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Prototypical Consolidation Demonstration Project Final Report

Joseph A. Gill
Vanessa K. Poston

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Idaho National Engineering Laboratory
EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

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ABSTRACT

This is the final report of the Prototypical Consolidation Demonstration Project, which was funded by the U.S. Department of Energy's Office of Civilian Radioactive Waste Management. The project had two objectives: (a) to develop and demonstrate a prototype of production-scale equipment for the dry, horizontal consolidation and packaging of spent nuclear fuel rods from commercial boiling water reactor and pressurized water reactor fuel assemblies, and (b) to report the development and demonstration results to the U.S. Department of Energy, Idaho Operations Office. This report summarizes the activities and conclusions of the project management contractor, EG&G Idaho, Inc., and the fabrication and testing contractor, NUS Corporation (NUS). The report also presents EG&G Idaho's assessments of the equipment and procedures developed by NUS.

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ACRONYMS

BWR	boiling water reactor
CAPS	Cost and Planning System
CCTP	Cold Checkout Test Program
CRWB	Civilian Rad-Waste Branch
CS	common support
D&D	decontamination and decommissioning
DOE	Department of Energy
DOE-HQ	Department of Energy Headquarters
DOE-ID	Department of Energy Idaho Operations Office
ES&Q	Environment, Safety, and Quality
F&OR	Functional and Operational Requirements
FAT	Factory Acceptance Test
FTR	Final Technical Report
FR	functional requirement
FY	fiscal year
INEL	Idaho National Engineering Laboratory
IST	Integrated System Test
MRS	monitored retrievable storage
MTHM	metric tons of heavy metal
NFBC	non-fuel bearing component
NUS	NUS Corporation
OCRWM	Office of Civilian Radioactive Waste Management
OH	overhead

PCDP	Prototypical Consolidation Demonstration Project
PWR	pressurized water reactor
QA	quality assurance
QPP	Quality Program Plan
RBT	robotic bridge transporter
RCS	rod consolidation system
RFP	Request for Proposal
SEP	Source Evaluation Panel
SOT	System Operation Test
SOW	Statement of Work
SWR	Site Work Release
TAN	Test Area North
TEC	Technical Evaluation Committee
TESS	TRW Environmental Safety Services
WR	Work Release
UNLV	University of Nevada at Las Vegas
VCR	video cassette recorder
YMPO	Yucca Mountain Project Office

Prototypical Consolidation Demonstration Project Final Report

1. INTRODUCTION

1.1 Purpose

The purposes of the Prototypical Consolidation Demonstration Project (PCDP) was (a) to develop and demonstrate a prototype of production-scale equipment for the dry, horizontal consolidation and packaging of spent nuclear fuel rods from commercial boiling water reactor (BWR) and pressurized water reactor (PWR) fuel assemblies, and (b) to report the development and demonstration results to the Department of Energy, Idaho Operations Office (DOE-ID).

The equipment would provide a design basis for future equipment to support high-level waste disposal at a monitored retrievable storage (MRS) facility or a geological repository. The goal of the PCDP was to obtain a 50% volume reduction relative to the volume of intact spent fuel. The reduced volume of the spent fuel would result in a significant savings in the handling, transportation, and storage of spent nuclear fuel. Fewer casks and canisters would be required, fewer transfer operations would take place, occupational radiation exposure would be reduced, fewer vehicle trips would be required, the public radiation dose would be reduced, and less storage area would be required, resulting in significantly lower cost and reduced personnel radiation exposure. The reduced requirements for canisters and casks would have reduced the total amount of nuclear waste generated. Consolidation would also practically eliminate the criticality concerns for spent fuel disposal due to the dense packing of the fuel rods. The private sector participated in all phases of development, demonstration, and reporting under contracts administered by DOE-ID. The hot demonstration of rod consolidation, packaging and storage was to take place in the Test Area North (TAN) Hot Shop facilities at the Idaho National Engineering Laboratory (INEL).

1.2 Participants

This project was funded by Department of Energy Headquarters (DOE-HQ), Office of Civilian Radioactive Waste Management (OCRWM), through the DOE-ID Civilian Rad-Waste Branch (CRWB). EG&G Idaho, Inc., through the Spent Fuel Technology Unit, provided project management and technical support for DOE-ID. The rod consolidation system (RCS) equipment was designed, built, and tested under a DOE-ID contract by the NUS Corporation (NUS). NUS engineering offices are located in Gaithersburg, Maryland, and the test facility was located just outside Pittsburgh, Pennsylvania. The test facility was leased from Contraves-USA, an NUS subcontractor, which provided much of the mechanical fabrication. The remaining mechanical fabrication and installation was performed by Pennsylvania Tool and Gages and U.S. Tool and Die.

1.3 Background

The PCDP was initiated by the OCRWM to develop rod consolidation equipment to support high-level waste disposal strategy for future use at a geological repository or an MRS facility. To adequately evaluate rod consolidation as a viable process step in the final disposal of fuels, OCRWM needs to understand the feasibility, cost effectiveness, and reliability of production-scale dry consolidation. This information is important because of the extreme high radiation under which consolidation equipment operates, the multiple remote operations that must take place during the consolidation process, and the need to maintain stringent safety conditions and absolute fuel accountability during all fuel handling and consolidation operations. To obtain this information, it was necessary to develop and test prototype consolidation equipment under laboratory conditions and to conduct hot operation of the equipment using highly radioactive commercial spent fuel obtained from electric power utilities.

2. EQUIPMENT DESIGN AND DEVELOPMENT

"Consolidation" of spent nuclear fuel assemblies is the process of removing the fuel rods from the grid spacers that hold the rods in an open array or matrix (to allow circulation of water for heat removal, neutron moderation, and criticality control), and then packing the rods tightly in fuel canisters. Consolidated fuel has about one-half the volume of the original fuel assemblies. Additionally, criticality calculations show that the closely packed fuel cannot become critical under a broad spectrum of wet and dry storage conditions. This enables the consolidated fuel to be safely stored dry (i.e., not surrounded by water, as in a storage pool).

2.1 Equipment Functional Requirements

When the Department of Energy (DOE) determined the need for the development of equipment to consolidate spent nuclear fuel, the first step was to determine the functional objectives of the project. The RCS equipment was designed to meet the following functional requirements (FRs):

1. The system shall consolidate 750 metric tons of heavy metal (MTHM) per year of spent nuclear fuel. This throughput rate is based on an availability of 75% for operation, two shifts/day, and five days/week over a 30-year lifetime. As a basis of design, 60% of the spent fuel, on an MTHM basis, will be PWR, and 40% will be BWR.
2. As a minimum, the system shall package all rods from two spent PWR fuel assemblies or from four spent BWR bundles in one canister. In addition, the system shall maximize the packaging of the rods in either a square, round, or trapezoidal canister. The system shall be capable of consolidating any type of PWR and BWR fuel used in the US light-water reactor industry that will exceed 1% of the fuel inventory at the year 2000.
3. The system shall be capable of being modified to utilize canisters of any of the following cross sections: square, round, or trapezoidal.
4. The system shall operate on a continuous basis during the operation period defined as two shifts/day and 5 days/week.
5. The system shall operate remotely during normal and off-normal operations. The system shall be semiautomatic or fully automatic.
6. The system shall provide for remote monitoring of operations from the consolidation process equipment control panels. Monitoring shall include audio and video monitoring of the equipment operation and instrumentation and alarm monitoring of the system operation.
7. The system shall minimize the volume of secondary wastes generated by the consolidation process and the dispersion of radioactive crud, fines, and cuttings. The system shall minimize the generation of liquid waste.

8. The system shall provide for collection and control of such radioactive crud, fines, cuttings, and fuel pellets or fuel pellet powder as may be generated.
9. The system shall provide for remote tooling changes, remote maintenance, remote component replacement, and remote decontamination of all consolidation and supporting equipment.
10. The system shall permit and facilitate accountability for all special nuclear material during the rod consolidation process. Accountability shall be provided for intact fuel rods, broken or stray fuel rods, fuel pellets, and parts thereof.
11. For criticality control, the system shall maintain K_{eff} less than 0.95 for all normal and off-normal conditions.
12. The system shall minimize the potential for the pyrophoric ignition of zirconium or any of the material(s) capable of ignition.
13. The system shall minimize the occurrence of and demonstrate the ability to recover from off-normal events occurring in the consolidation of spent fuel rods. Such events, which shall be identified by the contractor, should include handling and packaging of a fuel assembly that has been partially disassembled when inspection criteria dictate that the specific fuel assembly cannot continue to be consolidated; rod rupture; rod sticking during disassembly; recovery of dropped fuel pellets; recovery of fissile material in the form of fines as the result of fuel rod rupture; fire; equipment breakdown and repair; loss of electrical power or other utilities; and loss of ventilation.
14. The system shall meet the requirements of quality assurance (QA) standards established in American Society of Mechanical Engineers Standard NQA-1 (1986) with all addenda.
15. The system shall include all equipment for the handling of materials, components, various spent fuel assemblies, and containers.
16. The system shall minimize the external contamination of the consolidation canisters during all operations involved in the rod consolidation.
17. The system shall be capable of being installed in the enclosure with dimensions of $20 \times 55 \times 33.5$ ft.
18. The system must be capable of maintaining the fuel rod cladding temperature equal to or less than 175°C while exposed to air. The maximum canister thermal loading shall be 2 kW.
19. The system shall accommodate fuel canisters with lengths of 171 ± 0.1 in.
20. The systems shall provide storage capacity for empty and loaded consolidated fuel rod canisters and non-fuel bearing component (NFBC) containers sufficient to support two continuous shifts of operation. A clean environment shall be maintained in the consolidated

fuel rod canister and NFBC container storage areas for empty and loaded fuel rod canisters and NFBC containers.

