


SOFTWARE RELEASE NOTICE

1. SRN Number: MGFE-SRN-186		
2. Project Title: Repository Design & Thermal-Mechanical Effects		Project No.: 20-5780-671 <i>1402 6/23/98</i>
3. SRN Title: ABAQUS Version 5.8		
4. Originator/Requestor: Bruce Mabrito		Date: 01/08/1999
5. Summary of Actions <input type="checkbox"/> Release of new software <input checked="" type="checkbox"/> Release of modified software: <input checked="" type="checkbox"/> Enhancements made <input type="checkbox"/> Corrections made <input type="checkbox"/> Change of access software <input type="checkbox"/> Software Retirement		
6. Persons Authorized Access		
Name	Read Only/Read-Write	Addition/Change/Delete
Goodluck Ofoegbu	Read Only	Change
Rui Chen	Read Only	Change
Amitava Ghosh	Read Only	Change
Simon Hsiung	Read Only	Change
7. Element Manager Approval: 		Date: 1/29/99
8. Remarks: Access is not limited for commercial software.		

SOFTWARE SUMMARY FORM

01. Summary Date: 01/08/99	02. Summary prepared by (Name and phone) Bruce Mabrito, (210) 522-5149	03. Summary Action: New	
04. Software Date: 01/08/99	05. Short Title: ABAQUS Version 5.8		
06. Software Title: ABAQUS 5.8 <i>6/29/99</i>			07. Internal Software ID: NONE
08. Software Type: <input type="checkbox"/> Automated Data System <input checked="" type="checkbox"/> Computer Program <input type="checkbox"/> Subroutine/Module	09. Processing Mode: <input checked="" type="checkbox"/> Interactive <input checked="" type="checkbox"/> Batch <input type="checkbox"/> Combination	10. APPLICATION AREA a. General: <input checked="" type="checkbox"/> Scientific/Engineering <input type="checkbox"/> Auxiliary Analyses <input type="checkbox"/> Total System PA <input type="checkbox"/> Subsystem PA <input type="checkbox"/> Other b. Specific:	
11. Submitting Organization and Address: CNWRA/SwRI 6220 Culebra Road San Antonio, TX 78228		12. Technical Contact(s) and Phone: Goodluck Ofoegbu (210) 522-6641	
13. Software Application: Used for Thermal and Mechanical modeling.			
14. Computer Platform "Pluto" Server (Silicon Graphics)	15. Computer Operating System: IRIS 6.5	16. Programming Language(s): FORTRAN	17. Number of Source Program Statements:
18. Computer Memory Requirements: N/A	19. Tape Drives: NONE	20. Disk/Drum Units: N/A	21. Graphics: XWINDOW System
22. Other Operational Requirements NONE			
23. Software Availability: <input type="checkbox"/> Available <input checked="" type="checkbox"/> Limited <input type="checkbox"/> In-House ONLY		24. Documentation Availability: <input checked="" type="checkbox"/> Available <input type="checkbox"/> Inadequate <input type="checkbox"/> In-House ONLY	
Software Developer: <i>[Signature]</i> Date: 1/28/1999			

*Contact person
(Not Developer)*

Pluto root: /apps/abaqus/tmp[2] /apps/abaqus/bin/verify

Running ABAQUS/Standard verification...

std_inst.inp ...

std_inst has passed verification.

Verification of ABAQUS completed successfully.

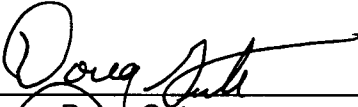
OK for sign
1/28/1999

**SOFTWARE VALIDATION TEST PLAN FOR
ABAQUS VERSIONS 5.8-16 AND 6.2**

January 2002

Center for Nuclear Waste Regulatory Analyses
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Author



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2/14/02
Date

Element Manager



Asadul Chowdhury

2-14-02
Date

1.0 Scope of the Validation

ABAQUS Versions 5.8-16 and 6.2 are acquired software not to be modified and under configuration control at the Center for Nuclear Waste Regulatory Analyses (CNWRA), software release numbers MGFE-SRN-250 and MGFE-SRN-247, respectfully. ABAQUS is a finite element (FE) analysis program developed by Hibbitt, Karlsson & Sorensen (HKS), Inc. The HKS, Inc. main office is located at 1080 Main Street, Pawtucket, Rhode Island, 02860-4847. The ABAQUS program can be purchased with several different analysis options and utilities. Of the many available options, the CNWRA is only licensed to use the implicit (ABAQUS/Standard) and explicit (ABAQUS/Explicit) solution algorithms and the model pre- and post-processing program module (ABAQUS/CAE).

