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TESTING AND QUALITY ASSURANCE OF THE CONTROL SYSTEM DURING NIF COMMISSIONING

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Abstract

The strategy used to develop the National Ignition Facility Integrated Computer Control System (NIF ICCS) calls for incremental cycles of construction and formal test to deliver nearly one million lines of code. Software releases that implement specific functionality are approved for deployment when offline tests conducted in the ICCS Integration and Test Facility verify functional, performance and interface requirements using test procedures derived from system requirements. At this stage of the project the controls team has delivered approximately 3/4 of the planned software by performing dozens of development and test cycles within offline test facilities and followed by online tests to confirm integrated operation in the NIF. Test incidents are recorded and tracked from development to successful deployment by the verification team, with hardware and software changes approved by the appropriate change control board. Project metrics are generated by the Software Quality Assurance manager and monitored by ICCS management. Test results are summarized and reported to responsible individuals and Project managers under a work authorization and permit process that assesses risk and evaluates control system upgrade readiness. NIF is well into the first phases of its laser commissioning program to characterize and operate the first four laser beams and target systems. The integrated control system has successfully fired over 100 coordinated shots into beam diagnostics and an initial set of target diagnostics in the 10-m diameter target chamber. Extensive experience has been gained by integrating controls in prototype laboratories and in the NIF. This paper will discuss NIF's software QC and QA processes, capabilities of offline test facilities, and metrics collection.

1 INTRODUCTION

Over the past 24 months, ICCS software has been developed, tested and delivered to perform hardware checkout, commissioning and initial operations for all NIF subsystems that support NIF Early Light (the first 4 of an eventual 192 total beamlines). Software is now in place for laser and industrial controls, safety systems, and initial target diagnostics. An iterative development and test approach is being used to provide incremental deliveries of functionality in support of NIF operations, and to more readily accommodate requirements evolution as operators gain experience with delivered controls (Figure1). More than 70 increments have been delivered to date, encompassing 780 thousand source lines of code (KSLOC) out of an estimated 1,000 KSLOC ultimately required for full NIF operations.

The ICCS organization is composed of 65 software developers, 15 testers, 3 configuration management professionals, plus 7 managers and administrative support personnel. New software quality control and quality assurance processes have been introduced to the software development effort as the team has grown in size and maturity. The basic test process in use begins with a review of applicable documented requirements that will be implemented as part of the upcoming increment. These are evaluated for correctness, completeness and verifiability, and updated as needed. Requirements derived from Software Requirements Specifications are parsed in a dedicated database with their verification methods (test, demonstration, inspection, analysis) identified. Individual requirements that will be verified by test or demonstrations are then mapped to individual tests, which are subsequently planned and peer reviewed.

With the test plan in place, a test procedure is prepared to define the specific steps needed to set up and conduct the test, together with expected results. For traceability, requirements intended to be verified by the test are mapped to individual test cases, and the procedures and eventual test results are archived in a database. Tests are conducted using configuration managed software and hardware. Emulation is used offline to "create" quantities of devices to evaluate controls for operating multiple beamlines, and to allow testing of controls for potentially hazardous and/or very expensive devices. Offline tests are conducted both in the ICCS Integration and Test Facility (ITF) and in hardware prototyping labs. Online tests are conducted in the production facility.

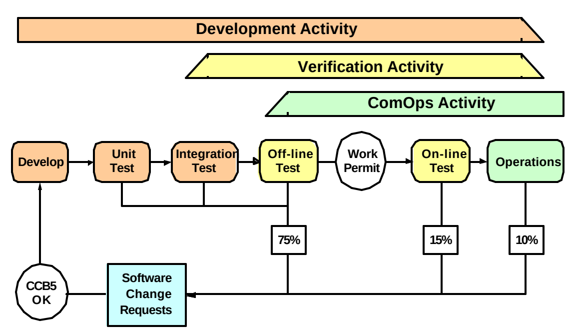

Figure 1: Fully 90% of software defects are removed prior to delivery for operational use.