During Phase III, the following FRs were not tested:

- FR-2 and FR-3—The trapezoidal geometry was not demonstrated
- FR-4—Continuous system operation was not demonstrated
- FR-5—Off-normal conditions and systems were not tested
- FR-9—The remote decontamination of consolidation and supporting equipment was not demonstrated
- FR-16—The capability of the systems to minimize external contamination of the consolidation canisters was not demonstrated
- FR-18—Cooling systems and temperature monitoring systems were tested in Phase III; however, actual thermal verification measurements were not scheduled to be performed until Phase IV.

2.2 EQUIPMENT DEVELOPMENT

The PCDDP was planned as a four-phase approach to develop, procure, and test the rod consolidation equipment. The four project phases were as follows:

- Phase I—Preliminary design
- Phase II—Final design
- Phase III—Fabrication and cold checkout
- Phase IV—Hot demonstration (cancelled).

The DOE goal of private sector involvement was implemented through multiple awards to private companies during the three phases of the project that were completed. Evaluation of the final products from each project phase, evaluation of proposals for succeeding phases, and selection of successful contractors for each follow-on phase was accomplished through a Source Evaluation Panel (SEP) comprised of DOE personnel. During Phase I, five preliminary designs were prepared by private sector contractors. The preliminary designs were evaluated and the three most promising ones were selected to proceed to Phase II, final design. Only two final designs were completed, and a single contractor, NUS, was selected to proceed with Phase III, the fabrication and testing of their design. After the equipment was fabricated, an extensive testing program using cold (nonradioactive) mockup fuel assemblies was completed. Upon completion of the cold testing program, the equipment was transferred to the DOE Yucca Mountain Project Office (YMPO), and loaned to the University of Nevada at Las Vegas (UNLV) for use in their robotics program. The equipment is available for further development by DOE if spent fuel

consolidation is reconsidered for use in the MRS program or for the national geological repository.

2.3 Phase I, Preliminary Design

Preparation of a DOE-ID administered Request for Proposal (RFP) for private sector equipment development began in June 1985 and the RFP was issued in January 1986. In August 1986, work started on Phase I, Preliminary Design. The following five companies were involved in the preliminary design process: (a) Babcock and Wilcox, (b) General Electric, (c) NUTECH Engineers, (d) NUS, and (e) Westinghouse Electric Corporation.

During fiscal year (FY) 1986, EG&G Idaho provided direct technical assistance to DOE-ID for preparation and issuance of Phase I and II Statements of Work (SOWs) for the private sector contracts and monitored technical progress of the Phase I contractors. The size of the rod consolidation enclosure to be installed at the TAN facility was defined, and a functional and operations requirements document for the rod consolidation enclosure was issued. Other supporting tasks completed included selection of fuel type, integration of Nuclear Waste Policy Act provisions, planning for data acquisition and analysis, identification of required fuel storage casks, definition of NFBC storage strategies, identification of mockup fuel assemblies required for Phase III activities, and identification of surveillance and monitoring requirements for consolidated fuel and NFBC storage. Phase I was completed in FY 1987.

2.4 Phase II, Final Design

After evaluation of the Phase I designs, the DOE SEP selected three of the five contractors to proceed with Phase II, Final Design. The three contractors selected were NUTECH, Westinghouse, and NUS. During FYs 1987 and 1988, EG&G Idaho provided technical monitoring of the Phase II contracts and technical review of the contract deliverables. Technical integration was provided with each of the contractors to ensure ultimate design compatibility with the TAN Hot Shop for the hot demonstration. Quality audits with appropriate follow-up were conducted on each of the contractors to ensure compliance to NQA-1 requirements. In FY 1988, Westinghouse withdrew from the competition and final designs were submitted by NUS and NUTECH, completing Phase II of the project.

During Phase II, EG&G Idaho also initiated procurement of mockup fuel, consolidated fuel canisters, and NFBC containers. These consumable items were procured to support the Phase III test program. This task was completed early in Phase III, with delivery of the items to the Cold Test Facility in Pittsburgh.

2.5 Phase III, Cold Checkout Testing

In FY 1988, the final designs of NUS and NUTECH were evaluated and the DOE SEP selected the NUS design for Phase III of the project. A contract was negotiated and signed with

NUS; Phase III began on June 5, 1989. Under a fixed priced contract with DOE-ID, NUS performed the following Phase III tasks:

- Quality assurance
- Procurement and fabrication
- Installation
- Cold checkout testing
- Cost Data Report
- Final Report
- Dismantle, package, and ship
- Technical integration
- Resident engineer support
- Training
- Project management.

Shortly after the contract was awarded, the mechanical contractor who had teamed with NUS during Phases I and II informed NUS that they would not continue with the project, and NUS had to select another fabricator. This caused significant delays to the NUS design and fabrication efforts. NUS completed the design and worked on fabrication, installation, component checkout testing, and factory acceptance testing through 1990 and 1991. SOT testing was started in November, 1991, concurrently with the final installation and factory acceptance testing activities.

In March 1992, NUS informed DOE-ID that they could not complete the final installation and the planned test program within the hours authorized and funded in the contract. Since the full extent of testing was not known when the contract was initiated, it contained an hourly rate and provisions for increasing the hours of testing. Also at that time, DOE determined that rod consolidation would not be considered in planning for the geological repository or MRS facilities, and cancelled Phase IV, hot demonstration, of this project. DOE-ID decided not to purchase additional testing hours and consequently, DOE-ID and NUS entered into negotiations to refocus the test program to obtain the maximum information and benefit from the project with the remaining funds, and all work not directly supporting the Refocussed Test Program was suspended. NUS completed the revised work scope on the Phase III contract in August 1993.

During the fabrication, installation, and testing of the rod consolidation equipment, EG&G Idaho supported DOE-ID by performing project administration and contract support tasks to ensure that the NUS equipment met the contract requirements and to monitor the NUS test.

2.6 Management Organization and Responsibilities

This section identifies the program participants and establishes interfaces, authorities, and responsibilities for management of the PCDP. Specific organizational responsibilities are defined below.

2.6.1 Department of Energy Headquarters

DOE-HQ, under the Office of Storage and Transportation, had overall programmatic responsibility for the project. Specific responsibilities for DOE-HQ were as follows:

- Establish project objectives
- Define programmatic guidance for achieving objectives
- Approve field work proposals
- Provide required funding
- Review overall programs against objectives.

2.6.2 Department of Energy, Idaho Operations Office

Direction for the project came from DOE-HQ to DOE-ID. Responsibility for implementing DOE-HQ program guidance rested with DOE-ID. Specific responsibilities for DOE-ID were as follows:

- Approve field work proposal and transmit to DOE-HQ
- Approve PCDP project documents
- Review compliance with overall project guidance, schedule, and budget
- Provide programmatic guidance and direction to the EG&G Idaho PCDP manager
- Provide funding to EG&G Idaho
- Administratively control the PCDP Phase III contractor
- Provide direction and act as interface with the Phase III equipment contractor in matters of cost, work scope, and schedule
- Act as chairman for the Technical Evaluation Committee (TEC), which is responsible for evaluating contract deliverables from the Phase III equipment contractor.

2.6.3 EG&G Idaho

Project management for the PCDP was the responsibility of the manager of the Spent Fuel Technology Unit, Technical Support and Program Management Group, Environmental Restoration and Waste Management Department, EG&G Idaho, Inc. The responsibilities and authorities of each organization are discussed in the following paragraphs.

2.6.3.1 Spent Fuel Technology Unit (Originally Remote Technology Unit). The Spent Fuel Technology Unit manager acted as the PCDP project manager; all full-time PCDP personnel were assigned to this unit. The PCDP project manager had the following responsibilities:

- Provide overall technical management of PCDP and assume day-to-day project integration and administrative responsibility
- Prepare, issue, and maintain the PCDP Project Management Plan and Quality Program Plan
- Prepare and maintain the DOE-ID PCDP Quality Management Plan
- Prepare and maintain overall project budgets and schedules
- Prepare weekly and monthly progress reports and conduct status meetings, as necessary, to resolve problems
- Provide primary interface to DOE-ID and DOE-HQ.

