COMMERCIAL GRADE DEDICATION OF RELAP5-3D©

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ABSTRACT

As the result of a needs analysis and a code evaluation/down-selection process, NuScale Power LLC (NuScale) chose the RELAP5-3D© code [1] developed by the Idaho National Laboratory (INL) to be the baseline code for development of NRELAP5, the company-proprietary system-level thermal-hydraulics analysis code. NRELAP5 is used to perform safety analyses and design engineering calculations in support of NuScale's reactor design certification application (DCA). In order to comply with NuScale's quality program [2] that includes implementation of the ASME NQA-1-2008 and NQA-1a-2009 (NQA-1-2008/9) quality standards for nuclear facility applications [3], it was required to perform commercial grade dedication (CGD) of RELAP5-3D© as a baseline for development of NRELAP5. The dedication was performed in-house by NuScale personnel.

In compliance with NuScale's CGD procedures, a Software Requirements Specification document was developed for RELAP5-3D© as a baseline for NRELAP5, including determination of the safety functions of the code, its performance requirements, and the critical characteristics that the code must possess to perform its safety functions. Acceptance criteria were then set for each of the critical characteristics, and a combination of code testing and inspections, commercial grade survey of the supplier, and supplier performance record evaluations were used to test against the acceptance criteria and to determine limitations of the code capabilities for the intended applications.

The resulting final dedication report, last in a series of some twenty quality records produced in the span of six months, documents the acceptance of RELAP5-3D© as a baseline for NRELAP5 development in an NQA-1-2008/9 compliant environment. To the knowledge of the authors, this is the first example of NQA-1-2008/9 CGD of a thermal-hydraulic safety analysis computer code in the nuclear industry.

KEYWORDS
RELAP5-3D©, NRELAP5, NQA-1-2008, NQA-1a-2009, commercial grade dedication

1. INTRODUCTION

NuScale chose the RELAP5-3D© code [1], developed by the Idaho National Laboratory (INL) to be the baseline code for development of NRELAP5, the company-proprietary system-level thermal-hydraulics (TH) analysis code, as a result of a needs analysis and software evaluation. Because the NRELAP5 computer program developed from the RELAP5-3D© baseline will be used to perform safety analysis and design engineering calculations, the RELAP5-3D© baseline code was designated as performing safety-related functions. Since the development of RELAP5-3D© at INL is not covered by all requirements of INL's 10 CFR 50 Appendix B quality assurance program, by NuScale's process [2] and conforming to NQA-1-2008/2009a requirements [3] endorsed by the NRC, it was then necessary to perform Commercial Grade Dedication (CGD) of the baseline code.

NQA-1-2008/9 [3], Subpart 2.7, Section 302, "Otherwise Acquired Software", states that Quality Assurance Requirements for Commercial Grade Items and Services shall be applied to the acquisition of software that has not been previously approved under a program consistent with this Standard for use in its intended application. A three-phased CGD process is outlined in this paper, stemming from application of NuScale's procurement and software procedures and resulting in the CGD of RELAP5-3D© as a baseline for development of NRELAP5 for safety-related uses. EPRI guidelines [4] and DOE guidelines [5] were also used for guidance in the CGD process.

2. PHASE I – SOFTWARE NEEDS ANALYSIS AND SELECTION

Work during this phase focused on defining the software's application requirements, utilizing input from the NRELAP5 end-users.

2.1. Needs Analysis

The first step in the software procurement process is to state the software needs. A brief document was developed to capture the needs for and intended uses of a thermal-hydraulics system, safety analysis computer code at NuScale. Initially this document captured the essential and high-level needs and applications, used to guide the subsequent evaluation and selection for procurement. With time this document is being revised to define more detailed needs and applications, as the analytical methodologies are being developed and mature with time, in order to guide corresponding revisions to the NRELAP5 Software Requirements Specifications (SRS). For example, as of to date, the T-H system code needs analysis has been revised to define details for non-LOCA safety analysis applications.

