to the assessment of the validation of physics, thermal hydraulics and system analysis computer codes and calculational methods used within the safety design basis. Calculations of beyond design basis conditions involve the prediction of extreme physical behaviour and the calculational methods used are often not amenable to rigorous validation. Nevertheless, any validation submission for beyond design basis calculational methods should conform in a general way to the guidance given in this TAG.

1.3 With respect to Computational Fluid Dynamics (CFD) analysis methods, which have special application, **Appendix 1** provides guidance to assessors of safety cases on the main issues which should be covered in CFD submissions, and their significance.

1.4 This TAG is not directly applicable to the assessment of the validity of software used for control and protection of operational nuclear plant and processes. Neither is it intended that this guide be applied to the validity of codes and standards of the type often employed in traditional engineering applications.

1.5 This TAG contains *guidance* to advise and inform NSD inspectors in the exercise of their professional regulatory judgement. Comments on this guide, and suggestions for future revisions, should be recorded on the appropriate registry file.

2. SAPs addressed

2.1 The NII Safety Assessment Principles (SAPs) address computer codes validation in SAPs 86 to 89. A discussion on the interpretation of these SAPs is given in sections **4.10**, **4.13**, **4.17** and **4.19** respectively.

3. Relationship to licence and other relevant legislation

3.1 Licence Condition 14 - Safety documentation

requires the implementation of adequate arrangements for the production of safety cases. Computer code analysis of plant design and operation forms an important part of a modern safety case. The computer codes should be validated prior to their use in the production of safety cases.

3.2 Licence Condition 19 - Installation of new plant

requires validated computer codes and calculational routes to demonstrate the safety of the plant.

3.3 Licence Condition 22 - Modification or experiment on existing plant

requires the implementation of adequate arrangements for the modification or experiment on existing plants. Computer code analysis of plant modifications forms an important part of the supporting safety cases. The computer codes should be validated prior to their use in the production of safety cases.

3.4 Licence Condition 23 - Operating rules

Licence Condition 24 - Operating instructions

LC23 requires the production of an adequate safety case which identifies the necessary operating rules and operating conditions. The adequacy of these rules and conditions are often demonstrated by computer codes analyses of design basis faults.

3.5 During the Sizewell B Public Inquiry, a public statement on the Inspectorate's requirements was made in a submission to the inquiry's QC **[2]**.

4. Advice to assessors

4.1 Definition

1) Validation is the testing and evaluation of the whole system at the completion of its development to ensure compliance with the requirements specified. In fault analysis, validation can be defined as the evidence which demonstrates that the computer code or calculational method is correct by comparison of models with experimental or other available data.

2) Verification is the process of ensuring that the controlling physical equations have been correctly translated into computer code or, in the case of hand calculations, correctly incorporated into the calculational procedures.

3) Quality Assurance is the act of reviewing, inspection, testing, checking, auditing or otherwise determining and documenting whether or not items, processes, services or documents conform to specified requirements.

4.2 The Inspectorate expects a licensee to present a validation statement for each of the calculational methods used in its safety case. In the assessment of the licensee's validation submission, the NII assessor needs to be satisfied in a number of areas as explained below. The extent of that satisfaction will depend on how important the calculational method is judged to be to the safety case.

4.3 An assessor should be aware of where the calculation fits into the overall estimate of risk and the safety case. Also the NII assessor should have an understanding of the confidence level that is required of any calculated results. That is, the confidence with which it can be stated that the actual result during the specified fault will be no worse than the calculated results.

4.4 A submission should ideally quote and substantiate confidence levels for its calculations. Where that is not practicable, a submission should, by breaking sample calculations down into manageable parts, provide enough information to allow a judgement to be made that the results are suitably conservative.

4.5 A submission should also identify the shortcomings in the computer code method of solution, the associated physical models and the inaccuracy in the experimental date used in the validation work. This information should be used to define sensitivity analyses to be performed as part of a plant analysis safety case. The object of such analyses is to confirm and demonstrate that “cliff-edge effects” do not exist. The sensitivity analyses should cover the uncertainties / approximation in the mathematical models, experimental data and boundary conditions.