The PCDP program responsibilities were broken into the following three areas:

- Project management responsibility for the PCDP.
- Contract support to DOE-ID for the technical review of contracts and deliverables for the phased design, fabrication, and cold checkout of the consolidation equipment.
- Quality assurance responsibilities were assigned to the PCDP quality assurance engineer. Quality is an integral part of all tasks.

2.6.3.1.1 Project Administration—In the area of project administration, EG&G Idaho had the following responsibilities:

- Prepare requirements and task baseline agreements for work performed by matrix or engineering personnel
- Manage scope, schedule, labor, and costs of assigned projects by negotiating and establishing budgets and schedules, authorizing and monitoring costs and schedules, and identifying and resolving problems to achieve optimum use of resources for assigned tasks

- Direct other PCDP project engineers in completion of project tasks
- Provide administrative and technical support of subcontracts for procurement of materials and services for assigned tasks.

2.6.3.1.2 Contract Support—In the area of contract support, EG&G Idaho had the following responsibilities and authorities:

- Participate as a member of the TEC, to provide technical review and to evaluate major products from the Phase III equipment contractor.
- Provide technical information to the Phase III contractor in areas not affecting project cost, scope, and schedule.
- Monitor equipment contractor performance by periodic visits to the contractor's facility and provide to DOE-ID a periodic summary and evaluation on technical, schedule, and budget performance.
- Provide for the receipt, distribution, and review of the equipment contractor's technical transmittals. Provide to DOE-ID review comments on the equipment contractor's transmittals.
- Maintain the official PCDP technical file, project files, and QA records for DOE-ID.
- Witness equipment cold testing and provide approval for final acceptance.
- Perform quality assurance overview of the equipment contractor and report status to DOE. This includes reviews and concurrence of the Quality Program Plans (QPPs) and quality procedures. It also includes performing periodic audits to ensure conformance with NQA-1 and OCRWM directives.
- Provide project integration and administrative functions as directed by DOE-ID.
- Provide technical assistance to the DOE-ID PCDP SEP chairman.
- Design and procure mockup fuel assemblies, canisters, and containers to support the equipment testing program.

2.6.3.1.3 Quality Assurance—The PCDP QA engineer had the following responsibilities:

- Help the PCDP manager prepare project quality documentation.
- Provide review of procurement requisitions and Site Work Releases (SWRs)/integrated planning.
- Perform incoming inspection and nonconformance reporting.

- Perform periodic internal auditing of PCDP project.
- Report quality findings.
- Perform inspection and acceptance of work as required by approved work release documents.
- Provide QA overview of equipment contractor in support of the DOE-ID administered Phase III contract. This includes review of QA documents and performance of the contractor as directed by DOE-ID.

2.6.3.2 Engineering Research and Applications Department. This Department had the following responsibilities:

- Provide engineering design and analysis support for PCDP tasks in accordance with applicable design and task baseline agreement requirements
- Provide engineering drawings in accordance with applicable Engineering Standard Practices and PCDP PMP Configuration Management Plan, Section 14
- Provide for the review and documentation of designs and analyses to ensure that they met the applicable standards and design requirements
- Initiate purchase requisitions, work releases (WRs), and SWRs in support of tasks, as authorized by the task baseline agreement
- Provide field engineering support for construction and fabrication activities performed by outside subcontractors and the Phase III equipment contractor.

2.6.3.3 Environment, Safety, and Quality (ES&Q) Department. The ES&Q Department had the following responsibility:

- Review PCDP design, fabrication, installation and operation documentation to ensure compliance with applicable safety regulations.

2.6.3.4 Procurement. Procurement personnel were responsible for processing and tracking procurement actions for all materials and services supporting the PCDP.

2.6.3.5 Business Management Services. Business Management Services had the following responsibilities:

- Prepare cost estimates and budgets using information from contributing organizations and under the direction of cognizant task manager
- Enter budget information in the EG&G Idaho, Cost and Planning System (CAPS)
- Monitor cost data and prepare cost reports

- Provide cost analysis support to project engineer.

2.6.4 NUS Corporation

As the Phase III contractor, NUS had the following responsibilities:

- Fabricate, procure, assemble, checkout, and test all systems, hardware, components, software, and controls of the prototypical rod consolidation system
- Develop reports, procedures, manuals, and as-built drawings of the prototypical rod consolidation system and supporting systems
- Disassemble, package, ship, and deliver all systems, hardware, components, software and controls, test results and, documentation to the final destination after completion of the Cold Checkout Test Program (CCTP).

2.6.5 Technical Evaluation Committee

The chairman of the SEP appointed the members of the TEC to evaluate the final products from each phase and the proposals for the follow-on phases. The TEC membership was comprised of a representative from each of the following:

- DOE-HQ (technical program representative)
- DOE-ID Civilian Rad-Waste Branch (technical program representative)
- DOE-Nevada
- EG&G Idaho (project management).

The following members served as independent technical consultants:

- J. W. Voss (Golder Associates)
- H. Yook (Martin Marietta)
- A. K. Jowdy (Ralph M. Parsons Co.).

EG&G Idaho provided management control, technical assistance, and contract monitoring services for the project.

2.7 Quality Program

A separate PCDP Quality Program Plan, EG&G Idaho QPP-128, was developed for this project. QPP-128 invoked the requirements of NQA-1, DOE Order 5700.6C, "Quality Assurance," and additional requirements of OCRWM as they applied to this project. EG&G Idaho also prepared and updated the DOE-ID PCDP Quality Management Plan.

3. EQUIPMENT DISPOSITION

After cold checkout testing was complete, the RCS equipment was dismantled and shipped to the YMPO and UNLV. The equipment is being stored until required for use in the UNLV Robotics Laboratory. Government furnished mockup fuel assemblies were disposed of to various organizations or shipped to the INEL for future use.

When this project was initiated, the national geological repository was expected to be one of, if not the prime user of this type of equipment. Although consolidation is not presently considered an option for spent fuel processing, the YMPO was interested in holding the equipment for possible future investigation. Accordingly, the rod consolidation equipment developed by NUS was shipped to the YMPO in Las Vegas, Nevada. The YMPO has loaned much of the equipment to UNLV for use in its Robotics Laboratory, and is storing the remainder at the Nevada Test Site. The equipment loaned to UNLV consists primarily of the general purpose equipment: the computers, electronic control equipment, the RM-10A remote manipulator, the robotic bridge transporter (RBT), and the manipulator transporter. The special purpose fuel handling and manipulating equipment is currently being stored by YMPO. This includes cutting systems, staging system, rod pulling equipment, rod compaction system, and canister loading equipment.

Twenty-four mockup fuel assemblies were procured for the project. Most of the fuel was manufactured by the original fuel vendors to simulate operational fuel assemblies, including simulating postulated failure modes. After completion of the test program, some assemblies were provided to DOE programs for research or public relations. Recipients were YMPO, UNLV, TRW Environmental Safety Services (TESS), DOE RW-5, and the Sacramento California, Municipal Utilities District (shipped to YMPO). The remaining assemblies, spare parts, and special tools were shipped to the INEL and placed in storage for possible future use. A summary of mockup fuel information and disposition is shown in Tables 1 and 2. Funds have been programmed to store the equipment for at least 10 years.

Table 1. Mockup fuel assemblies—disposition.

Manufacturer	Type	Matrix	Quantity	Cost (\$ ea)	Total cost (\$)	YMPO	RW5	TESS	IST ^a	INEL
Babcock and Wilcox	I C1 1	15 × 15	1	137,484	137,484	1	—	—	—	—
Babcock and Wilcox	I C12	15 × 15	1	49,555	49,555	—	—	1	—	—
Babcock and Wilcox	II	15 × 15	1	62,624	62,624	—	—	—	1	—
Combustion Engineering	II	14 × 14	2	34,827	69,654	—	—	—	—	2
General Electric	I P1	8 × 8	4	12,900	51,600	—	2	2	—	—
General Electric	I P2	8 × 8	8	12,900	103,200	—	2	—	—	6
Westinghouse	I	15 × 15	3	49,214	147,642	2	—	1	—	—
Westinghouse	II	15 × 15	2	200,000	400,000	1	—	—	—	1
Westinghouse	I	17 × 17	2	50,000	100,000	—	—	—	2	—
Totals			24		1,121,759	4	4	4	3	9

Type 1 assemblies represent authentic fuel assemblies.

Type II assemblies are short and have two upper end fittings.

P1 assemblies are slightly shorter than P2.

C1 1 assemblies are "new condition."

C1 2 assemblies simulate irradiated assemblies with different length rods and can use the mockup bent and broken rods supplied.

a. Disassembled during integrated system tests and shipped to INEL.

Table 2. Spare parts and tools stored at the INEL.

