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Radioactive waste management

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Project 2240-2
PNL-7149
UC-85
Final Report
June 1990

Fuel Consolidation Demonstration Program: Final Report

Prepared by
Northeast Utilities Service Company
Berlin, Connecticut

REFERENCE COPY

R E P O R T S U M M A R Y

SUBJECTS	Radioactive waste management / Light water reactor fuel	
TOPICS	Spent-fuel storage Fuel rods	Radioactive waste management
AUDIENCE	Fuels engineers / R&D scientists	

Fuel Consolidation Demonstration Program: Final Report

Utilities can substantially increase the capacity of spent-fuel storage pools by using fuel consolidation systems. A demonstration at the Northeast Utilities Service Company Millstone unit 2 nuclear power station provided valuable information and operating experience for evaluating fuel consolidation systems for widespread use and led to NRC approval of a new consolidation system.

BACKGROUND	Utilities must find the means to store spent nuclear fuels until DOE can provide a repository, which is unlikely before the turn of the century. Advanced storage alternatives include on-site dry storage and spent-fuel consolidation. The latter approach has economic advantages because it effectively increases the capacity of existing reactor storage pools. In support of an NRC license, EPRI, Northeast Utilities Service Company (NUSCO), DOE, Baltimore Gas & Electric Company, and Combustion Engineering, Inc., cosponsored a program to develop consolidation methods and to demonstrate a full-scale fuel storage system. EPRI report NP-4327, revision 1, provides a preliminary overview of the entire program.
OBJECTIVE	To demonstrate that spent-fuel consolidation methods and equipment meet or exceed NRC licensing and design criteria and industry standards for equipment, structural, and personnel safety.
APPROACH	Researchers performed consolidation equipment design, development, construction, and testing at Combustion Engineering in Windsor, Connecticut. NUSCO conducted seismic and structural evaluation of the Millstone-2 spent-fuel pool capacity and obtained a partial license amendment to store a limited amount of consolidated fuel in their pool. They then made a 10 CFR 50.59 safety evaluation of spent-fuel consolidation at Millstone-2 and performed a hot demonstration of the integrated consolidation system.
RESULTS	NUSCO has now received NRC acceptance of the consolidation process and a full license to store large quantities of consolidated spent fuel. The project confirmed the technical feasibility of consolidating PWR spent fuel. The target consolidation ratio of 2:1 was consistently achieved. As expected, developers encountered minor problems of equipment operation.

One significant problem area was an inability to meet the design criteria for the treatment and packaging of residual bundle scrap hardware.

EPRI PERSPECTIVE

Through this and several other research projects, EPRI is developing a range of viable alternatives to help electric utilities meet the pressing need for spent-fuel storage. EPRI considers the spent-fuel consolidation project a key element in this program. This is the final report of the fuel consolidation demonstration project. It reviews the overall program, summarizes results obtained and lessons learned, and assesses the present status of the consolidation system developed in the program. Other reports from this project address total system concept development (EPRI report NP-6722), structural design and analysis (report NP-5945), storage area analysis (report NP-6551), and cold and hot system demonstrations (report NP-6893).

PROJECT

RP2240-2

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Fuel Consolidation Demonstration Program: Final Report

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Research Project 2240-2
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Final Report, June 1990

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NOTICE

This report was prepared by Combustion Engineering, Inc. as an account of work sponsored by Northeast Utilities Service Company (NUSCO), the U.S. Department of Energy (DOE), the Electric Power Research Institute, Inc. (EPRI), Combustion Engineering, Inc. (C-E), and the Baltimore Gas and Electric Company (BG&E). Neither NUSCO, DOE, EPRI, C-E, BG&E, their employees or members of EPRI, nor any person acting on their behalf: (a) makes any warranty, express or implied, with respect to the use of any information, apparatus, method, or process disclosed in this report or that such use may not infringe privately owned rights; or (b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

ABSTRACT

EPRI, Northeast Utilities, Baltimore Gas and Electric, the U.S. Department of Energy and Combustion Engineering are engaged in a program to develop a system for consolidating spent fuel and a method of storing the consolidated fuel in the spent fuel storage pool which is licensable by the U.S. Nuclear Regulatory Commission. Fuel consolidation offers a means of substantially increasing the capacity of spent fuel storage pools.