2 TEST PROGRAM

2.1 Offline Testing

The first stage of offline testing is developer integration. The intent of these tests is to perform initial integration of software products from multiple developers to verify basic functionality (e.g., software startup and shutdown, ability to execute the shot cycle, archival of critical data, etc). Upon completion of developer integration, formal tests are conducted by test personnel who are independent of the development process, using approved procedures (Figure 2). The software is extensively tested to verify functional, performance and interface requirements. A spreadsheet is used to track verification of Software Change Requests (SCRs) that have been implemented in the current release. All software defects identified during developer and formal tests are documented in a defect tracking database. Hardware issues are similarly conveyed to the hardware development organization. Any urgent defects (those that prevent correct operation of critical functions) are corrected and re-tested before the software increment is delivered for online testing in the NIF.

Figure 2: Shot control software undergoes offline testing.

Both normal and off-normal tests are conducted offline. Normal tests verify ability to conduct routine operations, including shot operations and LRU maintenance activities. Off-normal tests verify the control system's ability to detect and robustly handle error conditions, and to provide the appropriate status indicators to operators. Offline testing is the preferred venue for off-normal testing since it is easier to inject faults and there is little or no risk to production hardware.

Off-normal tests are identified by evaluating operations procedures to identify what could go wrong during each step of the operation (e.g., failure of a capacitor to reach full charge during shot countdown). Failure modes are reviewed to confirm that associated requirements have been documented; missing requirements are recommended for addition via SCR, where appropriate. Off-normal tests are prioritized with input from Operations personnel. High priority test cases are run prior to deployment for online tests; lower priority cases are run in parallel with online tests and subsequent operations.

NIF Shot Directors and console operators participate in offline testing as formal tests are being concluded and there is increasing confidence in readiness to move to online tests (Figure 3). During this stage, operators receive early training on bug fixes and new features, and then validate software and operating procedures. Training conducted while running off-normal test cases is particularly valuable for maximizing the number of successfully completed shots in the facility.

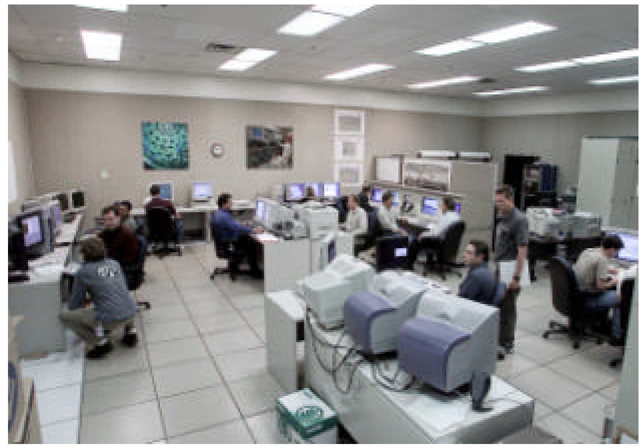

Figure 3: Operator validation and training in the ITF.

A recent process addition is incorporation of the Work Authorization Point (WAP) checklist. WAP checklists identify all key tasks that must be completed before a software release is deemed ready for online testing, and identify responsible individuals and due dates for each task. The WAP must be approved prior to software deployment. A key element of the WAP for software releases is the online Test Readiness Review (TRR). Offline test results are presented by test managers to Operations personnel and management. Operations management must concur with the decision to deploy a build for online testing.

2.2 Online Testing

To facilitate online tests, an information "packet" is prepared for each subsystem that consolidates relevant information about the release: the list of new features, bug fixes, offline test results and online test plans. Online tests are conducted for each subsystem by console operators, the NIF Shot Director, responsible hardware engineers, and ICCS developers and testers (Figure 4).

Subsystem tests are followed by shot tests involving the entire NIF system. The principal functions of ICCS personnel during online tests are to verify that the software operates as expected in the operational environment, to ensure that any issues are documented for subsequent resolution, and to provide additional operator training and coaching as required.

Figure 4: Online tests verify operability in the NIF.

If Urgent defects are identified during online tests, the Configuration Management (CM) team is able to quickly revert to the prior software and database versions, permitting facility operations to resume with minimal delay. Issues can then be resolved and regression tests performed in the ITF before the repaired version is re-introduced for additional online tests. Software builds are retained for operational use with concurrence of Operations management.

