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Integrated Computer-Enhanced Remote Viewing System

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1. Introduction

The Interactive, Computer-Enhanced, Remote Viewing System (ICERVS) is designed to provide a reliable geometric description of a robotic task space in a fashion that enables robotic remediation to be carried out more efficiently and economically that with present systems. The key elements are a robust way to store empirical data and a friendly user interface that provides an operator with timely access to all that is known about a scene.

ICERVS will help an operator to analyze a scene and generate additional geometric data for automating significant portions of the remediation activity. Features that enable this include the following:

- Storage and display of empirical sensor data,
- Ability to update segments of the geometric description of the task space,
- Side-by-side comparisons of a live TV scene and a computer generated view of the same scene,
- Ability to create and display computer models of perceived objects in the task space, together with textual comments, and
- Easy export of data to robotic world models for robot guidance.

The development of ICERVS is to occur in three phases.

- Phase 1 (Level III) will focus on the development of the Data Library, which contains the geometric data about the task space and the objects in it, and the Toolkit, which includes the mechanisms for manipulating and displaying both empirical and model data.
- Phase 2 (Level IV) will concentrate on integrating these subsystems with a sensor subsystem into one working system. Some additional functionality will be incorporated in the Data Library and Toolkit subsystems.
- Phase 3 (Level V) will expand the configuration to meet the needs of a full scale demonstration of the interactive mapping of some waste site to be identified.

We essentially completed the Phase 1 effort in the month of June.

2. Summary of Progress to Date

The Phase 1 activity consists of eight tasks which are described in Appendix A. The first task was to provide the required National Environmental Policy Act documentation. This was readily accomplished because only computer related activities are involved in this Phase.

The Preliminary Design task developed a conceptual design for the system. Typical mission profiles were used to generate a set of requirements from which a system architecture was devised. This has been documented in the System Design Report which was included in the first Quarterly Report.

The Computer Platform and Rapid Prototyping task is essentially a risk reduction effort to validate our approach to critical design issues before embodying them in a detailed design. A two dimensional quadtree was used in lieu of the three dimensional octree and a software package providing many user interface functions was tested. This task was completed during the last quarter.

3. Progress Report

3.1 Data Library and Toolkit Systems

The development of these two subsystems involved the three Computer Software Components (CSC) which make up the analysis software for Phase 1: an octree engine CSC, an object modeling CSC and a user interface CSC. The software design is object oriented to promote modularity and code re-use, to simplify maintenance, and to reduce software life-cycle costs. The design of the analysis software began with an allocation of the system requirements to each CSC and the derivation of those additional requirements which were implied but not explicitly set forth in the initial statement of the system requirements. From this set of requirements, a set of classes were defined and specified for each CSC. The class descriptions were documented in MTI 93TR24, "ICERVS Subsystem Design Report", which was included in the previous Quarterly Report. A summary of these classes is given in the attached Table.

The effort in the third quarter was devoted to the coding, debugging and unit testing of these various classes. The integration of the class software was rather straightforward because of the care taken with the design; the bulk of the integration challenge was gaining a more detailed insight into a tool from RogueWave called "Mouse Wrapper". The initial integration was completed by early June, with several weeks required to identify and correct a number of commands that were causing the system to "crash". Reliable code was available during the final weeks of June to permit performance testing and the End of Phase Demonstration.

3.2 TrueSolid Evaluation

The Octree Corporation completed their task of porting the TrueSolid code to the Silicon Graphics platform. A copy of the code was delivered to MTI in the beginning of June with a three month evaluation license. An MTI engineer was given a week's familiarization and training on the system at the time of delivery. The TrueSolid package is quite attractive and contains several features required in ICERVS Phase 2 (arbitrary point of view, arbitrary cut planes, wild point removal, etc.). An aspect requiring further study is the most effective way to superimpose the display of wire frame representations of objects on the basic octree display.