	Number boxes	Estimated cost (\$)	Estimated weight (lbs)
Babcock and Wilcox	4	99,901	1,065
Combustion Engineering	1	84,695	525
General Electric	2	12,000	490
Westinghouse	6	104,825	1,556
Totals	13	301,421	3,636

4. TEST PROGRAM

4.1 Test Philosophy

The PCDP CCTP was planned to verify the operation of the RCS and associated equipment under normal, off-normal, and maintenance conditions prior to the hot demonstration of the system in Phase IV. NUS prepared a formal test plan, *Prototypical Spent Fuel Rod Consolidation System Test Plan*, NUS Specification No. 9315-P-106, to define the testing program and ensure that all contract requirements were considered.

The contract required functional testing of all components and systems comprising the rod consolidation system, all supporting and handling systems, and the complete control system. This functional testing was to be performed in sequence from component testing to subsystem testing to full system testing.

The first testing phase consisted of construction component testing for purchased equipment, and factory acceptance tests (FAT) for equipment fabricated by NUS subcontractors. These tests were performed to verify the fit and function of each fabricated part or catalog item.

As each individual system was completed, a System Operation Test (SOT) was performed. The SOTs were performed under both loaded and unloaded conditions to verify all critical dimensions, to verify operability through the full range of motion, verify equipment interfaces, and to verify the computer interface, interlocks, and permissives. The equipment was first tested under manual control and then tested under the computer control system.

The Integrated System Test (IST) was to be performed after all systems were assembled, interconnected, and had completed an SOT. The entire RCS was to be tested, using mockup fuel assemblies and operating the system by the computer control system.

EG&G Idaho provided a resident engineer to witness performance of all SOTs and ISTs. This coverage was provided by the rotating assignment of project engineers from Idaho Falls to the Pittsburgh Cold Test Facility.

In March 1992, NUS informed DOE-ID that the proposed test program could not be completed in the hours originally estimated. Also at that time, DOE determined that rod consolidation would not be considered for the future geological repository or any planned MRS facility, and cancelled Phase IV, hot demonstration, of this project. Accordingly, DOE-ID declined to purchase additional test hours, and entered into negotiations with NUS to refocus the test program to obtain the maximum information and benefit from the project with the remaining funds. The revised test program, which processed one fuel type only, is referred to as the Refocussed Test Program.

4.2 Construction Component/Factory Acceptance Testing

Commercially procured standard catalog items were not subjected to formal acceptance testing by NUS. NUS procurement agreements with vendors required them to perform their

normal factory testing for production runs and then submit certifications of conformance to the NUS requirements.

Commercially procured engineered systems were subjected to acceptance tests at the vendor's facilities. The vendor was required to prepare the formal test procedures for approval by NUS. Performance of all FAT procedures were monitored by NUS personnel; selected FATs were monitored by EG&G Idaho personnel (representing DOE-ID). The following systems were subjected to these tests:

- Control System Cabinets and Panels
- Operator Console
- RM-10A Remote Manipulator
- Robotic Bridge Transporter
- Manipulator Transporter
- Lower Cutting System (band saw).

Systems fabricated by NUS and their subcontractors at the Cold Test Facility were subject to formal FATs. Test acceptance criteria and test procedures were developed by NUS for the system fabricator. Approved copies of the criteria and procedures were sent to DOE for review. The FAT procedures performed four basic types of tests: Operating Tests to check that all moving parts operated satisfactorily; Load Tests to verify that design loads could be accommodated without damage; Dimensional Checks to verify critical dimensions; and Component Removal Tests to verify that components were accessible and could be removed by the remote operation. FAT procedures were prepared for the following systems:

- Rod Extraction System
- Clamping Table
- Downender
- NFBC Upender
- Fuel Assembly Handling Fixture
- Fuel Canister Upender
- Rod Compaction System
- Waste Collection System
- Waste Container Transfer Fixture

- Staging and Cutting System
- Upper Cutting System
- Lower Cutting System
- NFBC Loading System
- Robotic Bridge Transporter
- RM-10A Robotic Manipulator
- Manipulator Transporter
- Fuel Assembly Storage Rack
- Off-Normal Station
- NFBC Storage Rack
- Fuel Canister Storage Rack and Grapple
- Surveillance System
- Fire Protection System
- Radiation Monitoring System
- Control System
- RM-10A End Effectors
- Equipment Storage Rack.

Factory Acceptance Testing (FAT) began in July 1991 and concluded on May 20, 1992. Fabrication, installation, and testing of equipment not required to support the Refocussed Test Program was suspended. The final status of the FAT procedures is provided in Volume I, Table 3.1-2 of the NUS Final Technical Report (FTR).

4.3 System Operation Tests

The SOTs began in November 1991 and concluded on October 19, 1992. SOTs were started on equipment as soon as the applicable FAT was complete and the control system could support the test. The following SOT procedures were prepared and approved for the CCTP:

SOT-TP-201	Rod Extraction System
SOT-TP-202	Clamping Table

SOT-TP-203	Downender
SOT-TP-204	NFBC Upender
SOT-TP-205	Fuel Assembly Handling Fixture
SOT-TP-206	Fuel Canister Upender
SOT-TP-207	Rod Compaction System
SOT-TP-208A&B	Waste Collection System
SOT-TP-208C	Waste Container Transfer Fixture
SOT-TP-209A	Staging/Cutting System
SOT-TP-209B	Upper Cutting System
SOT-TP-209C	Lower Cutting System
SOT-TP-211	NFBC Loading System
SOT-TP-212	Robotic Bridge Transporter
SOT-TP-213	RM-10A Robotic Manipulator
SOT-TP-214	Manipulator Transporter
SOT-TP-501	Fuel Assembly Storage Rack
SOT-TP-503	Off-Normal Station
SOT-TP-504	NFBC Storage Rack
SOT-TP-505	Fuel Canister Storage Rack and Grapple
SOT-TP-600	Surveillance System
SOT-TP-600A	Fire Protection System
SOT-TP-600B	Radiation Monitoring System
SOT-TP-601	Control System.

When the test program was refocussed, all work not required to support the limited objectives was suspended. As a result, only two of the SOT procedures were fully performed (SOT-TP-206 and 501). However, other SOT procedures were performed in sufficient detail to ensure that the equipment required to support the refocussed test program functioned as designed. The completion status can be found in the NUS FTR, Volume 1, Table 3.2-2.

4.4 Integrated System Test

The original concept for the IST was to operate the entire system simulating actual operation and using trained operators, approved operating procedures, and mockup fuel assemblies designed to resemble actual fuel assemblies. The equipment would be operated in the normal operational mode to observe and document the expected performance. Following normal operations, simulated problems would be introduced. This phase, off-normal testing, would test equipment operation in the event of problems predicted in the Design Basis Accident Report and the Failure Mode and Effect Analysis. Finally, remote maintenance operations would be performed to verify that selected equipment could be repaired or removed by remote operations. The following test acceptance criteria and test procedures were prepared for the proposed IST:

IST-TP-215	Normal Operation
IST-TP-216	Off-Normal Operation
IST-TP-217	Maintenance Operation.

When the Refocussed Test Program was implemented, the normal operations were significantly reduced and the off-normal and maintenance testing was eliminated. NUS prepared

a revised normal operation test procedure, IST-TP-215A—Normal Operation (Reduced Testing), to test the most significant portions of the equipment.

Work on this test procedure began on November 11, 1992, and concluded on November 19, 1992.

4.5 Photographic Documentation

Still 35 mm photographs were taken during the SOTs and ISTs of individual consolidation equipment systems with close-ups of unique or complex system mechanisms. Proof sheets and a log identifying the photographs were submitted by NUS. The ISTs were recorded on videotape. The video record documented the equipment functional performance during the testing. A picture album of selected still photographs and a videotape production of the test program are available by request.

4.6 Problems and Recommendations

All problems experienced by NUS during the testing phase are documented in the NUS Final Test Report, along with their recommendations. EG&G Idaho grouped the NUS comments into major categories and provided additional comments in Section 6 of this report.

4.7 Summary

Test results are summarized by NUS in Volume I of the FTR. With the cancellation of Phase IV, the test program was not as comprehensive as originally intended. All test objectives of the Refocussed Test Program were completed successfully. Future programs should stress the importance of software configuration control and formal testing methods.

5. FINANCIAL AND SCHEDULE SUMMARY

This section presents the Phase III funding in detail. (Summary information only is provided for Phases I and II; detailed information can be found in the Phase I and II reports.) Phase III work for PCDP was funded under two contracts. The equipment design, fabrication, assembly, and testing was performed by NUS under DOE-ID contract DE-AC07-86ID12651. EG&G Idaho provided engineering and contract monitoring services to DOE-ID under the INEL master site contract DE-AC07-76ID01570.

5.1 NUS Budget Summary

The contract with NUS to begin Phase I was awarded in 1986 and was modified to support Phases II and III, as required. A summary of the Limit of Government Obligation (LOGO) funds for Phase III and the funds obligated to NUS by each contract change is shown in Table 3. All funds obligated to NUS were invoiced, as shown in Table 4. A total of \$38,974 of management reserve fund was not obligated and will be reprogrammed by DOE-ID. Phase III direct costs paid to NUS amounted to \$17,179,731.