Online tests are conducted in various locations around the NIF. While most tests are run from the control room, tests are also conducted in the laser and capacitor bays, switchyards and target bay, which are class 10,000 clean room environments. In addition, tests can involve high voltage, laser hazards and require use of specialized test support equipment. Consequently, test personnel receive extensive training in safety, clean room protocol and equipment operations, as well as test process.

2.3 Integration and Test Facilities

The 2,200 square foot ICCS Integration and Test Facility (ITF) contains servers, workstations, network equipment, front end processors, embedded controllers and devices (both real and emulated) that support the majority of developer and formal offline tests, as well as operator training. In the ITF, software can be thoroughly tested for correct operation, from individual device control to execution of the full NIF shot cycle. Fault conditions can also be easily injected during tests to confirm expected system behavior in a benign environment, which does not place personnel or hardware at risk.

Software emulation is used to perform normal and off-normal tests, and will be used to simulate multiple beamline operations to evaluate network and CORBA performance in preparation for system scaling. Initial emulation has so far been developed for 55 of 89 device classes. A recent exercise to identify an expanded suite of off-normal test cases resulted in identification of additional requirements for emulation. Emulator enhancements are prioritized, by selecting key test cases for subsystems where reliability improvements would have the biggest benefit to increased shot rate. Test personnel are working closely with developers to define appropriate user interfaces that control fault injection.

In addition to the ITF, many hardware integration labs have been established to support development, assembly and pre-installation testing of the large NIF laser optics modules. These labs represent early integration opportunities for controls, and have been very beneficial in identifying interface and requirements defects, as well as supporting both initial and ongoing operator training. These labs also provide the means to exercise software modifications without risking production hardware or impacting shot operations.

A review of SCRs shows that typically 75% of software defects are found during offline testing, 15% are found during online testing, and the remaining 10% are found during subsequent operations. SCRs resulting from tests in the ITF are usually functional and performance defects, those in integration labs are typically interface and requirements defects, and those found online are most often caused by configuration database, hardware and requirements issues.

The ITF is currently undergoing a major upgrade. Specific upgrade objectives include adding laser hardware devices to increase ability to replicate problems experienced in the production facility, adding processors to improve ability to conduct parallel software development and testing, and adding processors and emulation needed to support software scaling for first cluster (48 beam) operations. Due to funding constraints, hardware upgrades are prioritized by identifying components that best support these goals, with emphasis currently placed on reliability-related improvements.

3 SOFTWARE CHANGE CONTROL AND CONFIGURATION MANAGEMENT

All software change is managed through the use of SCRs, which can be submitted by any member of the Project. Key information contained in each SCR includes a description of the reported problem or requested change, affected product, and type (problem, new implementation of an existing requirement, request for enhancement).

SCRs are also assigned a priority for resolution: Urgent, Important, Normal or Low. SCRs assigned at Urgent priority are normally resolved via patches to the software version currently in use in the NIF, or by modifications to the version under test. Important SCRs are normally resolved in the upcoming deployment, and lower priority SCRs are typically resolved in subsequent deployments.

Each week, software product managers evaluate newly submitted SCRs in their areas of responsibility, first determining whether they support implementation of the change request; if so, the estimated time to implement, targeted deployment and the person responsible for verifying successful implementation are documented on the SCR form.

SCRs are presented by the evaluator to the NIF Software Change Control Board, which manages changes to each increment. Chaired by the Software Architect, SCCB membership includes the Test, CM and Software Quality Assurance (SQA) managers, and the software Cost Account Manager for each of the NIF subsystems (e.g., Beam Controls, Laser Diagnostics, Power Conditioning, etc).

The SCCB approves or withdraws change requests, and reviews/approves assigned priority and targeted deployment. SCRs that have substantial impact to the ICCS team as a whole or are controversial are briefed weekly to a level 5 CCB. This board, composed of senior project managers, decides whether to implement these change requests, and provides guidance on priorities.

As SCRs are resolved, developers provide additional information including problem root causes, affected software modules, and actual time to implement the associated code modifications. A new policy has been implemented to perform desk checks on all code modifications. Peers are selected to perform the check, and can request formal code inspections for extensive or especially complex modifications.