A general overview of the capabilities, utilities, and functionality provided by the ABAQUS software codes used by the CNWRA can be found in Appendix A. A more extensive presentation of this information can be found on the CD-ROM included with this SVTP (see Table 1.1)

Table 1.1 Files Conveying the Capabilities, Utilities, and Functionality of the ABAQUS Software Codes Used by the Center for Nuclear Waste Regulatory Analyses

ABAQUS Software Code	File Name
ABAQUS/Standard	6-2standard.pdf
ABAQUS/Explicit	6-2explicit.pdf
ABAQUS/CAE	6-2cae.pdf

HKS, Inc. maintains a rigorous Quality Assurance (QA) program. Appendix B presents the full text of the HKS, Inc. description of their QA standards and corresponding certifications. This documentation was obtained from the HKS, Inc. web site (www.hks.com). In summary, HKS, Inc. QA procedures meet the ISO 9001 and American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME) NQA-1 QA standards. The ANSI/ASME NQA-1 standard is designed to ensure compliance with Appendix B of U.S. Code of Federal Regulations 10 CFR 50 (1-1-86 Edition) and, as a result, conforms to the U.S. Nuclear Regulatory Commission's QA requirements. Verification, Benchmarking, and Example Problems Manuals (HKS, Inc.; 1998a, b, c, d; 2001a, b, c) and Error Status Reports are integral components of the HKS, Inc. QA program. In addition, ABAQUS also performs installation tests automatically when the software is installed on a client's computer platform. The ABAQUS program notifies the installer of the program, by way of messages written to the screen and a log file, the nature of any errors indicating that the installation of the program was not done correctly.

Before releasing updates of the various ABAQUS software codes for commercial use, HKS ensures that the code must be capable of solving an extensive number of verification, benchmarking, and example problem test cases satisfactorily. The results of these test cases are documented in the aforementioned Verification, Benchmarking, and Example Problem Manuals. Table 1.2 delineates the names of the files for the various ABAQUS Manuals that have been stored on the CD-ROM included with this SVTP. The ABAQUS Verification Manual

contains a large number of test cases that serve as basic verification of the various ABAQUS programs. Each test case verifies one or several well-defined options in the code. The test cases are sufficiently small that, in most cases, the correct results can be calculated by hand. This manual is divided into chapters based on the type of capability that is tested. The problems in the element verification chapter test the element library extensively. Other chapters document tests of materials, procedures, user subroutines, miscellaneous options, and importing results from ABAQUS/Explicit into ABAQUS/Standard. In addition to the Verification Manual, there are two other manuals that contain worked problems. The ABAQUS Benchmarks Manual contains benchmark problems (including the NAFEMS suite of test problems) and standard analyses used to evaluate the performance of ABAQUS. The tests in this manual are multiple element tests of simple geometries or simplified versions of real problems. The ABAQUS Example Problems Manual contains many solved examples that test the code with the type of problems that users are likely to solve. Many of these problems are quite complex and test a combination of capabilities in the code.

Table 1.2 ABAQUS Manuals Relevant to Software Validation and the File Names for the Available Electronic Versions

Manual	Applicable Software	File Name
ABAQUS/Standard [†] Verification Manual, 5.8	<ul style="list-style-type: none"> ABAQUS/Standard 	–
ABAQUS/Standard Example Problems Manual, 5.8	<ul style="list-style-type: none"> ABAQUS/Standard 	Examples_Manual_Stndrd5-8.pdf
ABAQUS/Explicit [†] Example Problems Manual, 5.8	<ul style="list-style-type: none"> ABAQUS/Explicit 	–
ABAQUS Verification Manual, 6.2	<ul style="list-style-type: none"> ABAQUS/Standard ABAQUS/Explicit ABAQUS/CAE 	Verification_Manual_6-2.pdf
ABAQUS Benchmarking Manual, 6.2	<ul style="list-style-type: none"> ABAQUS/Standard ABAQUS/Explicit ABAQUS/CAE 	Benchmarking_Manual_6-2.pdf
ABAQUS Example Problems Manual, 6.2	<ul style="list-style-type: none"> ABAQUS/Standard ABAQUS/Explicit ABAQUS/CAE 	Examples_Manual_6-2.pdf
[†] Hard copy only.		