5.2 EG&G Idaho Budget Summary

Table 5 contains information on the costs expended by EG&G Idaho to provide contract monitoring services to DOE-ID during Phase III. Work started in 1989 with \$940K carryover from Phase II, and an additional \$5,899.4K was provided as new work during 1989 through 1993. Of this, \$64.5K was reprogrammed to other work by DOE-ID, leaving a total available of \$6,774.9K.

As of August 30, 1993, EG&G Idaho has expended an estimated \$6442.8K, and expects to complete the project by the end of calendar year 1993. EG&G Idaho will retain approximately \$12K to store the remaining mockup fuel assemblies for at least 10 years. The remaining \$320K will be used to complete the project. Any unexpended funds will be returned to DOE-ID.

5.3 Total Cost of PCDP

A summary of the total cost of all phases of the PCDP is shown in Table 6. These figures contain the costs for purchasing the mockup fuel, which is included in the figures for EG&G Idaho during Phase III, and the cost of other contractors who participated in Phases I and II. The project expended a total of \$34,357K. Phase IV was estimated to cost approximately \$23,570K, and the total cost would have been nearly \$58M if Phase IV had been approved.

Table 3. Summary of LOGO and funds obligated.

			Obligated to NUS (\$)	Total obligated (\$)	
Phase I					
Basic Contract				295,938	295,938
Phase II					
Modification No. A001				1,000,000	1,295,938
Modification No. A002				575,572	1,871,510
Modification No. A003				100,000	1,971,510
Modification No. A004				40,000	2,011,510
Modification No. A006				46,400	2,057,910
	Increase LOGO (\$)	Total LOGO (\$)		Phase III total obligated (\$)	
Phase III					
Modification No. A005	9,500,000	9,500,000	9,500,000	9,500,000	2,057,910
Modification No. A011	5,500,000	15,000,000	5,500,000	15,000,000	17,057,910
Modification No. A013		15,000,000	80,471	15,080,471	17,138,381
Modification No. A015	2,173,695	17,173,695	2,173,695	17,254,166	19,312,076
Modification No. A020	6,036	17,179,731	6,036	17,260,202	19,318,112
Modification No. A022	(80,471)	17,099,260	(80,471)	17,179,731	19,237,641

Table 4. Phase III NUS invoice payments.

Activity	FY-89 (\$K)	FY-90 (\$K)	FY-91 (\$K)	FY-92 (\$K)	FY-93 (\$K)	TOTAL (\$K)
Procurement	299	5,769	699	1,860	0	8,627,471
Fabrication	0	1,841	1,078	918	0	3,837,000
Installation	0	145	317	396	0	857,646
Test preparations	0	31	46	130	0	207,013
Miscellaneous	335	614	480	254	627	2,309,431
Shipment	0	0	0	0	270	269,984
Refocussed test	0	0	0	242	0	242,345
Total invoiced	634	8,400	2,620	3,800	897	16,350,890
Withholding	0	996	0	4	(1,000)	0
Paid, fixed price	634	7,404	2,620	3,796	1,897	16,350,890
UP and T&M testing					823	822,805
Mockup fuel boxes					6	6,036
Contract total						17,179,731

Table 5. PCDP funding history for EG&G Idaho.

Fund category	FY-89 (\$K)	FY-90 (\$K)	FY-91 (\$K)	FY-92 (\$K)	FY-93 (\$K)	FY-94 (\$K)	Total (\$K)
BA available to EG&G	2,710.0	1,000.0	970.0	829.4	390.0	0.0	5,899.4
Previous year carryover	940.0	1,944.6	766.0	668.2	406.6	232.1	—
Carryover + BA	3,650.0	2,944.6	1,736.0	1,497.6	796.6	232.1	—
Reprogrammed	0.0	0.0	0.0	0.0	(64.5)	0.0	(64.5)
Total available funding	3,650.0	2,944.6	1,736.0	1,497.6	732.1	232.1	—
Expenditures	1,705.4	2,178.6	1,067.8	1,091.0	500.0 ^a	232.1	6,774.9
Uncosted	1,944.6	766.0	668.2	406.6	232.1	0.0	—

Summary of estimated FY-93 expenditures

Reprogrammed	Summary, Phase III
Documentation upgrade	BA available to EG&G
Mockup fuel boxes	Carryover, Phase II
Total	Reprogrammed
	Expenditures
	TOTAL

a. Estimated.

Table 6. PCDP total costs.

Phases completed	DOE contracts (\$)	EG&G Idaho (\$)	Combined total (\$)
Phase I Preliminary design	2,042	1,448	3,490
Phase II Final Design	4,553	2,359	6,912
Phase III Cold testing	17,180	6,775	23,955
Total expended	23,775	10,582	34,357
Phase IV Hot demonstration	1,485	22,085	23,570
Original total program	25,260	32,667	57,927

5.4 Schedule Performance

In FY 1988, the final designs of NUS and NUTECH were evaluated and DOE selected the NUS design for Phase III of the project. A contract was negotiated and signed with NUS. Phase III was scheduled to began on June 5, 1989, and to complete 29 months later, in October 1991.

Shortly after the contract was awarded, the mechanical fabrication company selected by NUS, Pennsylvania Tool and Gages, Inc., dropped out of the project and NUS had to select another fabricator. Contraves-USA was selected, and the Cold Test Facility was set up in a Contraves-USA building in Pittsburgh, near the machine shops performing the fabrication. Changing fabricators caused a significant delay in the NUS work. Additionally, the NUS design had been approved with many missing details when the contract was awarded, causing additional delays before fabrication could begin. In December 1991, NUS was formally granted a nine month extension to the contract, with a new completion date of June 23, 1992.

In early 1992, Contraves-USA stopped all mechanical work. NUS subcontracted the remaining fabrication and installation services to Pennsylvania Tool and Gages, Inc., and U.S. Tool and Die, Inc. NUS did not maintain their published schedule for fabrication, installation and testing, and in March 1992, NUS informed DOE-ID that they could not complete the final installation and planned test program with the available funds.

Consequently, DOE-ID and NUS entered into negotiations to refocus the test program to obtain the maximum information and benefit from the project with the remaining test hours. As a result, all work not directly supporting the Refocussed Test Program was suspended. NUS completed the refocussed test program in November 1992, and completed the reduced work scope on the Phase III contract in August 1993.

NUS stated that they had an agreement with Pennsylvania Tool and Gages, their first fabricator, that fabrication could begin with the incomplete drawings and the fabricator would provide the missing details. When Pennsylvania Tool and Gage withdrew, NUS had to assume the task of providing the final details. This appears to have contributed significantly to the delay in final design and fabrication.

6. SYSTEM AND EQUIPMENT RECOMMENDATIONS

As required by Contract No. DE-AC07-86ID12651, Modification No. A005, Paragraph C.3 (c)7, "The Contractor shall provide a Final Report which describes all Phase III activities. The Final Report format and contents shall be in accordance with the Final Report Outline in Section J." The Final Report Outline in Section J, Attachment 1 of the contract, specifies that the contractor must classify the recommendations as follows:

- **Additional Cold Tests**—Component/System changes, material changes, reliability tests, and closure systems for specific canister configurations.
- **Phase IV Tests**—Recommended equipment modifications, additional analysis recommended, data expected, and number of tests required.
- **Design Modifications and Improvements**—Description of modifications at the component, subsystem, and system level that would enhance system throughput, reliability, and maintainability. This description also includes narratives on the effects on the equipment layout and the rod consolidation system performance if current cell dimensions were optimized.

6.1 NUS Recommendations

According to the NUS Phase III FTR, Volume I, Section 7.2, a considerable number of design changes that result in modifications to the existing system must be implemented before the system can be utilized to process actual spent nuclear fuel from commercial nuclear power plants. These modifications are necessary to achieve the design FRs to process 750 MTHM spent fuel per year based on a 60/40 split between PWR/BWR fuel types, to permit remote control of necessary in-cell activities, to recover from off-normal events, and to perform in-cell maintenance and component changeout activities.

The following section is a summary of the recommendations included in the NUS Phase III FTR. These recommendations were taken from the following sections of the FTR:

- **Volume I, Section 7—Recommendations**
- **Volume II, Section 2.5.2—Design Considerations**
- **Volume II, Section 3—Detailed Design Description (Paragraph 5 of each system description).**

6.1.1 Recommendations for Additional Phase III Cold Cell Testing

In the NUS Phase III FTR, Volume I, Section 7.3, NUS recommended completing the original scope of the Cold Checkout Test as defined in the NUS Test Plan, and some additional tests to resolve problems discovered during the tests that were performed. Since Phase IV has

been cancelled, no additional testing will be performed. EG&G Idaho would agree with the proposed additional testing if Phase IV is revived at a later date.