Table 2-2. ICERVS Software Classes

Group	Class Name	Function
USER INTERFACE CSC		
Utility	C3dPoint CConfigManager CEditWindow CFileListWindow CIcerWindow CMessageWindow COrderedStringList CSortedStringList CVertex CVertexSet	Represents a point in 3D space Manages configuration parameter files Base class for editor windows Provides list of files for operator selection Base class for ICERVS windows Implements window for displaying short messages An ordered collection of items A collection of items sorted alphabetically by name Represents vertex of 3D polyhedral object (derived from C3dPoint) An ordered list of CVertex objects
Main Window	CIcerLoginWindow CIcerMainWindow CViewList	Provides user login window Implements main window and menus Manages list of active view windows
System Parameter	CEditLog CEditParameters CIcerModel CModelData CModelList CModelLogFile	Allows operator to edit model log file (derived from CEditWindow) Allows operator to edit model parameter file (derived from CEditWindow) Manages all data for an ICERVS "model" (derived from CModelData) Manages model parameter file Manages list of available models Manages log file associated with each model
View Window	CCutPlaneHandler CGraphicHandler CIcerViewData CIcerView Window CScalingHandler CTranslationHandler CTreeList CViewStatusArea	Manages cut plane operations Manages the model object display Manages all parameters pertaining to a view Implements view window and menus Manages scaling of view display Manages translation of view display Manages list of trees Manages data/status display area attached to each view
Object Modeling Interface	CEditObjects CIcerGraphic CModelObjectInterface CIcerPolygon CIcerRectangle	Allows user to edit geometric object information (derived from CEditWindow) Base class for 2D displayable graphic object classes (derived from CModelObjectParameters) Handles interface to object modeling CSC Implements drawable polygon (derived from CIcerGraphic) Implements rectangle (derived from CIcerPolygon)
Octree Engine Interface	CDisplayAttributes CIcerTreeInterface	Manages boundary and cut plane data fo octree display Handles interface to octree engine CSC

Table 2-2. Continued

OCTREE ENGINE CSC		
Tree Structure	CCube CNodeData CNodeNext COctNode COctree CScaling	Manages geometry associated with tree node Implements node state data Implements Link between nodes in the tree Implements octree node Implements root node of octree (derived from COctNode) Converts between internal/external units
Tree Traversal	COctDisplay COctDualScan COctScan COctPrint COctStats	Provides output for graphic display (derived from COctDualScan) Provides traversal of two trees in synchronization Provides tree traversal Provides output of tree structure data (derived from COctScan) Computes tree/node statistics (derived from COctScan)
OBJECT MODELING CSC		
	CModelEntity CModelObjectList CModelObjectParameters CModelPrismoid	Base class for all geometric object classes (derived from CModelObjectParameters) Manages all geometric objects defined for current model Manages common parameters for geometric objects Implements prismatic-shaped geometric objects (derived from CModel)

3.3 System Demonstration

Phase 1 of ICERVS concluded with a Demonstration to test system performance. These tests were designed to show that the software developed during Phase 1 could meet or exceed the success criteria set forth in the original proposal. These success criteria were analyzed to develop a test plan whose procedures would provide the basis for assessing the performance of the developed software. The test plan concluded with the End of Phase Demonstration which was held on June 24, 1993, in MTI's Latham facility. The Demonstration was witnessed by Gary Nelkin (METC), the Contracting Officer's Representative (COR), by Kevin Kostelnik (INEL), the manager of the Buried Waste Integrated Demonstration at Idaho Falls, ID, by Fred DePiero (ORNL), representing Bill Hamel, the Robotics Technology Development Program coordinator for METC robotic projects, and by John Fedeema (SNL) who is interested in using ICERVS as the world model/database for GISC systems at Sandia.

The details of the performance of the performance test and its results are described in Appendix B. The Demonstration was quite successful; all the features were demonstrated and the system performed flawlessly. There was significant interest in the system's ability to display and manipulate the surface description generated by ORNL when they mapped the waste tanks at Fernald, Ohio.

As a result of the Demonstration and the positive feedback from the representatives of the National Laboratories, the COR decided to proceed with Phase 2.

3.4 Other

In accord with the contract provisions, MTI submitted a comprehensive proposal to continue the project. This included a draft Topical Report and a Phase 2 proposal, describing the work to be accomplished in Phase 2. This proposal contained an additional task to provide an ICERVS system to the Idaho National Engineering Laboratory to be used in the next phase of the Buried Waste Integrated Demonstration there. These documents were submitted in mid May, as the projected completion date of the development effort was the end of June.