The most recent versions of the Error Status Reports, which are constantly updated and maintained by HKS, Inc., are accessible at any time via their public ftp site (i.e., <ftp.abaqus.com>). The complete Error Status Reports for the program modules of interest to the CNWRA at the time this SVTP was developed are stored on the attached CD-ROM. The applicability and file names of these Error Status Reports can be found in Table 1-3. These Error Status Reports document the assigned error number, nature of the error, the status of the error resolution process, and the affected program modules.

Table 1.3 Files Names for the ABAQUS Error Status Reports

ABAQUS Application/Utility	File Name
ABAQUS/Standard, Version 5.8	stde58.pdf
ABAQUS/Standard, Version 6.2	stde62.pdf
ABAQUS/Explicit, Version 5.8	xple58.pdf
ABAQUS/Explicit, Version 6.2	xple62.pdf
ABAQUS/CAE, Version 5.8, and related program and system utilities	caee58.pdf, intfe58.pdf, designe58.pdf, pste58.pdf, utle58.pdf
ABAQUS/CAE, Version 6.2, and related program and system utilities	caee62.pdf, intfe62.pdf, designe62.pdf, pste62.pdf, utle62.pdf

According to Table 1 of Technical Operating Procedure TOP-018, Development and Control of Scientific and Engineering Software, acquired software not to be modified must undergo Acceptance and Validation Testing and satisfy Configuration Control, QA Verification, and QA Release documentation requirements. Furthermore, as noted in Table 1 of TOP-018, Acceptance Testing for acquired software not to be modified is limited to Installation Testing only. Software Validation Testing, per Subsection 5.10.1 of TOP-018, for acquired software not to be modified "... shall consist of one or more of the following (i) tests that provide evidence of correct and successful implementation of the underlying theory and algorithms, as outlined in the CNWRA initiated Software Requirements Description (SRD)/Software Change Report (SCR) or the development organization's literature, for acquired software, (ii) comparison to research papers, laboratory experiments, existing test cases or previously published sources of data, and (iii) benchmarking or comparative testing against results from other software. The software validation may be limited to a range of the capability of the software, commensurate with its anticipated use in regulatory reviews. For software with separately operable modules the Software Validation Testing Plan (SVTP) will describe which modules are to be validated and with what couplings (if any) between modules."

Because of the extensive tests and error documentation made available by the vendor (i.e., HKS, Inc.), the scope of the ABAQUS software validation will be limited to verifying that a sample of test problems presented in the ABAQUS Verification, Benchmarking, and Example Problems Manuals are solved satisfactorily on the computer platforms used by the CNWRA. This approach to validating the ABAQUS software programs provides "...evidence of correct and successful implementation of the underlying theory and algorithms, as outlined in the ... development organization's literature, for acquired software" as required by TOP-018. The specific test problems to be used for this purpose are identified in Section 6, Test Cases. These test problems have been chosen such that they represent an acceptable percentage (i.e., >10 %) "...of the capability of the software, commensurate with its anticipated use in regulatory reviews."

2.0 References

Hibbitt, Karlsson & Sorensen, Inc. ABAQUS/Standard Verification Manual, Version 5.8. Pawtucket, Rhode Island: Hibbitt, Karlsson & Sorensen, Inc. 1998a.

Hibbitt, Karlsson & Sorensen, Inc. ABAQUS/Standard Example Problems Manual, Volume I, Version 5.8. Pawtucket, Rhode Island: Hibbitt, Karlsson & Sorensen, Inc. 1998b.

Hibbitt, Karlsson & Sorensen, Inc. ABAQUS/Standard Example Problems Manual, Volume II, Version 5.8. Pawtucket, Rhode Island: Hibbitt, Karlsson & Sorensen, Inc. 1998c.

Hibbitt, Karlsson & Sorensen, Inc. ABAQUS/Explicit Example Problems Manual, Version 5.8. Pawtucket, Rhode Island: Hibbitt, Karlsson & Sorensen, Inc. 1998d.

Hibbitt, Karlsson & Sorensen, Inc. ABAQUS Verification Manual, Version 6.2. Pawtucket, Rhode Island: Hibbitt, Karlsson & Sorensen, Inc. 2001a.

Hibbitt, Karlsson & Sorensen, Inc. ABAQUS Benchmarking Manual, Version 6.2. Pawtucket, Rhode Island: Hibbitt, Karlsson & Sorensen, Inc. 2001b.

Hibbitt, Karlsson & Sorensen, Inc. ABAQUS Example Problems Manual, Version 6.2. Pawtucket, Rhode Island: Hibbitt, Karlsson & Sorensen, Inc. 2001c.