6.1.2 Recommendations for Phase IV Testing

Volume I, Table 7.3-1, of the NUS Phase III FTR lists the recommendations for Phase IV Testing. Since Phase IV was deleted in 1992, these recommendations will not be discussed.

6.1.3 Recommendations for Design Modifications and Improvements

During the course of the setup and testing of the PCDP System, many potential improvements to the design were identified. These design improvements are based on observations and evaluation of the system performance during operation and testing. NUS recommendations were classified into the following categories for discussion, and are followed immediately by the EG&G Idaho comments on the recommendations:

- **Logic Revisions**
- **Rod Extraction and Compacting Equipment Modifications**
- **Clamps—Design Improvements**
- **Video/audio Improvements**
- **Instrumentation Improvements**
- **Cell Dimensions and Layout Changes**
- **Drive System Improvements**
- **Adjustment or Alignment Corrections**
- **Fuel Canister and NFBC Container Modifications**
- **Control System/Software Revisions**
- **Tool Recommendations**
- **Mockup Fuel Recommendations.**

6.1.3.1 Logic Revisions. The largest category of NUS recommendations involved changes to the system logic. These recommendations included revisions and/or additions of reference points, enhancement to reporting capabilities, improved display screens, and reevaluation of many program interlocks. All recommendations were suggestions to enhance usability and to simplify movement of the system during normal operations.

EG&G Idaho comments: "Most of the NUS recommendations are the result of incomplete program development and testing, and can be resolved by changing the control program. In any system of this complexity, many improvements will be discovered when the program is put into use. Many of the recommendations were aimed at adding to or changing the information displayed or available to the operators; these can only be evaluated during actual operations. EG&G Idaho agrees with the recommended changes, and expects many more to surface if the equipment is ever placed into operation."

6.1.3.2 Rod Extraction and Compacting Equipment Modifications. The second most frequent category of recommendations dealt with rod extraction and compacting equipment. NUS recommends redesign of the pull head assembly to increase motor speed, to simplify installation during remote operations, and to allow the grippers to open a greater distance. NUS also recommends modifications to the extraction table and associated equipment to augment rod support and rod transfer functions. Additional recommendations included lengthening and increasing the number of rake extensions, installing additional hold down supports, and increasing the number of support rails on all rod handling equipment. All recommendations involved improvements to rod handling capabilities.

EG&G Idaho comments: "EG&G Idaho engineers generally agreed with the NUS recommendations to improve the rod extraction and compacting systems. Most of the recommendations would resolve minor problems with the system. EG&G Idaho does not believe that the present gripper design can be easily modified to work more effectively, and would recommend a complete redesign of the gripper mechanism."

6.1.3.3 Clamps—Design Modifications. NUS recommends modifications to the clamps and the clamp drive system to improve fuel assembly transport and storage. These recommendations involve redesigning the clamps to prevent rotation of the fuel assemblies, increasing clamp openings, improving the alignment and location of gripping, increasing range of movement, spring loading the clamps, and several additional recommendations to improve control of the clamping forces.

EG&G Idaho comments: "The clamps designed by NUS were generally inadequate. The major problem was the inability to control the clamping forces to provide a secure grip without damaging the item being held. The NUS design measured the clamp forces directly, stopping the motor when the force reached a certain level. However, the force increased suddenly when the clamps came into contact with the fuel assembly, and the computer could not react quickly enough to prevent the forces from exceeding the high limit. EG&G Idaho does not believe that the NUS recommendation to increase the control system sampling speed is the best solution. The clamping mechanism should be redesigned to eliminate the sudden increase in pressure (possibly by adding a "spring" to the clamp) or to provide a drive motor with controllable torque."

EG&G Idaho generally agreed with the other recommendations, although the specific engineering solutions presented must be evaluated.

6.1.3.4 Video/Audio Improvements. Recommendations for improvements to the video system focussed mainly on relocating the cameras and video cassette recorders (VCRs). NUS suggested relocating existing cameras and adding additional cameras to improve coverage, using color cameras if radiation resistant ones can be procured, and providing zoom lenses with greater ranges. Also, NUS recommended relocating the VCRs to a console located between the two operator stations for improved accessibility. NUS also recommended replacing the existing cameras and pan/tilt units with smaller models to minimize interference with cell equipment.

NUS recommends that the audio mixing system be reevaluated to introduce the capability to select which microphone would record on which VCR and to include additional microphones on the canister closure system and both upenders.

EG&G Idaho comments: "During performance of the SOT and IST procedures, the video system proved inadequate for operator control of the equipment for all but routine tasks. Significant improvements in the system must be made if full remote control is to be implemented. EG&G Idaho agrees with the need to relocate and add cameras, the need for color to increase visibility, and the other NUS recommendations. EG&G Idaho also recommends investigation of 3-D camera systems that may have been developed since the original design requirements were specified."

6.1.3.5 Instrumentation Improvements. The NUS recommendations for instrumentation changes were general suggestions for the process cell. These included replacing proximity sensors with a more accurate method of sensing end-of-travel, redesigning the rod counters to improve on sensitivity, providing each drive system with an absolute resolver for position control, and redesigning load cells to consistently sense the presence of the fuel assemblies. Other recommendations included providing a chain tensioner on the RBT and manipulator transporter telescoping tubes to prevent backlash of gears, computer controlled breakers for the light fixtures, and the addition of several new sensors to the system.

EG&G Idaho comments: "EG&G Idaho generally agreed with most of the NUS recommendations, including the additional sensors and absolute resolvers to the system. The proximity sensors were unreliable and had very poor repeatability, requiring repeated manual realignment and adjustment. Remote controlled maintenance of these sensors would be impossible. The rod counters were not reliable, and both NUS and EG&G Idaho recommend a complete redesign. The load cells were unreliable and failed frequently. The entire instrumentation system must be evaluated and redesigned if any future use of the system is contemplated."

6.1.3.6 Cell Dimensions and Layout Changes. NUS firmly recommends an increase in the physical dimensions of the process cell to allow better access for maintenance, to allow greater clearances between equipment, and to reduce interferences during movement of fuel and equipment in the cell. NUS recommends many changes to the layout of the cell that would allow design improvements currently restricted by the size of the cell.

EG&G Idaho comments: "EG&G Idaho agrees with the basic NUS recommendation to increase the size of the enclosure and to change the layout of the equipment, but not necessarily with any specific details. The current design was required to fit into the TAN

Hot Shop at the INEL, which severely restricted the size and layout of the equipment. These restrictions are not necessary for a generic layout, since the building can be designed to accommodate the equipment. EG&G Idaho would recommend a complete review of the design and layout if the equipment is modified for use in a generic facility."

6.1.3.7 Drive System Improvements. Recommendations for improvements to the drive system dealt mainly with increasing speed and eliminating backlash. NUS also recommends increasing the motor size for the telescoping tube drive to alleviate torque faults and to provide the pusher drive screw with a structural support sleeve to allow the drive system to operate at full capacity.

EG&G Idaho comments: "EG&G Idaho agrees with these recommendations. All of them could be implemented with minor design changes."

6.1.3.8 Adjustment or Alignment Corrections. Slight misalignments with the RBT, cutting system, and interfacing equipment suggest minor adjustments to the existing design. NUS recommends redesigning the fuel assembly handling fixture and the load cell removal tool rack to allow both vertical and lateral adjustments to align with mating equipment.

EG&G Idaho comments: "EG&G Idaho agrees with these recommendations."

6.1.3.9 Fuel Canister and NFBC Container Modifications. NUS recommendations for the containers and canisters include adding remote operating capabilities to the fuel canister grapple, providing a method to control the rotation of the crane hook during transportation of the grapple, and reversing the operation of the mechanical latch on the square canister so that the cam plates extend out a greater distance when threaded up.

EG&G Idaho comments: "EG&G Idaho agrees with these recommendations. Modification of the mechanical latch is not required, since an operational facility would use a welded closure."

6.1.3.10 Control System/Software Revisions. The recommendation most crucial for the control system is the improvement of response times. The main reason for the slow response is the MODBUS network connecting the programmable logic controllers and the three IBM PC control stations. MODBUS uses a serial data transmission link operating at 19.2 K baud. NUS recommended that this network be replaced with another one with a much greater data transmission capacity. It should be noted that not all response times can be improved by switching to a faster network. For example, time to swap screens is simply a function of the combined hardware (computer operating speed, disk access speed, etc.) and software efficiency of Desqview and the disk operating system. However, these could be improved with newer, faster computers and software.

EG&G Idaho comments: "EG&G Idaho agrees with the NUS recommendation to upgrade the equipment to increase speed and computational power. The existing computers use 80386 chips operating at 20 MHz, and could be upgraded to at least a 80486DX/2, 66 MHz system for minimal additional cost."

"However, many problems and recommendations discussed by NUS were related to the control system. Slow operation speeds, improper logic, slow response time for both displays and commands, and many other problems point to serious deficiencies in the control system. EG&G Idaho believes that the control system hardware and software should be completely redesigned to improve operation and reliability."