A meeting was held at Morgantown, WV, in May to review the METC robotic projects with the EM Robotics Technology Development Program. The ICERVS was one of four projects reviewed. Comments on the project were informational or complimentary. There were two requests for inclusion of ICERVS as a world model in other programs (Bill Hamel for D&D and CMU for a mobile excavator).

Dave Bennett of Pacific Northwest Labs (PNL) requested that we present a paper on ICERVS at the Robotics Forum which Sandia hosts for DOE each year in Albuquerque NM during July. Dave also indicated the desirability of having ICERVS able to accept data from the laser range finder being developed at PNL.

4. Plans for Future Activity

The Phase 1 of ICERVS was completed under budget and three months ahead of schedule. The next activities include the following.

- Update of the draft Topical Report,
- Presentation of paper at Robotics Forum, and
- Support of negotiations for Phase 2 modifications.

5. Assessment of Prospects.

The future prospects of ICERVS are extremely bright.

- The development risks in Phase 2 are low.
    - Phase 1 addressed the high risk elements and provided a solution which is readily expanded to offer the functionality needed in Phase 2
    - The sensor development work originally scheduled for Phase 2 has largely been accomplished with MTI's IR&D funds as part of a CRADA with two of the National Labs.
- There is significant interest in ICERVS as a world model.
    - INEL has asked for ICERVS for the next phase of BWID.
    - ORNL has asked for access to ICERVS for Decontamination and dismantlement (D&D) projects
    - CMU has asked for ICERVS for use as a world model in their remote D&D robot.
    - Commercial vendors of robotic simulation and control software have approached MTI asking about possible access to the ICERVS software.
- There is growing interest in ICERVS as a volumetric database.
    - Sandia is considering it as the database for GISC
    - Hanford Westinghouse is interested in ICERVS as a means to understand the meaning of the floods of data being generated during their current monitoring operations.
    - US Geodetic Service has expressed interest in its use for geophysical data.

6. Appendices

A. Phase 1 Task Descriptions

B. System Performance Testing

Appendix A. ICERVS Task Description

The eight tasks in this Phase and the accomplishments involved are described below.

Task 1. National Environmental Policy Act (NEPA) documentation.
MTI will prepare a report containing the environmental, health, and safety information for the NEPA documentation which the DOE must submit for this project. During this Phase, the project efforts are confined to a laboratory where the primary activities involve the use of computers. Hence only the OSHA aspects will be involved.

Task 2. Preliminary design.
MTI will design, analyze, and identify appropriate implementations of the four major subsystems, namely, the Sensor, Data Library, Toolkit, and Computational subsystems. The design of these subsystems will reflect the current understanding of the needs of the user community.

Task 3. Computing Platform and Rapid Prototyping
MTI will provide a workstation to be used as the computer platform for this phase of the effort. A 2D database will be developed as a rapid prototyping tool to validate design approaches for the two subsystems. This task will conclude with a design review.

Task 4. Detailed Design
MTI will detail the preliminary design, providing means to store empirical 3D geometric data (the Volumetric Database), a means to display the data (Display Engine), and the software tools (Model Building) necessary to create and manipulate models of objects. This task will conclude with a design review.

Task 5. Data Library Subsystem
MTI will construct software modules to implement the detailed design of the Data Library subsystem. These modules will store the empirical 3D geometric data in the volumetric database, the wire frame models used in the world model and maintain the associated data in the object files.

Task 6. Toolkit Subsystem
MTI will also construct software modules for the Display Engine, which will retrieve and display the data in the volumetric database and in the world model in a fashion that exploits the speed and efficiency of the octree technology. A set of Model Building modules will provide the operator with the tools to define a region of interest in a scene and create a model of the object s/he perceives there. These models will be stored in the world model and the volumetric database.

Task 7. Demonstrate Data Library and Toolkit Subsystems
MTI will integrate the software modules developed in Tasks 5 and 6 in the Computational subsystem. A demonstration will be made of the basic

functionality incorporated in these two subsystems, namely, the ability to accept, store, and retrieve empirical geometric data rapidly and accurately and to enable an operator to create, store, display and manipulate models of objects that are perceived in the database.

Task 8. Topical Report and Decision Point
MTI will submit a comprehensive report on the technical results achieved during this phase of the project. The Contracting Officer will decide whether to continue on with the next phase.