3.0 Environment

3.1 Software

- ABAQUS/Standard, Version 5.8-16, UNIX compatible operating system
- ABAQUS/Standard, Version 6.2, UNIX compatible operating system
- ABAQUS/Explicit, Version 5.8-16, UNIX compatible operating system
- ABAQUS/Explicit, Version 6.2, UNIX compatible operating system
- ABAQUS/CAE, Version 5.8-16, UNIX compatible operating system
- ABAQUS/CAE, Version 6.2, UNIX compatible operating system

3.2 Hardware

- Sun 1420R Server (Solaris 8 operating system)
- Silicon Graphics Inc. (SGI) ONYX 2 (IRIX 6.5 Release 12 operating system)

4.0 Prerequisites

No prerequisites required to implement the SVTP.

5.0 Assumptions and Constraints

No assumptions and constraints required to implement the SVTP.

6.0 Test Cases

The test cases identified in Table 6-1 were taken from the ABAQUS Benchmarks Manual, Version 6.2 (see the Benchmarks_Manual_6-2.pdf file stored on the CD-ROM). These test cases will be used to validate ABAQUS/Standard, Versions 5.8-16 and 6.2, and ABAQUS/Explicit, Versions 5.8-16 and 6.2. ABAQUS/CAE will be validated by demonstrating that the hardcopy version of the calculated results obtained from the test cases are accurately displayed via the Graphical Users Interface (GUI). Documentation provided in the ABAQUS Benchmarks Manual, Version 6.2, addresses the input, procedure, and results relevant to each test case. Specifically, the test cases demonstrate the codes ability to model concrete, missile impact and penetration, damped vibrations, and brittle material (e.g., concrete) failure. As pointed out in Chapter 1, these test problems have been chosen such that they represent an acceptable percentage (i.e., >10 %) "...of the capability of the software, commensurate with its anticipated use in regulatory reviews."

Table 6-1. ABAQUS Validation Test Problems

Test Case Number	Test Case Title	Applicable ABAQUS Module
1.1.10	Concrete Slump Test	ABAQUS/Standard Versions 5.8-16 and 6.2
1.3.16	Plate Penetration by a Projectile	ABAQUS/Explicit Versions 5.8-16 and 6.2
1.4.4	Free and Forced Vibrations with Damping	ABAQUS/Standard Versions 5.8-16 and 6.2
3.2.12	Mixed-mode Failure of a Notched Unreinforced Concrete Beam	ABAQUS/Explicit Versions 5.8-16 and 6.2

7.0 Notes

None.

APPENDIX A
ABAQUS Product Descriptions

A.1 ABAQUS/Standard

As described in the available HKS, Inc. web site documentation (www.hks.com/products/p_abstandard.html), ABAQUS/Standard is a general purpose, production-oriented finite element program designed specifically for advance analysis applications. ABAQUS/Standard provides a variety of time- and frequency-domain analysis procedures. These procedures are divided into two classes: "general analyses," in which the response may be linear or nonlinear, and "linear perturbation analyses," in which linear response is computed about a general, possibly nonlinear, base state. A single simulation can include multiple analysis types. The following enumerates the various analysis and modeling capabilities of ABAQUS/Standard.

General Analyses

- Static stress/displacement analysis
- Viscoelastic/viscoplastic response
- Transient dynamic stress/displacement analysis
- Transient or steady-state heat transfer analysis
- Transient or steady-state mass diffusion analysis
- Steady-state transport analysis

- Coupled problems:
 - Thermo-mechanical (sequentially or fully coupled)
 - Thermo-electrical
 - Pore fluid flow-mechanical
 - Stress-mass diffusion (sequentially coupled)
 - Piezoelectric (linear only)
 - Acoustic-mechanical (linear only)

Linear Perturbation Analyses

- Static stress/displacement analysis:
 - Linear static stress/displacement analysis
 - Eigenvalue buckling load prediction

- Dynamic stress/displacement analysis:
 - Determination of natural modes and frequencies
 - Transient response via modal superposition
 - Steady-state response resulting from harmonic loading
 - Response spectrum analysis
 - Dynamic response resulting from random loading

Materials

Models are provided for metals, cast iron, rubber, plastics, composites, resilient and crushable foam, concrete, sand, clay, and jointed rock. The material response for each of these models may be highly nonlinear. General elastic, elastic-plastic, and elastic-viscoplastic behaviors are provided. Both isotropic and anisotropic behavior can be modeled. User-defined materials can also be created with a subroutine interface.