6.1.3.11 Tool Recommendations. NUS recommendations for tool improvements include locating the pneumatic tools outside of the cell to decrease radiation degradation, adding safety lanyards to all RM-10A tools to prevent damage if dropped, and standardization of fasteners to minimize the sockets needed for the impact wrench.

EG&G Idaho comments: "EG&G Idaho agrees with these recommendations."

6.1.3.12 Mockup Fuel Recommendations. NUS suggests that mockup fuel assemblies be identical to the actual fuel.

EG&G Idaho comments: "The mockup fuel assemblies procured specifically for this program were designed to be equivalent in size, weight, and other mechanical properties of actual fuel elements. The range of tolerances in the actual fuel was also considered in the design. The NUS comment applied to several assemblies that were not specifically designed for this program, but were used in the IST. If the full testing program had been carried out, the tests in question would have been repeated with assemblies more closely resembling an actual fuel assembly."

6.1.4 Design Considerations for Generic Facility

In the Phase III FTR, NUS provided an overview of specific design changes from the baseline design that should be considered for a generic facility. These design changes should simplify the design of the equipment, improve material flow to and from the process cell, and improve system life cycle costs. In addition, some of these changes are designed to improve system operations. They should enable significant improvements in the production rate of the facility with minimal cost increase.

6.1.4.1 Recommendation 1. NUS recommends that all fuel assemblies, empty and loaded fuel canisters, empty and loaded NFBC canisters, and loading equipment be stored outside the cell. Individual fuel assemblies, fuel canisters, and NFBC canisters can be transferred into the cell from an external storage area as required during normal process operations. This option would require that the general storage area for the assemblies and the canisters be within close proximity of the cells or that an intermediate storage area be provided. In addition, it is recommended that all fuel and canisters be handled in a horizontal orientation during all transfers to and from the process cell. These changes will result in the following advantages over the baseline design:

- Significantly reduce the height requirements of the cell and equipment, therefore, simplifying the RBT requirements, simplifying seismic requirements of the equipment and cell structure, and facilitating maintenance by enabling some remote manual operations (personnel equipped with long-handled tools) to be performed through access panels in place of remote robotic operations.

- Eliminate the need to place the downender, both upenders, and all storage racks, within the process cell enabling the north/south spacing between equipment to be increased within the existing envelope, thus improving access for maintenance.
- Reduce the shielding requirements, and therefore the wall thickness; and reduces the thermal requirements as well as the associated heating, ventilation, and air conditioning requirements of the process cell without affecting the onsite storage facility requirements (since it must be designed for maximum fuel loading).

EG&G Idaho comments: "EG&G Idaho does not necessarily agree with the specific recommendations and the justifications presented by NUS, but, as discussed above (cell dimensions and layout), does agree with the need to completely review the cell dimensions and equipment layout."

6.1.4.2 Recommendation 2. NUS recommends that a separate in-line cell be provided for end-fitting removal operations. This would be an approximate 25 x 25 x 15 ft cell that would house all cutting systems. The fuel assemblies will be transferred horizontally into this cell. Once in position, the end fittings will be removed and the cut fuel assemblies transferred through the divider wall into the process cell. An independent cell for cutting operations will minimize both the spread of contamination and the safety hazards associated with the machining of zircaloy. In addition, multiple cutting systems can be used for removing the end fittings from several assemblies in parallel. This will significantly increase the throughput of the system at minimal cost to the facility.

EG&G Idaho comments: "See comments for 6.1.4.1, Recommendation 1."

6.1.4.3 Recommendation 3. NUS recommends that a separate cell be provided parallel to the process cells for the handling of fuel assemblies that cannot be consolidated (off-normal conditions). This cell should be approximately 10 ft wide and as long as the process cell (a minimum of 35 ft). It should be located adjacent to and between two process cells so that this off-normal cell can be shared by them. All assemblies that cannot be consolidated will be transferred horizontally into this cell. The assembly can then be remotely disassembled with no impact on the normal process operations. Since this cell is shared by two process cells, the major problem to be addressed is how to eliminate the potential of packing fuel rods from two different types of assemblies in the same broken rod container. This potential problem can be eliminated by having two independent process streams within the same cell.

EG&G Idaho comments: "See comments for 6.1.4.1, Recommendation 1."

6.1.4.4 Recommendation 4. NUS recommends that cable rooms be provided beneath the cell for the routing of cables to the process equipment. The cables will be routed from the control room to the appropriate cable room. Here they can be separated and spread out to the respective equipment modules. These cable rooms will be set up for complete man access during all operations. The cables should be routed to the process equipment in a shielded access pathway through the floor. All cables should terminate in the vicinity of the equipment subassemblies with a quick disconnect-type connector. The access pathway should be designed so that the quick disconnect connector can be passed through the cell floor from the cable rooms.

This approach will minimize the length of cables in the cell, thus significantly reducing the amount of cable that must be replaced. In addition, since man access is possible in the cable rooms, the task of replacing cables is greatly simplified in this design. The cable routed along the equipment in the cell will also be able to be easily replaced simply by removing the in-cell cables with the equipment modules they service.

EG&G Idaho comments: "Again, EG&G Idaho agrees with the need to evaluate all facets of equipment layout. The NUS design and installation did not adequately protect the cables from damage or minimize contamination, and any future installation must ensure that the cable installation meets industry standards for remotely maintained facilities."

6.1.5 Recommendations for Future Prototype Development Programs

NUS provided the following two programmatic recommendations for use in future programs:

- Prototype development activities should not require the enforcement of NQA-1 quality assurance requirements until the basic design has been proven in cold testing.

EG&G Idaho comments: "EG&G Idaho does not agree. DOE-ID determined that NQA-1 applied to the design and development of this equipment, intended to use the prototype equipment with real spent nuclear fuel, and intended for the contractors to include the cost of implementing NQA-1 for the project. In addition, NQA-1 requires the performance and documentation of specific design activities and must be implemented at the beginning of any project specifically designed for the nuclear industry. The requirements of NQA-1 cannot be implemented only after most of the design activities have been completed."

- Prototype development activities should be kept as simple as possible to prove basic design concepts before an extrapolation of the design is made to handle different variations of the basic design.

EG&G Idaho comments: "EG&G Idaho does not agree with the recommendation. The flexibility must be designed in from the beginning, or the basic design concept may not be amenable to the specific variations required."

6.2 Additional EG&G Idaho Recommendations

The following are additional EG&G Idaho recommendations for improvements and additional testing for future development of the PCDP:

- An exhaustive research program should be performed on physical characteristics of BWR and PWR fuel assemblies to enable all systems to easily interface with the fuel and thus eliminate the rework of the servicing subsystems.
- EG&G Idaho does not believe that the cutting system will perform reliably on all fuel types and that tool life will be adequate to process a full day's production run. The cutting tools are not remotely changeable in the current design and therefore any cutting tool change during an operational shift will reduce the production rate. EG&G

Idaho recommends performance of additional tests of the cutting systems to verify its performance.

- Thorough cold checkout testing of the control system software must be performed to verify proper operation of all system interlocks. Throughout the Cold Test Program, NUS encountered significant time delays directly attributable to the control system. One incident involved collision of the upper cutting system with an adjacent equipment structure.
- EG&G Idaho recommends that the RM-10A be replaced with another robotic system to perform the maintenance and off-normal operations. The replacement manipulator should be capable of lifting greater weight and better able to work in restricted spaces.
- The downender should be redesigned to support the fuel assembly on the top of the downender rather than underneath the clamping mechanism. This would allow for easy removal of the fuel assembly if the downender fails while rotating the spent fuel to the horizontal position. In addition, the single pivot arm driving the carriage up and down produced excessive rotational torque and stress on the carriage. The downender should be redesigned with either two pivot arms or the single pivot arm in another configuration.
- The hopper loading operation must be reevaluated. Additional cold testing should be performed to evaluate the effects of rod diameter changes due to crud buildup, swelling, etc, on the hopper loading process.

7. COST PER METRIC TON

One of the objectives of the PCDP was to generate cost data to estimate the cost of performing fuel rod consolidation on spent nuclear fuel. If the fuel is consolidated, there are obvious cost savings available to both an MRS and a geological repository. The primary advantage is that consolidated fuel would require approximately one-half the space for storage. This results in savings in the number of final storage containers required as well as saving space in the MRS or repository. Where volume and not weight are the limiting factor, the number of transportation shipments would also be reduced if the fuel were consolidated before shipment.

During the 1991 DOE-HQ Annual Project Meeting, DOE-ID made a commitment to calculate the expected cost for consolidation of spent nuclear fuel, per MTHM. Two methods of calculating the cost are presented. The calculations using the NUS lifetime costs suggest a total cost of \$7,400 per MTHM. EG&G Idaho also calculated the cost, using information extracted from the NUS Cost Data Report and additional information gained from experience in constructing and operating facilities at the INEL. This calculation estimated a total cost of \$8,200 per MTHM.