Appendix B. System Performance Testing

(Excerpt from MTI 98TR25 Phase ! Topical Report)

3.0 SYSTEM PERFORMANCE TESTING

As described in this section, the Phase I ICERVS was tested to demonstrate its performance. Testing was based on the Phase I success criteria:

- ICERVS will accept, integrate, store, and display dimensional data input in the form of discrete 3D points. Conversion will be done on a point-by-point basis. Display will consist of three orthogonal face views, with pan and zoom, cut planes, and pseudo-coloring.
- ICERVS will provide interactive synthesis, storage, and display of geometric objects. The Phase I models are restricted to simple prismatic shapes defined by a convex polygon in one view and front/back positions defined in an orthogonal view. Each geometric object may have text data associated with it. Display consists of wireframe images in three orthogonal face views, with pan and zoom.
- ICERVS will provide concurrent display and modeling of dimensional data and geometric objects through a cohesive, integrated user interface. User synthesis of geometric objects to denote features in the dimensional data will be accomplished in a timely and effective manner.

3.1 Test Plan

The Phase I test plan involved three tests to reflect each of the three success criteria: octree synthesis and display, geometric model synthesis and display, and integrated system operation.

3.1.1 Octree Synthesis and Display

The purpose of this test was to demonstrate the ICERVS capability for converting input data, in the form of 3D points, to an equivalent octree-based data structure and for the display of that data structure. Three test procedures were used. The first test procedure used individual points entered by keyboard to demonstrate simple recursion through the tree and handling of redundant data. The second test procedure used simulated input data extracted from a test surface. The test surface was defined using second-order primitives to imitate features representative of underground storage tanks. The third test procedure used actual measurement data obtained by a structured light sensor used to map a surrogate waste surface.

3.1.2 Geometric Model Synthesis and Display

The purpose of this test was to demonstrate the ICERVS capability for user-interactive synthesis of geometric objects defined by enclosing planar surfaces (prisms). The test procedures consisted of a series of operations to synthesize and manipulate a set of geometric objects. Each geometric object was generated by the operator first constructing a 2D polygon in one view, and then positioning the polygon (in another, orthogonal view) to establish front and back faces of a prismatic shape. Manipulations such as translating and resizing objects were also tested, as was the capability of annotating text to each object. Display was tested in three orthogonal views, including pan and zoom.

3.1.3 Integrated System Operation

The purpose of this test was to demonstrate the ICERVS capability for modeling octree-based and geometry-based data concurrently. Two test procedures were used. The first test procedure demonstrated the functionality of generating geometric objects to represent features measured in the workspace. An octree generated in earlier testing was used as the measurement data. In the first test procedure, an operator interactively synthesized geometric objects in a view window that displayed octree data. The second test procedure was a measurement of operational effectiveness, in which an operator was timed in the generation of geometric objects. The "average time per object" provided the first baseline of performance for ICERVS effectiveness. The desired goal was 15 minutes per object.

3.2 ICERVS Demonstration

All of the ICERVS tests were completed and a demonstration of the system was presented to DOE on 24 June 1993. All Phase I success criteria were demonstrated, as described in the following paragraphs.

The first procedure demonstrated the generation of a tree representation from a collection of input data points. The data points were generated to effect a simulated 2D representation. Figure 3-1 shows the resulting ICERVS display for this test. A total of 500 data points were generated from an analytic description made from straight-line and circular-arc primitives. The octree was generated at 8 levels of resolution (1 part in 256). The octree comprised 22,900 nodes and occupied 215 kilobytes of computer storage.

The second procedure demonstrated the display of an octree generated from an analytic description of a half-cylinder and "bump" feature. Figure 3-2 shows the resulting ICERVS screen display for top, front, and right-side views. Independent pan and zoom, cut planes, and pseudo-coloring features were demonstrated for each view. Pan and zoom were demonstrated by control bars at the periphery of each view window. A pair of cut planes were enabled and disabled by menu command, and manipulated (translated) by mouse control within each view. Pseudo-coloring was enabled/disabled by menu command for each view. Surface data were colored in gray scale according to Z-coordinate (height). The system allows the user to set the range (minimum/maximum Z values) over which coloring is applied. The octree resolution was 8 bits. The octree comprised 85,800 nodes and occupied 844 kilobytes of computer storage.