4.6 An additional consideration will be the extent to which the calculational method has been approved for use in safety case calculations by relevant committees. Methods developed within the UK nuclear industry will generally have been subjected to detailed examination by expert committees and a particular version is usually approved for use in specified applications. An endorsement of a calculational method for safety case calculations by the licensee's own safety assessors would add further weight to any accompanying validation package provided the usage is within the conditions of the endorsement.

4.7 The following paragraphs list a number of areas, which the Inspectorate would expect to form significant elements of a validation package. It is recognised that requirements will vary depending on the structure of the method and its application. For example, codes used to carry out fault tree analysis do not model physical processes and would not therefore require consideration against all of the items listed in the next paragraph.

4.8 In order to fully meet the requirements of the SAPs (and interpretation of SAPs) given above a validation submission (validation package) should cover:

1) limits of application;

2) details of models used;

3) details of numerical methods;

4) correlations used;

5) details of comparisons with experimental data;

6) details of comparisons with plant data;

7) comparison with analytical solutions;

8) details of comparisons with other calculational methods;

9) biased calculations

10) quality assurance;

11) user proficiency and support;

12) shortcomings and proposed sensitivity analyses.

Each of these items is discussed in more detail in the following paragraphs.

4.9 Limits of application

The submission should define the limits of application of the calculational method and indicate the dominant processes which are expected to occur in any situation to which it is applicable. Calculational methods are often developed to apply to a limited range of plant states. For instance different calculational methods are frequently used to model steady state operations and transient operations. Similarly, in analysing a particular fault situation, different calculational methods may be used for different phases of the fault. In these situations the calculational method may have been developed to model a definable range of phenomena and will not necessarily be applicable outside that range. The limits of applicability are often based on an identifiable change in the dominant processes which are predicted to take place. The validation submission should therefore define the processes which the calculational method is designed to model and should identify the changes in those processes which make the method no longer applicable.

4.10 Details of physical models used

The derivation of the equations used to model the various processes and the simplifying assumptions made should be fully described. 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.

4.11 Numerical methods

In many case the physical complexity of the process being modelled means that a mathematical model cannot be derived. Solution of the controlling equations requires numerical approximation techniques, such as finite differences and finite elements methods. The submission should justify the solution methods used and should demonstrate the accuracy of the numerical approximation. 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 for. The codes should check that any basic conservation laws, such as for mass or energy, are indeed conserved by the numerical scheme employed. There should be a demonstration that the nodalisation used is fine enough to provide 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.

4.12 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'. The validation submission 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.

2) If a correlation is being used outside the range justified by its database, the submission should provide an assessment of the effects on the accuracy of the calculational results. 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 wide enough data base to ensure applicability to all anticipated plant conditions.

4.13 Comparison with experimental data

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 reactor situation to occur in an interactive way. Both types of tests 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. Assessors need to be particularly wary of the selective use of experiments in the validation submission and should seek justification for the exclusion of experiments which seem particularly relevant.

2) When analysing separate effects tests, the correlations that are being tested should be identified and reference to the accuracy claimed under item **4.12** above should be made. A distinction should be drawn between any data base that was used to develop the correlations and that which is being used as input data for the validation exercise itself. Wherever possible, comparisons should be made with integral experiments at a range of scales and the ability of the calculational method to extrapolate from small scale tests to the reactor situation should be discussed in relation to such integral experiments.

3) Many calculational methods are 'tuned' to a greater or lesser degree to results from a specific experimental facility. Tuning is 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. A calculational method that has been gradually tuned to a succession of slightly differing test cases may show excellent agreement with

results from a particular facility but this does not indicate its predictive comparison calculations for a range of different facilities and should contain, where appropriate, 'pre-test', 'blind' or 'double-blind' calculations. A 'pre-test' calculation is carried out prior to the test being done and has to assume appropriate test starting and boundary conditions.

4) A 'blind' calculation is usually carried out after the test and will 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.

4.14 Comparison with plant data

Tests carried out in full sized plant 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 calculational accuracy. Such data may however be used to check the validity of computed trends as the boundary or initial conditions are parametrically varied. Plant tests generally do not provide the physical conditions which occur in more severe transients and conclusions based on such comparisons should be carefully drawn.

4.15 Comparison with analytical solutions

1) 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:

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

ii) every term in the equations defined and written down explicitly and

iii) the initial and boundary conditions defined explicitly.

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.