2.2. Software Evaluation and Selection

A software evaluation team was formed consisting of end users and code developers. It was determined that no commercially available software product would meet NuScale's safety analysis needs "off the shelf". It was stated that the development of a T-H system code from the ground-up would have been prohibitively expensive and time consuming. It was easily determined that, similarly to the experience of other reactor design vendors in the nuclear industry world-wide, it would have been necessary to select an existing safety analysis code and to further develop it to allow acceptable modeling of the NPM's unique design features and to meet its analysis requirements. The list of candidate T-H system codes for NRELAP5 development baseline was down-selected to two versions of the RELAP5 computer codes, widely used in the nuclear industry for many years: RELAP5/MOD3.3 and RELAP5-3D©. The final determination of which code to select was aided by a Kepner-Tregoe [6] decision making process. The evaluation team selected RELAP5-3D© to be used as baseline for NRELAP5 development, where a key factor in the decision was the more modern code architecture including use of Fortran90 in RELAP5-3D©.

2.3. Software Classification Evaluation

RELAP5-3D© and NRELAP5 were then evaluated for software classification. Both products are classified as software used to perform a design process where the software output directly affects the design development of safety-related systems, structures, and components. The software classification determines the details of the software lifecycle, defined in separate procedures.

2.4. Software Requirements Specification

As part of the evaluation process, an SRS document was written for RELAP5-3D© to perform as a baseline for NRELAP5 code development. The SRS served as a key input to the CGD plan and evaluation discussed in the following section, and provided the basis for acceptance testing.

3. PHASE II – TECHNICAL EVALUATION

At this stage, a commercial dedication plan was developed. Details were captured in order to identify the critical characteristics necessary for RELAP5-3D© to perform its intended function, and to identify the means for verification of fulfillment of the critical characteristics.

The goals of the technical evaluation were to define the safety functions of the computer code; identify performance requirements; determine applicable service/state conditions including failure modes analysis; confirm that the computer code meets the commercial grade definition criteria; identify the critical characteristics of the computer code; and determine how the critical characteristics are to be verified.

Both DOE [5] and EPRI [4] guidelines categorize critical characteristics as: a) physical characteristics, b) performance characteristics and c) dependability characteristics.

Critical physical characteristics for dedication of RELAP5-3D© were related to the media on which the computer program and associated files are provided and to the computing platform.

Critical performance characteristics were identified to ensure the baseline code has the required features, models and correlations necessary to serve as supporting platform for NRELAP5 development.

Critical dependability characteristics were related to the assurance of inherent quality of the procured software from the vendor (INL), including such items as error identification and correction procedures, user community base, personnel qualification and training, software testing and update processes, quality of the documentation, and other items related to embedded quality features in the product being dedicated for use, i.e. RELAP5-3D©.

The critical characteristics for RELAP5-3D© as a baseline for NRELAP5 were identified based on NuScale's requirements, stakeholder input, and a failure modes and effects analysis (FMEA). The EPRI guidelines and the DOE guidelines were used to assist in ensuring that the list of critical characteristics and acceptance criteria was complete and that each had acceptance criteria specified.

Methods of verification and acceptance criteria were then defined to allow for verification of fulfillment of the critical characteristic. The EPRI guidelines identify four methods for verifying that acceptance criteria for critical characteristics are met:

- Special tests and inspections - activities conducted after the receipt of a commercial-grade item to verify one or more critical characteristics as a method to accept the item for safety-related use. These activities are documented in a testing report or an inspection report.

- Commercial-grade survey - activities conducted by the purchaser or its agent to verify that a supplier of commercial-grade items controls, through quality activities, the critical characteristics of specifically designated commercial grade items as a method to accept those items for safety-related use.

- Source verification - activities witnessed at the supplier's facilities by the purchaser or its agent for specific items to verify that a supplier of a commercial-grade item controls the critical characteristics of that item, as a method to accept the item.

- Acceptable item/supplier performance record – a methodology that evaluates processes or activities on the basis of their performance and allows subsequent conclusions about the products of the process or activity and the quality assurance program of the supplier.

For each of the critical characteristics, the acceptance verification was defined using one or more of the methods listed above. Multiple methods were utilized where this was required to support the CGD process as directed by industry guidelines.

4. PHASE III - CODE TESTING, ASSESSMENT AND ACCEPTANCE

NuScale's CGD plan and evaluation called for a commercial grade survey, receipt inspection, software inspection, and acceptance testing of the RELAP5-3D© computer code to verify that the acceptance criteria are met. Based on information in the evaluation plan, a procurement requisition was developed to acquire RELAP5-3D© as a commercial grade item. Four subsequent activities resulted from implementation of this plan.