7.1 NUS Calculations

The NUS Cost Data Report calculated a total cost for a single rod consolidation cell to be located at a future geological repository or MRS facility, during 30 years of operation (the design life of the equipment). The total cost was estimated as \$166 million (1989 dollars), which included acquisition, installation, operation, and maintenance (including spare parts). Calculations are shown in Table 7.

The specifications for the equipment required it to process 750 MTHM per year, operating three shifts a day, 5 days a week. During the 30 years of operation, the cell should process 22,500 MTHM. Dividing the unit lifetime cost by the tons processed gives a figure of \$7,400 per MTHM.

After review, EG&G Idaho concluded that the NUS estimate was not accurate for several reasons. NUS states that they did not include shared costs, assuming that the equipment would be located at a larger facility. This resulted in several significant costs not being considered in the estimate. The specific concerns were as follows:

- The workpower needs estimated by NUS were significantly less than the workpower requirement for a facility handling hazardous radioactive substances, such as spent nuclear fuel.
- Real estate and physical plant costs were not considered. (Note: this was in accordance with the contract).

Table 7. Cost per MTHM using NUS estimated lifetime cost.

NUS calculations	\$K
NUS lifetime cost	166,000.0
Metric tons/year	750
Total metric tons	22,500
Cost/metric ton	7.4

- NUS used the entire cost of canisters and containers developed for the test program, including design costs charged by the fabricator. They were custom designed and built in very small quantities. Procurement of over 1,000 per year would greatly reduce the cost of containers and amortize the design costs over a great many units. For instance, NUS estimated the cost of a fuel canister at \$4,500, while EG&G Idaho believes that they could be procured in quantity for under \$1,000 each. Also, EG&G Idaho does not believe that NUS correctly calculated the current net worth of the 30-year supply of canisters and other consumables. Since the canisters and containers represent nearly 75% of the total lifetime costs estimated by NUS, reducing their cost would make a significant difference.
- NUS did not include decontamination and decommissioning (D&D) costs. The facility will be highly contaminated, and these costs will be significant.

7.2 EG&G Idaho Calculations

Because of the stated concerns with the NUS cost estimates, EG&G Idaho prepared a separate cost estimate, using NUS data where possible. This estimate is presented in the following paragraphs.

The major cost expenditures to procure and operate a spent fuel consolidation facility are initial procurement of the equipment, construction of the facility, workpower, and operation consumables for the life of the plant.

The cost of procuring a single unit of the equipment designed by NUS, with spare parts, was extracted from the NUS Cost Data Report and presented in Table 8. The total of the facility was amortized over the 30-year life, using the inflation rate assumed in the NUS Cost Data Report for the interest calculations (4.8%). The cost of a 30-year loan to purchase the equipment is shown as the annual payment in Table 8.

Table 9 presents the estimated size and costs (in 1989 dollars) of constructing a facility containing four consolidation units, the facility size recommended by NUS. The total cost is divided by four to obtain the cost per unit. Using the same methods as in the previous paragraph, the plant could be purchased for the annual payment shown in Table 9.

Table 8. Cost of rod consolidation equipment and spare parts.

ROD consolidation equipment	\$K
Purchased equipment	5,911.0
Fabricated equipment	3,206.0
Spare parts	2,717.9
Major subassemblies	1,072.8
Total cost, 1 time	12,907.7
Annual payment	820.6

Table 9. Estimated size and cost of facility.

Plant cost	Unit	Quantity	Unit (\$)	Cost (\$K)
Real estate	Acres	200	2,000	400
Operating hot cells	Square feet	12,000	1,000	12,000
Control rooms	Square feet	4,000	250	1
Hot storage/loading	Square feet	5,000	500	2,500
Hot workshops	Square feet	2,000	350	700
Cold storage/garage	Square feet	5,000	75	375
Cold workshops	Square feet	2,000	85	170
Office space	Square feet	5,000	100	500
Total	Square feet	35,000		16,646
Total, prorated 4 units				4,162
Annual payment				264.6

Table 10 presents the consumables estimated for 1 year of operation. The data is taken from the NUS Cost Data Report (in 1989 dollars) except for the cost of canisters and containers, where the EG&G Idaho estimates are used. The total represents the cost of consumables for 1 year of operation.

Table 11 presents the manpower EG&G Idaho estimates would be required to operate a facility of this size and mission, extrapolated from the manpower required in comparable facilities currently operating on the INEL. The salary column represents the estimated rates charged for equivalent work at the INEL in 1989. The total cost per year is shown for each labor category except management overhead (OH) and common support (CS) OH, which are not charged directly to the facility. The total amount is then divided among the four units, with the final amount representing the cost of labor to operate one unit for 1 year, in 1989 dollars.

D&D represent a large cost for the facility. The cost is a rough estimate, since the rules and procedures are not fixed, and forecasting requirements 30 years into the future is nearly impossible. The cost of D&D is estimated as three times the cost of construction. The yearly costs assigned for D&D represent an annual payment into an interest bearing account to yield the estimated costs in 30 years, using the same interest rates above for both future value and compound interest gain calculations. As can be seen in Table 12, the yearly cost to accumulate a very large sum in 30 years is relatively minor compared to the facility operating costs.

In Table 13, the total costs discussed above are summed and divided by the yearly production, 750 MTHM, giving an estimated cost for consolidating spent nuclear fuel of \$8,200 per MTHM.

Table 10. Estimated cost of consumables over 30 year lifetime.

Consumables	Cost/each (\$K)	Quantity (yr)	Cost/yr (\$K)
Canisters	1.0	1,077	1,077.0
Containers	0.7	538	376.6
End fitting canisters	0.5	301	150.5
Filters	—	—	3.7
Cutting tools	—	—	13.6
Welding supplies	—	—	1.5
Administration supplies	—	—	20.0
Utilities	—	—	51.0
Total cost/year	—	—	1,694.0

Table 11. Facility staffing and labor costs for 1 year operation.

Labor	FTE	hr/year	\$/hr	\$/yr (\$K)
Facility manager	1	2,000	120	OH
Operations supervisor	1	2,000	110	OH
Maintenance engineer supervisor	1	2,000	100	OH
Shift supervisor	4	8,000	100	800
Quality supervisor	1	2,000	80	OH
Administrative supervisor	1	2,000	90	OH
Operators	24	48,000	90	4,320
Maintenance	10	20,000	50	1,000
Plant engineers	5	10,000	85	850
Administrative	8	16,000	25	400
Quality engineer/insp	8	16,000	60	960
Health physics	8	16,000	50	800
Equipment operators	6	12,000	60	720
Laborers	8	16,000	30	480
Firemen	8	16,000	50	CS
Medical technician	4	8,000	50	CS
Security	8	16,000	50	CS
Totals	106	212,000		10,330
Per consolidator		53,000		2,583

Table 12. D&D cost.

		\$K
Cost of facility, prorated for one unit		4,162
D&D, multiple of cost -->	3.0	12,485
Future Value of D&D		50,958
Annual payment		794

Table 13. EG&G Idaho estimated cost per MTHM.

EG&G calculations	K\$
Equipment	820.6
Consumables	1,694.0
Labor	2,582.5
Plant	264.6
D&D	793.7
Total	6,155.4
Cost/metric ton	8.2

The results of both calculations are reasonably close. The NUS overestimation of the cost of canisters and containers apparently balances the NUS underestimation of the labor required to operate the facility. In the EG&G Idaho estimate, it is obvious that the cost of operating the facility is driven by labor costs, both the workpower required and the labor rates. EG&G Idaho believes that if rod consolidation is ever resurrected as an option, the emphasis should be placed on reducing the labor required to operate the facility (i.e., equipment automation, safety, and contamination control).

8. SUMMARY AND PROJECT CLOSEOUT

The PCDP successfully met the objectives of the first three phases of the project, which were to prove the concept and to obtain an estimate of the cost of consolidating commercial spent nuclear fuel. The objective of Phase IV, proof of operation using a prototype plant and actual spent nuclear fuel was not pursued because of the high cost and the decision of DOE to no longer consider consolidation. The cost estimates and design principles are available for any future evaluations.

8.1 Completion of NUS Contract

NUS has completed all contract requirements except completion of all software licenses to DOE. Upon transfer of the licenses, DOE-ID will approve the NUS FTR and pay the final invoice. All government equipment has been recovered and transferred to the INEL, YMPO, or UNLV, and is available for future study or other use.

8.2 Completion of EG&G Idaho Project

EG&G Idaho will complete and close the PCDP by the end of calendar year 1993. Currently, EG&G Idaho is completing its review of all remaining deliverable documents received by DOE-ID and providing QA support to ensure compliance of Phase III activities with NQA-1 requirements. The still photography album and the videotape of the test program are in progress and will be completed this year. EG&G Idaho will also provide for vendor data control and maintenance of DOE-ID project files to ensure that all project records are acquired in the Records Inventory and Disposition System. The final task will be the final reviews, documentation control, and financial audits required to close out the project.

DATE

FILMED

10/21/94

END