The third procedure demonstrated the display of an octree generated from actual sensor data. The data, provided courtesy of ORNL, was measured by a structured light sensor at Fernald Environmental Management Project. The ORNL data were used to generate an octree representing the surface inside an underground storage tank before and after the deposition of a 1-ft bentonite cap. The ICERVS cut plane features were used to view sections of the data, showing the bentonite cap and underlying waste surface. A typical screen display is shown in Figure 3-3. The left-hand view window shows a top view of the data with two cut planes set to extract a cross section of the data. A front view of that cross section is shown in the right-hand view window. It was generally agreed that this method of display effectively provided insight to human operators. The octree resolution was 8 bits. The octree comprised 178,600 nodes and occupied 1822 kilobytes (1.822 megabyte) of computer storage.

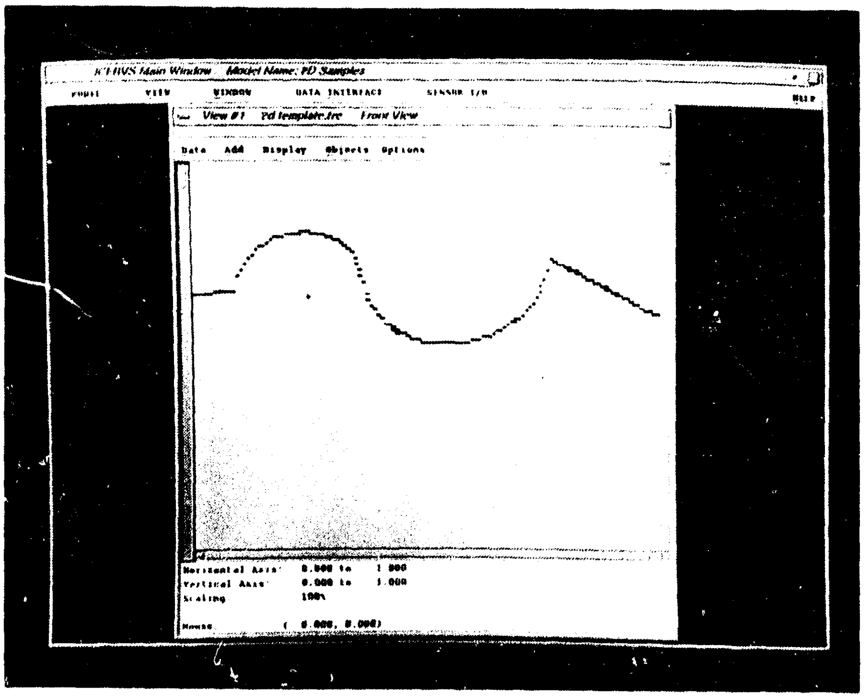

Figure 3-1. Two-Dimensional Example of ICERVS Display

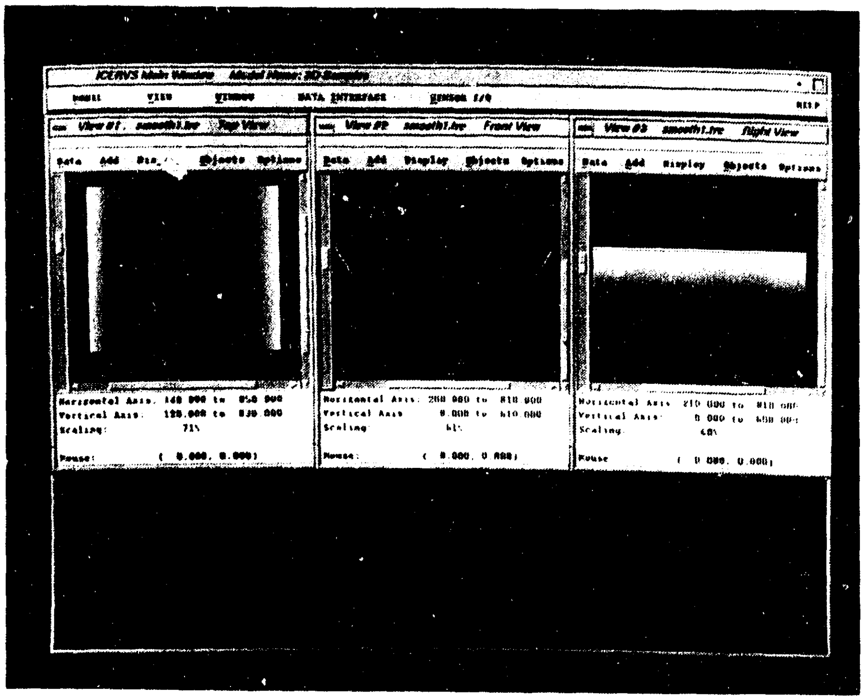

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Figure 3-2. Top, Front, and Right-Side Views of Cylindrical Object