Geometry

Structures and continua can be modeled. One-, two-, and three-dimensional continuum elements are provided, as well as beams, membranes, and shells. The beam and shell elements are based on modern discrete Kirchhoff or shear flexible theories and are very cost-effective. Shell elements are provided for heat transfer and stress analysis, which makes it straightforward to analyze shell structures subjected to thermal loads. ABAQUS/Standard is a modular code: any combination of elements, each with any appropriate material model, can be used in the same analysis.

Kinematics

All elements in ABAQUS/Standard (except for some special-purpose elements) are formulated to provide accurate modeling for arbitrary magnitudes of displacements, rotations, and strains.

Prescribed Conditions

Boundary conditions can include prescribed kinematic conditions (single- and multi-point constraints) and prescribed foundation conditions. Loading conditions can include point forces, distributed loads, and thermal loading. A special tool for prescribing forces on assemblies allows direct specification of bolt or other fastener loads. Follower force effects such as pressure, centrifugal, and Coriolis forces are included where appropriate. Loads and boundary conditions for pore fluid pressure, electric potential, and other scalar fields are also available. Initial conditions for temperature, velocity, stress, and numerous other fields can be specified.

Interactions

ABAQUS/Standard has general capabilities for modeling interactions between bodies, including surface-to-surface contact, with or without friction. Fully coupled thermal-stress interfaces are provided, where heat and traction may both be transmitted and where the thermal resistance of the interface may depend on the pressure between contacting surfaces or the mechanical separation of the surfaces. Surface-based interactions are available to couple structural and acoustic medium models for dynamic and vibration analysis. Coupled pore fluid flow-stress and coupled thermal-electrical interactions are also available.

Additional Analysis Techniques

- Continue simulations begun with ABAQUS/Explicit
- Transfer results to ABAQUS/Explicit to continue simulations
- Fracture mechanics design evaluation
- Material removal and addition

- Restart analyses from intermediate states
- Superelements and substructures
- Submodeling
- Parameterization and parametric studies

Product Features

ABAQUS/Standard uses a high-performance, parallel, sparse, multifront equation solver to solve both symmetric and unsymmetric systems of equations and automatically uses the unsymmetric solution scheme when the physics of a problem demands it. Parallel processing is available on most supported platforms. For eigenvalue problems ABAQUS/Standard uses a Lanczos eigensolver that is designed for efficiency in large models.

In nonlinear problems the challenge is to provide a convergent solution at minimum cost. This challenge is addressed by automatic control of the time incrementation, which is provided for all relevant analysis procedures. The user defines a "step" (a portion of the analysis history, such as a thermal transient, a stage in a manufacturing process, or a dynamic event). ABAQUS/Standard then automatically selects the convergence tolerances and the increments required for the step. This approach is highly effective for nonlinear problems because the model's response may change drastically during an analysis step. Automatic control allows nonlinear problems to be run with confidence without extensive experience with the problem. This capability is a good example of the many features in ABAQUS/Standard that make it a production-oriented analysis tool and distinguish it from other finite element programs.

A.2 ABAQUS/Explicit

As described in the HKS, Inc. web site documentation (www.hks.com/products/p_abexplicit.html), ABAQUS/Explicit is a finite element program designed to serve advanced, nonlinear continuum and structural analysis needs. The program addresses highly nonlinear transient dynamic phenomena and certain nonlinear quasi-static simulations. It is designed for production analysis environments, so ease of use, reliability, flexibility, and efficiency are key ingredients in its architecture.

Analyses

ABAQUS/Explicit uses explicit time integration for time stepping and includes the following types of analyses:

- Explicit dynamic response with or without adiabatic heating effects.
- Fully coupled transient dynamic temperature-displacement procedure. Explicit algorithms are used for both the mechanical and thermal response.
- Annealing for multistep forming simulations.
- Acoustic and coupled acoustic-structural analyses for the simulation of wave propagation in an acoustic medium, such as shock loading propagated to an underwater structure.
- Automatic adaptive meshing allows the robust solution of highly nonlinear problems.

Materials

Models are provided for metals, rubber, plastics, composites, concrete, soils, and resilient and crushable foams. Strain-rate-dependent response and heat generation can be included. Two equation-of-state models are available for modeling hydrodynamic materials and explosives. A general interface for user specification of material behavior is also available.

Geometry

Structures and continua can be modeled. One-, two-, and three-dimensional continuum elements are provided, as well as shells, membranes, beams, and trusses. ABAQUS/Explicit is a modular code: any combination of elements, each with any appropriate material model, can be used in the same analysis.