4.16 Comparison with other calculational methods

In addition to comparing the calculations with experiments, useful information can be obtained by comparing one calculational method against another. 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. Clearly comparison with a calculational method which is a derivative of, or very similar to that used in the safety case would not necessarily yield useful results. The calculational method used for comparison will also need a statement about its validation, since comparisons against a demonstrably unreliable calculation would be pointless. 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.

4.17 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 calculational procedure. Any claim to conservatism in such modelling should be justified. Unless otherwise stated, conservatism should mean that the calculated relevant safety parameters (e.g. temperature, pressure, radiation field, strain etc.) is biased on the conservative side throughout the calculation for the whole spectrum of operational or fault conditions being modelled. 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 may be necessary in which calculations are made with any deliberately pessimistic bias removed from selected parts of the modelling.

2) Best estimate calculations.

i) A best-estimate calculation employs modelling that attempts to describe realistically the physical processes occurring in the plant. 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. 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.

ii) 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.

3) The methodology used to combine the various sources of calculational uncertainty should be described and justified. 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. For each parameter, which 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.

4.18 Assurance of quality

1) Additional to the justification of the modelling process, 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 the American Nuclear Society has produced a useful guide against which the degree of assured quality can be judged, namely, ANSI/ANS-10.4-1987 **[7]**.

2) Also, a computer code should be validated and verified for a particular hardware and software configuration as well as a particular engineering application. The submission should contain a Validation and Verification Report for the particular hardware and software configuration used. 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 and library routines. Evidence that the hardware and software have been suitably qualified should be provided. For a high level of assurance, the computer programming language should conform to the appropriate national and international standards.

3) User manuals should be suitable for their purpose and of an appropriate standard: IEEE Standard 1063 **[8]** gives guidance on the content of software and user documentation against which the submission can be judged.

4) Evidence that the software has been produced and maintained to the required standard for the application should be sought. For example, conformance with ISO 9000 series **[3,4,5]** will indicate that good programming practices have been used.

5) It should be demonstrated in the submission that the sections of code used in the generation of the results have been adequately tested (**Reference 4** gives guidance). Further support could include sample problems and benchmark files.

6) Evidence should be supplied that adequate procedures are in place to control the production and maintenance of the computer code used in the submission. In particular there should be auditable controls over how source code can be amended and new versions issued. Collectively these procedures are known as Configuration Management. Compliance with relevant company, national and international codes of practice or guidelines should be sought.

7) 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. 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. Since it is often impossible to check manually the integrity of input data, there should be suitable measures within the computer code to trap input data errors and erroneous results.

4.19 Review of new data

In general, as new experimental results and/or plant data become available, the computer code’s developers should demonstrate that no new model developments are needed and that the computer code’s calculations are in good agreement with the new data i.e. the plant safety case is still valid. Computer codes validation should be regarded as ongoing, not a once-and-for- all process.

4.20 User proficiency

1) The licensee's validation submission should contain sufficient information to enable the Inspectorate to make a judgement on the proficiency of the user. A particularly important source of information comes from 'blind' or 'double-blind' calculations of test problems and whenever possible the submission should include such calculations.

2) In several international Standard Problem (ISP) exercises, several users modelled the same experiment using the same code, nevertheless the code calculated results varied significantly. User effect has been examined in **References 9 and 10**. The reports point out that the analyst must have a good knowledge of

i) the reactor systems

ii) the phenomena addressed, applicability of the models, and their limitations

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

3) Given the complexity of the issues, the codes should not be treated as “black boxes”. The choice of the time step should be checked through sensitivity studies focused on convergence. If numeric instabilities cannot be avoided, the submission will need to provide special justification for any reliance being placed on the results.

4) It is also very important that the licensee's organisation is set up to support the proficient users. There should be adequate procedures for reviewing calculations 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. This means that there is an adequate resource for reviewing calculation methods and the data used in them by keeping abreast of expert opinion, relevant scientific and engineering knowledge and understanding, plant data and experimental data. For a code which has been widely applied and accepted in a series of safety cases, confidence in the user is also increased by comparison of new results with past analyses to confirm that variations in conditions have the physically expected effect, or in accordance with previous experience. This should be monitored by the Inspectorate and safety submissions should reference the endorsement statements. The issue of adequate resources within the relevant part of the licensee's organisation should be borne in mind by the assessor.