Rational Apex is the tool used for code management. As software changes are implemented, developers compile software modules in working views; the CM team also performs automated regression checks to ensure that prior versions of software executables are not inadvertently delivered.

Once a software build is delivered to test, the individual assigned to verify successful implementation for each SCR performs the appropriate test or inspection, and logs pass/fail results and any comments onto the SCR form. Developers are notified of any failed SCRs for further rework; over the past three years, the success rate for repaired defects has exceeded 95%.

4 QUALITY ASSURANCE AND METRICS

A full time Software Quality Assurance (SQA) manager supports the ICCS organization. The SQA manager is independent of ICCS, reporting to the Project QA manager. They are responsible for ensuring that processes necessary to produce quality software are in place and are being followed, including collection of the appropriate metrics. Additionally, QA audits are performed approximately annually. Audits have been conducted both by internal LLNL auditors and by external agencies.

The SQA manager continuously monitors ICCS software engineering processes for improvement opportunities. The current focus is on expanding formal technical reviews. Most formal reviews take the form of code inspections, although design reviews are also held. These activities constitute a cost-effective method for removing software defects. Reviews are prioritized based on module criticality, complexity and demonstrated reliability.

Metrics used to monitor ICCS progress and processes are primarily collected from the code management tool (Apex) and the SCR database. Approximately 250 KSLOC have been added to the ICCS inventory over the past year. Ada is the predominant software language employed at 61% of the total, followed by Java (22%) and C (7%). CORBA is the communications interface technology used to enable multiple languages running on dissimilar platforms.

To date, over 6,000 SCRs have been submitted. Approximately equal percentages were filed to address code problems uncovered by testing at various levels, to authorize implementation of existing requirements plus code modifications caused by other software changes such as framework upgrades, and to request enhancements and implementation of new requirements.

Higher priorities are typically assigned to SCRs that document defects than for enhancement-type SCRs. A review of monthly SCR statistics shows that higher priority (Urgent and Important) SCRs are usually filed at a considerably higher rate during periods of intense commissioning activities, as commissioning teams strive to resolve open issues in preparation for operations.

A major effort is now underway to identify and begin collecting additional metrics to help manage software activities such as code inspections and process improvement campaigns. Metrics are needed to answer questions such as: How reliable is the control system? Which subsystems/modules are the major contributors to unreliability, and should therefore receive the most QC/QA focus? Which process improvements would result in the biggest gains in reliability? These questions yield a list of the needed metrics, including reliability, system availability and defect density.

With the desired metrics defined, data necessary to generate the metrics can be identified (e.g., number of shots attempted, number successful, products responsible for failed shots, root causes for each defect). Algorithms for calculating the desired metrics can then be defined, and the tool that will be used to collect the data selected; tool modifications are in some cases needed to collect the required data. It is also desirable to carefully describe each data item in order to achieve collection consistency, and ultimately accurate and meaningful metrics.

5 SUMMARY

Robust processes are in place for NIF software quality control. Change control processes prioritize fixes and delivery of new features, consistent with the needs of Operations and overall Project goals. CM processes ensure that the correct version of code is delivered to test and is stable during testing. Offline tests in the ITF and in hardware integration labs, and online tests in the NIF together identify 90% of software defects before the software is delivered to Operations.

QA is applied to assure that approved processes are adhered to, as well as to identify opportunities for process improvement. Metrics are collected to evaluate organizational progress; additional metrics will be collected in the near future to improve monitoring of software quality and process effectiveness.

Operator training is performed offline in the ITF to support efficient upgrades of the NIF control system, increasing the number of successful shots during subsequent operations. Capital improvements to the ITF are currently underway to enhance offline test and training capabilities.

ICCS QC and QA activities played a major role in the control system's support of NIF commissioning and initial operations over the past 2 years. During this period the Project activated the first 4 NIF beamlines and initial target diagnostics, and successfully fired over 100 shots for system performance characterization and early experiments. The QC and QA teams will continue to be one of the keys to success as NIF construction and commissioning is completed over the next several years, leading eventually to full system operations and ultimately to fusion ignition.

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