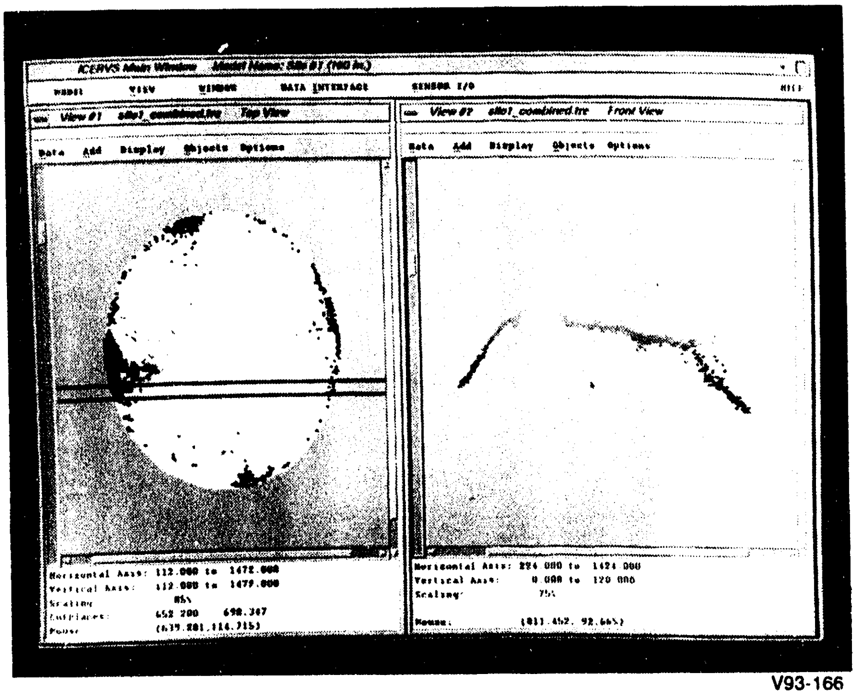

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Figure 3-3. Top and Cross-Section Views of Waste Surface and Bentonite Cap

The fourth procedure demonstrated the interactive synthesis of geometric objects to represent features in the dimensional data. Again, the sensor data from ORNL was used. In this case, MTI used only the bentonite sensor data, plus MTI-generated additional data points to "add" two simulated features: a vertical pipe protruding out of the bentonite, and a section of the tank wall with a small anomaly ("bump"). The ICERVS was used to view each feature in detail and interactively generate a geometric object (prismatic shape) to enclose each feature. A third object was generated to enclose the feature observed in the sensor data itself. The resulting screen display is shown in Figure 3-4. Informal timings showed the "average time per object" to be less than 3 min.

3.3 TrueSolid Demonstration

During the system design, MTI investigated a commercial software product called TrueSolid, which provides octree generation, visualization, and analysis capabilities that are very applicable to the ICERVS needs. MTI undertook an evaluation and concluded that TrueSolid would be an effective product for incorporation into the next level of ICERVS maturation. This evaluation included a demonstration of the stand-alone TrueSolid capabilities. In the TrueSolid demonstration, octrees were created from a number of measurement data sources, such as medical computed tomography (CT) scanners and magnetic resonance imaging (MRI) scanners. The TrueSolid product demonstrated interactive display of complex objects, with cut plane operations, surface connectivity processing, physical property manipulations, and a number of pseudo-coloring capabilities. TrueSolid also demonstrated capabilities for defining and manipulating geometric objects.