Appendix 1. Guidance for the assessment of Computational Fluid Dynamics (CFD) simulations in safety cases.

A1.1 CFD is a powerful, rapidly evolving, simulation tool used for the prediction and analysis of fluid flows. The reliance which can be placed on results of CFD simulations depends on a number of issues, such as the modelling of physical processes, numerical sub-models employed, user expertise, etc. Satisfactory assessment of CFD simulations in safety cases requires that these issues are addressed. The main objective of this Appendix is therefore to provide guidance to assessors of safety cases on the main issues which should be covered in CFD submissions, and their significance. Most of these issues reflect those raised in the main text of this guide, but special consideration is needed because of the flexibility and power of modern multi-purpose CFD codes and the fact that the code details are usually commercial secrets.

A1.2 CFD is the use of computer-based simulation to obtain an approximate solution to the equations which govern fluid motion for particular applications. The technique is characterised by a division of the region in which flow is to be computed - the computational domain, into a very large number of much smaller domains referred to as mesh, or grid cells. The solution consists of values of flow parameters of interest, such as velocity or temperature, calculated at each of the grid cells.

A1.3 Although these codes offer impressive features and the capability to model flows in and around highly complex geometry, the physical and numerical sub-models embodied or applied by the user, are, in many cases, often little removed from the relatively crude techniques developed in the early 1970's. In addition, the codes still require considerable user expertise, physical insight and experience if meaningful results are to be generated.

A1.4 Validation is usually undertaken by comparison of CFD results to reliable and appropriate experimental data - often referred to as 'benchmarks'. This data commonly consists of simplified test cases which nevertheless encompass the key physical processes and / or geometrical complexity seen in the problem of interest.

A1.5 Inter-code comparison exercises can be helpful in circumstances in which experimental data is lacking, to assess whether a code is consistent with other predictive CFD models.

A1.6 It is not uncommon to find that CFD models have been tuned or calibrated by reference to validation data. If this is the case, evidence of applicability of the model to the particular case of interest should then be sought.

A1.7 Statements such as 'the model has been validated' are misleading, and betray overconfidence, lack of understanding or over-selling, since in theory only lack of validation can be demonstrated - in much the same way as physical 'laws' are repeatedly tested for differing situations. In practice most validation studies are limited in scope to certain classes of flow and geometrical complexity.

A1.8 In a wider context, there are national and European validation initiative's underway whose aim is to generate datasets of benchmark experiments and CFD results, leading to guidelines for best CFD practice. These are led by NAFEMS in the UK and ERCOFTAC (European Research Community On Flow Turbulence And Combustion). HSL is involved in both of these activities. These initiative's are at a very early stage and, if successful, will take some years to bear fruit. Assessors should seek advice from qualified sources such as HSL.

A1.9 It is important to remember that code validation is a necessary but not sufficient condition for ensuring that CFD model results lie within acceptable bounds. The code user must also be 'validated', as outlined in the following paragraphs.

A1.10 CFD-generated results rely strongly on the competence and expertise of the user. It is generally accepted within the CFD community that the user is one of the prime causes of uncertainty in results of CFD simulations. To begin to construct a CFD model of a particular flow the user must have a good appreciation of the physical phenomena which are significant. The reason is that at the outset the user must specify, for instance, whether the flow is laminar or turbulent, steady or unsteady, whether the Boussinesq approximation for buoyancy effects is applicable or not, what are appropriate and sufficient boundary conditions, etc. Training in fluid mechanics is thus essential.

A1.11 The user has to be aware of the consequences of selecting these various options or accepting code default values, including limits of applicability. This demands expertise in not just fluid mechanics, but also the numerical solution of fluid flow equations and the idiosyncrasies of various solution algorithms.

A1.12 User competence is thus a major issue in CFD applications. It is must therefore be recommended that submissions which include the results of CFD simulations should include information which demonstrates that the analysis has been carried out by trained, competent users.

A1.13 It should be noted that it is difficult to put error bands on CFD-computed quantities. This is partly because the governing equations exhibit highly non-linear behaviour such that small errors in some aspects of the physical or numerical sub-models or boundary conditions can either be amplified or attenuated in ways which are not readily predicted, and partly because of the strong influence which the user's modelling decisions exert on the end result.