- Commercial grade survey (CGS) conducted at the Idaho National Laboratory
- Receipt inspection of the RELAP5-3D© deliverable
- Software inspection to perform an extent of condition on findings from the CGS and to support the technical evaluation of the critical characteristics
- Acceptance testing to verify that the RELAP5-3D© code has the required characteristics identified in the project plan and evaluation

Concurrently with the above activities, a configuration-controlled environment was established for NRELAP5 code development and testing, to include CGD acceptance testing of the RELAP5-3D© baseline code.

4.1. Commercial Grade Survey

A supplier survey team performed a commercial grade survey (CGS) of the Quality Assurance (QA) program controls and processes applied to the RELAP5-3D© code development at the Idaho National Laboratory (INL). The CGS team found that thirteen (13) of the twenty one (21) critical characteristics reviewed during the survey were acceptable and generally indicated effective implementation of the INL QA program applied to RELAP5-3D© code development.

The team identified eight (8) issues where the remaining critical characteristics for acceptance identified in the RELAP5-3D© commercial grade dedication plan were not fully met. These issues were variances with the acceptance criteria and based on the CGS team's judgment, represented partial fulfillment of the CGS critical characteristic acceptance criteria. The CGS verified that the RELAP5-3D© code development generally includes adequate and effectively implemented processes and controls invoked by the INL QA program.

4.2. Receipt Inspection

NuScale received the RELAP5-3D© deliverable from INL in response to a procurement requisition. The contents of the deliverable and receipt inspection activities that were carried out on the delivered package are documented in the receipt inspection report. Examples of the activities included in the receipt inspection are:

- Verification that the transmittal letter correctly and fully identified the physical content of the package, and that the serial numbers in the letter matched those labeled to the CD-ROM media.
- Verification that the transmittal index correctly and fully identified all the items requested by procurement requisition document.
- Executed a checksum on the zipped files and verified match to information transmitted by INL.
- Unzipped the files and verified that the transmittal index sheet pointed to the correct electronic files and folders.
- Verified functionality of provided compiler files, source code and executable file. The purpose of this activity was merely to verify elementary functionality of the delivered computer code for suitability to next undergo the technical evaluation, i.e. acceptance testing.
- Uploaded all files to the NRELAP5 repository hosted on the secure and configuration-controlled server where it is available to the code development and validation teams for performing acceptance testing.
- Verified that INL addressed the issues that were identified during the CGS performed by the QA team.

The receipt inspection determined that the CGD deliverable fully conformed to the criteria in the procurement requisition.

4.3. Software Inspection

The software inspection was performed in order to verify the quality of software products, including the computer code and associated documentation, against functional, quality, and regulatory requirements. The specific activities carried out during the software inspection included identification of discrepancies between the source code and the supporting documents (i.e., code manuals), assessment of the extent of obsolete programming standards in the source code, quantification of code coverage, determination of code ability to detect errors in the input, review of the compliance of the RELAP5-3D© physical properties model with the IAPWS-IF97 standard [9], and evaluation of the open RELAP5-3D© error reports.

Each of the above items was evaluated and open items were entered in the error tracking system in accordance with NuScale's Software Error Reporting Procedure.

4.4. Software Acceptance Testing

In the RELAP5-3D© plan and evaluation it was determined that some of the critical characteristics required to be verified by acceptance testing. A software test plan (STP) was developed following NuScale's Software Verification and Testing Procedure. The STP identified the test cases used for verification, figures of merit and acceptance criteria. Included were models of the NPM, proprietary test programs, legacy tests and special feature tests. These cases constitute the matrix for CGD acceptance testing.

Completion of the test cases listed in this matrix assured that RELAP5-3D© has the critical characteristics and required capabilities as a baseline for NRELAP5 development, and that any limitations of these characteristics and capabilities had been identified. The limitations are being addressed during NRELAP5 development under NuScale's NQA-1 software program.

All of the assessment cases are described in the CGD Software Testing Report (STR).

5. SOFTWARE CONFIGURATION MANAGEMENT

NuScale's corporate Software Configuration Management (CM) Plan provides a framework for software configuration management and change control in conformance with the requirements outlined in the Software Quality Program. NRELAP5-specific procedures were developed by the Code Development team to establish the work processes for code development, configuration management and testing. The NRELAP5 development configuration is resident in a high performance computing environment at NuScale.