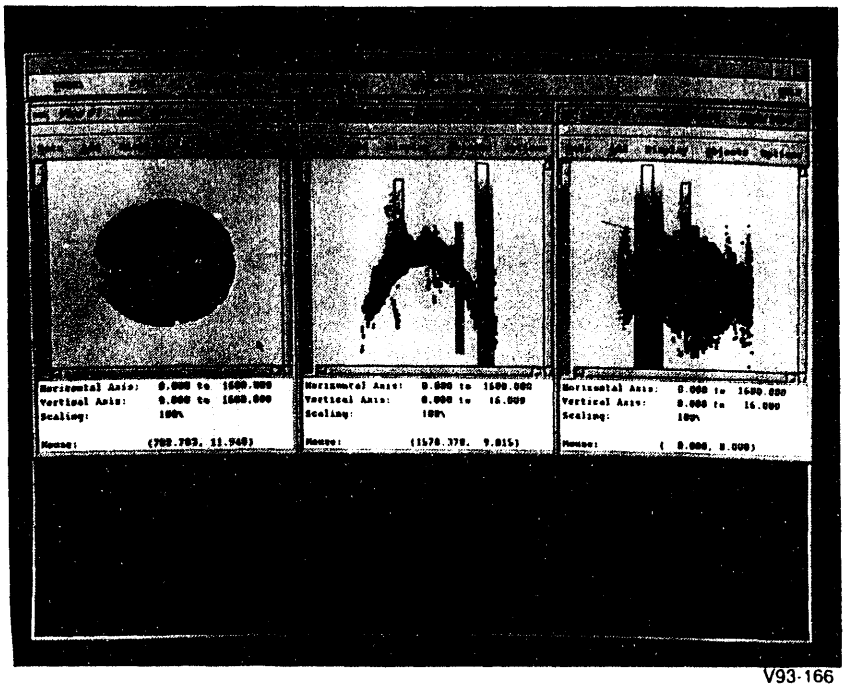

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Figure 3-4. ICERVS Display of Waste Surface and User-Defined Geometric Objects

As part of the ICERVS Phase I demonstration, MTI included a brief demonstration of the TrueSolid product, which had been ported to the Silicon Graphics workstation. Data from ORNL was used to generate a bentonite-plus-waste-surface tree for a different underground storage tank. The TrueSolid display is shown in Figure 3-5. The system demonstrated many of the octree features desired in Phase II, such as display from arbitrary viewpoint, arbitrary cut plane orientation, and physical property operations. (The visual display in Figure 3-5 appears broken up due to the sparseness of the input data.)

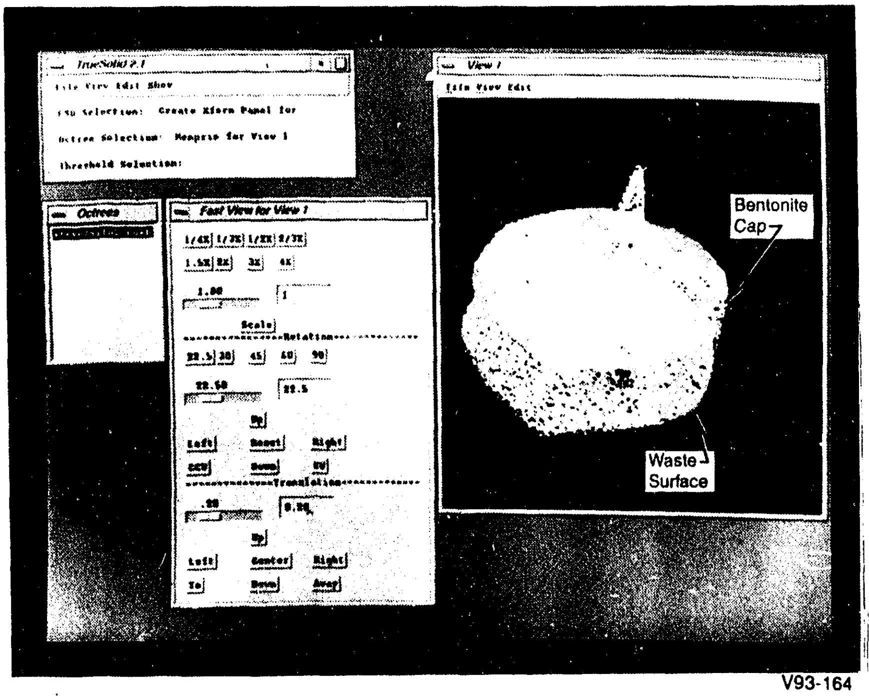

Figure 3-5. TrueSolid Display of Waste Surface and Bentonite Cap

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