A1.14 To generate meaningful results the user must be aware of the consequences of selecting various options or accepting code default values. This demands that users are highly trained, experienced and have physical insight into the flow being modelled.

A1.15 Firstly a mathematical model is constructed. The equations describing the conservation of mass, momentum and energy are then simplified. To obtain a solution to the simplified flow equations, a discretisation method is used. This is a means of approximating the differential flow equations by a system of algebraic equations which can be solved on a computer. The approximations are applied to small domains in space; the grid or mesh cells referred to earlier. A solution algorithm is used to solve the system of algebraic equations, giving results at discrete locations in space, i.e. at each grid cell, and in time. Submissions should therefore describe the model basis and its application and should address the consequences of the above simplifying assumptions on the end results.

A1.16 Boundary conditions are needed for the specific application. It should therefore be expected that a submission will state all boundary conditions and include an assessment of the effects of any uncertainties.

A1.17 The accuracy of the overall numerical solution method depends on a number of factors; the sub-division of the region of interest into grid cells; the accuracy of the discretisation method; the effectiveness of the solution algorithm in solving the algebraic equations. Safety case submissions which include CFD modelling should therefore include an assessment of each of these factors. In addition, sensitivity analyses can be employed, whereby the effects of uncertainties in, for example, boundary conditions, are studied by carrying out further simulations which investigate the consequences of realistic perturbations to values of key controlling parameters.

A1.18 The computational mesh of grid cells has to represent the geometry in the region of interest and be constructed to allow adequate resolution of the key flow features. From the point of view of assessment, the main point to be highlighted is that the simulation results always depend on the number and disposition of grid cells. Generally-speaking, the greater the number of grid cells, the closer the results will be to the exact solution of the modelled equations.

A1.19 Real flows are three-dimensional and must usually be modelled as such. In certain cases an assumption of two-dimensionality may be applicable. However, the validity of this assumption must be carefully scrutinised: If a flow which in reality exhibits significant three-dimensionality is specified to be two-dimensional then the code will force it to be two-dimensional. This may mask important features.

A1.20 A knowledge of the use to which results will be put is also needed to judge the level of predictive performance required, i.e. whether qualitatively correct results would be adequate to provide just an overall indication of flow behaviour, or whether quantitatively-accurate values are required.

A1.21 CFD software is available from a variety of sources. The main software packages likely to be encountered by NSD inspectors are general-purpose codes developed and available from commercial vendors or those developed and used in-house by the industry. In the former category are the four main commercial CFD codes:

1) FLUENT: Marketed and developed by FLUENT Europe.

2) PHOENICS: Marketed and developed by CHAM - Concentration Heat And Momentum.

3) CFX (Formerly FLOW3D): Marketed by AEA Technology.

4) STAR-CD: Marketed by Computational Dynamics.

In the latter category is the Nuclear Electric code 'FEAT'.

References

1. HM Nuclear Installations Inspectorate, Safety Assessment Principles for Nuclear Power Reactors, ISBN 0 11882043 5, 1992.

2. HM Nuclear Installations Inspectorate, The Inspectorate’s Approach to the assessment of Code Validation Submissions, NII/S/2 (Saf), March 1983.

3. ISO 9000-1 Quality management and quality assurance standards - Part 1: Guidelines for selection and use.

4. ISO 9000-2 Quality management and quality assurance standards - Part 2: Generic guidelines for the application of ISO 9001, ISO 9002 and ISO 9003.

5. ISO 9000-3 Quality management and quality assurance standards - Part 3: Guidelines for the application of ISO 9001 to the development, supply and maintenance of software.

6. ISO/IEC 15504 Information Technology - Software Process Assessment.

7. ANSI/ANS-10.4-1987. Guidelines for the Verification and Validation of Scientific and Engineering Computer Programs for the Nuclear Industry.

8. "IEEE Standard for Software User Documentation", IEEE Std 1063-1987.

9. CSNI Report “User Effect on the Transient System Code Calculations”, January 1995, NEA/CSNI/R(94)35.

10. CSNI Report “Good Practices for User Effect Reduction “, November 1998, NEA/CSNI/R(98)22.

11. HSL Report “Guidance for the Assessment of CFD Simulations in Safety Cases”, May 1997, FFS/97/8.