Kinematics

All elements in ABAQUS/Explicit (except for some special-purpose elements) are formulated to provide accurate modeling for arbitrary magnitudes of displacements, rotations, and strains.

Prescribed Conditions

Boundary conditions can include prescribed kinematic conditions (single-point constraints) such as specification of displacement, velocity, and acceleration histories. Loading conditions include point forces and distributed loads such as pressure, centrifugal loads, incident wave loads, and gravity loads. Thermal loading options are also provided.

Interactions

A general capability for modeling interactions between bodies is provided, including surface-to-surface contact and multi-point constraints.

Additional Analysis Techniques

ABAQUS/Explicit offers several additional analysis techniques, including restart and recover capabilities and the ability to transfer results to and from ABAQUS/Standard.

Product Features

Multistep analysis is straightforward in ABAQUS/Explicit. The user divides the loading histories into "steps" solely on the basis of convenience. Each step is typically one stage in the overall loading history. The initial condition for each step is the state of the model at the end of the previous step, which provides a convenient method for following complex loading histories, such as in a manufacturing process.

A.3 ABAQUS/CAE

ABAQUS/CAE is a complete environment for modeling, managing, and monitoring ABAQUS analysis jobs, as well as visualizing results from the ABAQUS analysis products (www.hks.com/products/p_abcae.html).

Product Goals

- Provides a complete, integrated modeling and analysis solution

ABAQUS/CAE integrates modeling, analysis, job management, and results evaluation seamlessly. The functionality is presented in modules, where each module contains a logical subset of the overall functionality. The user interface is highly consistent throughout the system, thus making it easy for a new user to learn. Familiar ABAQUS concepts---such as steps, interactions, sections, sets, materials, and amplitudes---make the graphical user interface intuitive for ABAQUS users.

- **Complements CAD systems and other modeling tools**

ABAQUS/CAE is based on the concepts of parts and assemblies of part instances, which are common to many CAD systems. Parts can be created within ABAQUS/CAE or imported from other systems as geometry (to be meshed in ABAQUS/CAE) or as meshes.

- **Works effectively with large models**

ABAQUS/CAE is designed to handle the large models that are increasingly common in practical applications of ABAQUS.

- **Includes an interactive environment that can be customized to create application-specific systems**

One of the keys to enhanced productivity is the ability to customize the user interface of ABAQUS/CAE for particular applications. The Python programming language (www.python.org) is embedded in ABAQUS/CAE as a command scripting and GUI extensibility tool.

APPENDIX B
Quality Assurance at HKS, Inc.

B.1 Background

The following was obtained from the HKS, Inc. web site (www.hks.hks.com/products/p_qa.html). HKS shares with its customers a strong interest in quality in the engineering analysis process. We both seek to maximize the value of numerical modeling as a design tool. One aspect of this task is to maximize the reliability of simulation at an acceptable cost. Having a formal Quality Assurance Plan for our products and services is another essential part of our contribution toward achieving this goal.

A "general purpose" finite element program is a complex product. Like all such products, quality assurance must be integrated into all aspects of the product's life. There are two principal reasons we impose strict quality assurance: customer satisfaction and product reputation. Our approach to quality assurance meets the ISO 9001 standard. But our QA Plan also gives us the ability to provide software that conforms to the US Nuclear Regulatory Commission's quality assurance requirements and may thus be used for calculations associated with the licensing of nuclear power facilities in the USA.

We also have a basic economic motivation for a formal QA Plan. Making a release of a complex software product is a laborious and costly process which we achieve annually. If we discover bothersome errors in the code after we have shipped a release, we have no choice but to do the job again. The cost of such a re-release is substantial. There are always errors in the code: the issue is whether they are tolerable. This judgment is not based solely on the quality of the analysis results. We must also consider the extent to which particular bugs annoy and frustrate our customers.

The remainder of this section describes some of the important ingredients in our QA Plan.

There are two principal quality assurance documents which govern software modification: the Project Control Document ("PCD") and the Suspected Error Report ("SER").

The PCD controls the development of new functionality and begins when the lead developer for a particular feature formally defines the project. This definition is in the form of documentation (both external and internal) of the new feature. Before any software is written, the PCD, together with its associated documentation, is submitted for independent review by two engineers who are not involved in the project. One engineer is typically a software developer who reviews the proposal for conformance with HKS's design standards. The other is typically from the technical support staff and acts as the customer's advocate to ensure that the development will provide the appropriate functionality and that the documentation is complete and clearly understandable. The proposal is then reviewed by product and functional managers. Finally, the proposal is reviewed by the QA Committee (composed of senior management), which has the ultimate responsibility for the quality of the design. Permission to begin code modification is based on this multi-level review and considers the adequacy of the testing program. These tests always include "regression tests," which examine whether existing features are broken by the addition of the new feature.