6. SUPPLIER PERFORMANCE RECORD EVALUATION

Evaluation of the CGD critical characteristics for acceptability relied heavily on testing and inspections. An evaluation of performance record of RELAP5-3D© was included in order to corroborate the conclusions of the dedication. The RELAP5 code, including the current RELAP5-3D© version, has an extensive record of usage and acceptable performance for nuclear safety analysis.

RELAP5-3D© is the latest version of the RELAP5 code that has been under continuous development since 1975, first under NRC sponsorship and then with additional DOE sponsorship beginning in the early 1980s. Systematic safety analyses were carried out for the DOE using RELAP5 that included the N reactor at Hanford, the K and L reactors at Savannah River, the Advanced Test Reactor (ATR) at INL, the High Flux Isotope Reactor (HFIR) and Advanced Neutron Source (ANS) at Oak Ridge, and the High Flux Beam Reactor (HFBR) at Brookhaven. A Naval Nuclear Propulsion laboratory chose RELAP5-3D© as part of their code suite for conducting safety analyses of new submarine and aircraft carrier reactor plants.

The worldwide RELAP5-3D© user community can participate in the International RELAP5 User Group (IRUG) which meets once a year to provide a forum for code users to share their RELAP5 development and analysis experiences. As evidenced by the presentations at IRUG meetings code users include reactor vendors, nuclear industry suppliers, a Naval Nuclear Propulsion laboratory, universities, and international organizations. NuScale participates in IRUG. RELAP5-3D© has been chosen as a code development platform for LOCA analysis by INER (Taiwan) and by Mitsubishi Heavy Industries. This wide usage of RELAP5-3D© over a long period of time has produced an extensive amount of user feedback. Submission of code error reports and the follow up code development has resulted in a robust code which can be used with a high level of confidence that significant code problems have been identified and corrected.

The more than 17 year history of code assessment and successful application of the RELAP5-3D© code, and codes based on the RELAP5-3D© platform, by the worldwide user community is a performance record that is at least as extensive as any other nuclear safety analysis code. This extensive usage has successfully exercised the fundamental capabilities of RELAP5-3D© that are the critical characteristics required of RELAP5-3D© for NuScale's application. This performance record provides additional evidence that RELAP5-3D© possesses the performance critical characteristics listed in the CGD project plan.

7. CONCLUSIONS

To meet the need for a system thermal-hydraulics code for safety analysis of the NPM, NuScale performed commercial grade dedication of RELAP5-3D© as a baseline to develop NRELAP5 under it's software quality assurance program.

The CGD testing and inspections verified that RELAP5-3D© had the critical characteristics necessary to use the software as a code development platform for a system thermal-hydraulics code. The receipt inspection concluded that the CGD deliverable fully conformed to the criteria in the procurement requisition. The software inspection verified the quality of RELAP5-3D©, including the computer code and associated documentation, against functional, quality, and regulatory requirements. Acceptance testing was performed following development of a test matrix selected to verify that RELAP5-3D© had the critical characteristics identified in the requirements specifications. Limitations of RELAP5-3D© for the intended applications were identified during the acceptance testing and are being addressed in the development of NRELAP5. INL's performance record on RELAP5-3D© use for nuclear safety applications by a worldwide user base further corroborated the code's acceptability as a baseline code development platform for NRELAP5.

The CGD effort culminated in a final dedication report, last in a series of some twenty quality records in the span of six months, that documents the acceptance of RELAP5-3D© as a baseline for NRELAP5 development in an NQA-1-2008/9 compliant environment at NuScale.

NOMENCLATURE

Table 0-1. Abbreviations and Acronyms

Term	Definition
CGD	Commercial-grade dedication
CGS	Commercial grade survey
CM	Configuration management
DCA	Design certification application
EPRI	Electric Power Research Institute
FMEA	Failure modes and effects analysis
HCSG	Helical Coil Steam Generator
HPCE	High Performance Computing Environment
INL	Idaho National Laboratory

IR	Inspection Report
IRUG	International RELAP5 Users Group
LOCA	Loss of coolant accident
NPM	NuScale Power Module
QA	Quality Assurance
SDID	Software Design and Implementation Document
SPR	Supplier performance record
SQA	Software Quality Assurance
SRS	Software Requirements Specification
SSC	Structures, systems and components
STI	Special Tests and Inspections
STP	Software Test Plan
SV	Source verification
T-H	thermal-hydraulic
TR	Testing Report

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