Once the lead developer considers the project to be complete, it is submitted for final approval. At that time the project goes through the review process again. One aspect of this review is to

ensure that a sufficient set of tests has been added to the QA test suite to help guarantee the functionality in future releases.

SERs document our response to suspected errors. The first stage in this process is to determine that a suspected error is indeed a code error and not a user error. Since many ABAQUS applications involve nonlinear response, this is often a matter of judgment. As soon as the SER has been classified as a code error, we must determine if the error is "serious" in the context of nuclear licensing applications. Here the term "serious" has a particular meaning: an error is serious when a reasonable analyst might accept the results of the computation as being correct when they are, in fact, wrong. Whenever we classify an error as serious, we provide immediate notification to our customers who have a Nuclear QA Version of the code. The SER is assigned to an engineer for investigation and correction. The corrections are reviewed by the QA manager for completeness. As part of the correction process, the QA manager decides whether the QA test suite used to qualify each release should be extended to ensure that this error does not reappear in a released product.

Errors in ABAQUS may disrupt a customer's ability to continue with a project. To alleviate these disruptions, maintenance releases of ABAQUS are available on request. These releases correct many of the reported errors and are provided on the most popular hardware systems. Maintenance releases undergo limited testing and are not intended to replace official releases. They should be used only to circumvent a known error.

There is no question that these efforts are resource intensive. Equally, there is no question that we are firmly committed to these procedures, because quality of our products is central to the long-term health of our relationships with our customers.

B.2 Quality Monitoring Service

HKS believes that its quality assurance procedures are among the best in the industry. Adding the Quality Monitoring Service to your ABAQUS license is a cost-effective way to take advantage of HKS's QA work in documenting your own quality assurance activities.

Introduction

Increasingly customers find that monitoring their suppliers' QA activities is a desirable or mandatory component of their own QA work. To assist customers in meeting this requirement, HKS offers the ABAQUS Quality Monitoring Service. The service has four components:

- A controlled copy of HKS's Quality Assurance Plan
- Notification of "potentially serious errors"
- A copy of HKS's annual QA audit
- The right to conduct the customer's own QA audit

HKS's Quality Monitoring Service is provided for the following ABAQUS products:

ABAQUS/ADAMS, ABAQUS/Aqua, ABAQUS/CAE, ABAQUS/CAT, ABAQUS/C-MOLD, ABAQUS/Design, ABAQUS/Explicit, ABAQUS/MOLDFLOW, ABAQUS/Safe, ABAQUS/Standard, and ABAQUS/Viewer.

Quality Assurance Plan

ABAQUS Quality Monitoring Service customers receive controlled copies of HKS's Quality Assurance Plan. This document defines the procedures used at HKS to ensure quality. It is designed to comply with the ISO 9001 and NQA-1 standards. A "controlled" copy means that customers receive all revisions to the Plan. In this way, such customers are assured that they know in detail what processes are used at HKS for quality control and are notified of any changes in those processes.

Notification of "Potentially Serious Errors"

For some years now HKS has offered "Nuclear QA" licenses of its software products. These licenses provide additional services and assurances so that such licensees may rely on HKS's QA activities in their use of ABAQUS for work associated with the licensing of nuclear power plants under US Nuclear Regulatory Commission regulations. The provision of such licenses requires HKS to comply with the ANSI/ASME NQA-1 Quality Assurance standard, which is designed to ensure compliance with Appendix B of U.S. federal regulation 10 CFR 50 (1-1-86 Edition). The NQA-1 standard requires HKS to notify all Nuclear QA customers immediately whenever HKS discovers "potentially serious errors" in its products. NQA-1 defines such errors as occurring when ABAQUS provides results that an experienced analyst might interpret to be correct when they are, in fact, wrong. Quality Monitoring Service customers also receive notification of such errors, sent on a regular, monthly schedule.

Annual QA Audit

HKS contracts with an independent quality assurance audit organization to audit HKS's quality assurance procedures. These "internal audits" are conducted annually. The audit organization is chosen for its experience and its ability to ensure that HKS complies with the provisions of the ISO 9001 and NQA-1 quality standards. Quality Monitoring Service customers receive copies of the annual audit reports, as well as copies of all follow-up correspondence that documents HKS's response to any audit findings or observations and the audit organization's review of that response. Such correspondence continues until the audit organization accepts HKS's response as compliant with the applicable quality standards.

Right to Audit

Quality Monitoring Service customers have the right to visit HKS's headquarters annually to audit HKS's quality assurance procedures themselves or to have their own contractors perform such quality audits. HKS covers its own costs for staffing, copying, etc. in cooperating with such audits. The customer is responsible for its auditor's costs.

We ask that reasonable notification of such audit visits be provided and that flexibility be shown in choosing dates so that the appropriate personnel are available to support the auditors.

B.3 Error Reporting

We encourage you to tell us about errors in any ABAQUS products. Please be as specific as you can. Just stating: "The attached ABAQUS analysis input file does not work," makes the

task of diagnosing and correcting the error time consuming. Your detailed report will help accelerate this process.

In many cases, because of the complexity of the analyses undertaken with ABAQUS, modeling errors rather than software errors are the source of the difficulty. Therefore, it is often best to contact our technical support staff first to discuss the problem before filing an error report. If our support engineers discover a software error in supporting your analysis, they will file the error report on your behalf. You can track the status of known errors online.

If you wish to submit a Suspected Error Report, please follow the procedure described below:

- Try to produce the error on the smallest model possible and include the data for that small model with the report.
- Try to establish whether the inclusion or exclusion of one particular ABAQUS option seems to trigger the difficulty. If you have done any such studies, please inform us of them in the description.
- Let us know if you have found any temporary ways to work around this problem.
- Let us know if you have had success with similar analyses in the past and what you consider to be the main difference between the current analysis and those.
- Finally, when describing the problem, always be as specific as possible.

B.4 Complaints

We like to think that our products and services are so good that customers will have no reason to complain. But, as hard as we try to achieve total customer satisfaction--and you can be sure that we do try very hard--we live in the real world and must acknowledge that occasionally you may want to tell us about a problem. For this purpose, as part of HKS's overall Quality Assurance Plan, we have a formal mechanism for reporting complaints. Your feedback about our products and services is very important to us. By identifying specific problems, you can help us correct them: we can only fix problems if we know about them.

We would like to be specific about what we mean by a "complaint." We hope that we can resolve minor problems with a quick conversation. For example, if you don't like the facilities we provide at a training seminar, rather than filling out a complaint as described here, make a note on the seminar evaluation form: we do read those evaluations and try to act on the items that can be improved. A "complaint" in the context used here is something more serious--especially anything that impacts quality.

We also want to be careful to distinguish between "bugs" and complaints. A "bug" is a problem with the software or documentation that causes the software not to work as documented. You should report bugs through the Suspected Error Report mechanism. A complaint is some problem other than a bug that you feel HKS should address. For example, you may wish to make a complaint if you think that HKS is taking too long to fix a bug or to resolve a technical support problem.

When you wish to lodge a complaint, we need it in written (preferably, electronic) form. If you like, you may call by telephone and ask one of our support engineers to enter your complaint for you. However, we prefer that you create the written description yourself, so that we have the best chance of starting with an accurate description of the problem. If you do not have access to a forms-capable web browser, you can send e-mail to our QA manager (qa@hks.com) or send a fax or letter to your local HKS office or representative, to the attention of the HKS QA Manager, with the following information:

- Your name
- Your organization
- Your address (including your telephone number, fax number, and e-mail address)
- The HKS product or service causing the complaint (for example, ABAQUS/Standard; the Heat Transfer Seminar; the technical support service in a particular branch office, etc.)
- The date (or range of dates) when the problem arose
- A detailed description of the complaint

Your complaint will be entered into an internal database, reviewed, and assigned to a responsible individual for investigation. The complaint entry is not closed until you have been informed of HKS's response to the complaint.

As with other components of the HKS QA Plan, complaints are tracked and used in trend analysis to determine areas that require corrective or preventive actions.

B.5 Tell Us How We Can Improve

We need your feedback in order to improve. There are two aspects to this: improving the functionality of our products and services and improving the quality of our products and services. The Suspected Error Reports and the complaint mechanisms allow you to help us improve the quality of our products and services. One way you can help us improve the functionality of ABAQUS is to request enhancements through our technical support engineers. Requested enhancements are logged on an internal database, which is reviewed by product management at the beginning of each development cycle. Requests are weighed in terms of popularity and estimated resource requirements. This information is combined with our strategic development plans to determine the project list for a given version. Your requests assist us in providing new releases with functionality helpful to the broadest cross section of our customer base.