Consolidation equipment design, development, construction and testing was performed by Combustion Engineering in Windsor, Connecticut. A 10CFR50.59 safety evaluation of the fuel consolidation process was performed by NU together with the seismic and structural evaluation of the capability of the Millstone Unit 2 spent-fuel pool and building to accommodate the increased fuel capacity. After obtaining a partial license amendment from the NRC to store consolidated fuel in the Millstone Unit 2 spent-fuel pool, Northeast Utilities performed a hot demonstration of the integrated consolidation system with spent fuel.

This is a final report of the Fuel Consolidation Demonstration Program. It provides a review of the overall program, a summary of the results obtained, the lessons learned, and an assessment of the present status of the consolidation system developed in the program.

1981, National Highway Traffic Safety Administration (NHTSA) issued a final rule requiring the use of seat belts in motor vehicles. The rule was based on a study of the effectiveness of seat belts in reducing the risk of death and serious injury in motor vehicle crashes. The study found that seat belts significantly reduced the risk of death and serious injury in motor vehicle crashes. The rule required that all motor vehicles manufactured after September 8, 1981, be equipped with seat belts. The rule also required that all motor vehicles manufactured after September 8, 1981, be equipped with a seat belt warning system. The rule was effective on September 8, 1981.

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Section 1

INTRODUCTION

OVERVIEW

A number of methods are being considered by U.S. utilities with nuclear power plants for extending their capacity to store spent fuel on site until it can be taken over by the U.S. Department of Energy as mandated by the U.S. Nuclear Waste Policy Act enacted in 1982 and amended in 1987. The 1987 draft mission plan of the Department of Energy scheduled the first High Level Waste Repository under this act to be ready to begin accepting spent fuel in 2003. This is five years later than the department's original schedule which was used as the basis for the takeover contracts negotiated by the Department of Energy with individual utilities. Furthermore, the possibility of a monitored retrievable storage facility recommended by the DOE being completed several years in advance of this high level waste repository was essentially precluded by the Congress in amending the Nuclear Waste Policy Act in 1987. Even if there are no more delays in the permanent repository schedule therefore, it appears that utilities will have to provide spent fuel storage until at least 2003. Most utilities have replaced their original spent fuel storage racks with high capacity racks, but in many cases this alone will be insufficient to store all the spent fuel generated to 2003 and maintain the capabilities of a full core offload.

The storage methods under consideration or being proposed can be subdivided into those using dry storage techniques and those using existing pool facilities (wet storage techniques). One of the proposed wet techniques involves consolidation of spent fuel in existing facilities and was selected for a demonstration program under EPRI project RP 2240-2. This alternative was selected because:

- The cost, compared to other storage expansion alternatives, appeared attractive.
- Only modification of existing facilities was required.
- A large fraction of the required hardware had been or was being developed.

- A number of utilities can use the same generic approach in pursuing a license for the storage of consolidated fuel.

In addition, this program was enhanced by the fact that substantial cost sharing was offered by the program participants—Northeast Utilities, Baltimore Gas and Electric, Combustion Engineering and, in the latter part of the program, the Department of Energy. The consolidation was to take place at Northeast Utilities Millstone Unit 2.

PROGRAM OBJECTIVES

The objectives of RP 2240-2 were to:

- Implement and document a program that resulted in a proven process for increasing the utilities' ability to store PWR spent fuel.
- Demonstrate the technical feasibility of consolidation of PWR spent fuel in nuclear power plants using fuel storage pools.
- Determine the degree of fuel consolidation obtainable under field conditions. (The goal was a 2:1 consolidation ratio in the pool).
- Identify and solve any technical problem inherent in a spent fuel consolidation operation.
- Provide actual cost data on the licensing process, facility modification, facility operation, and consolidation equipment.
- Develop benchmarked analytical methods and related data on consolidated fuel characteristics.
- Apply for appropriate licenses to the USNRC for reracking and storage of consolidated fuel in Millstone Unit 2's pool.
- Develop nonproprietary codes for use in licensing activities.
- Present topical reports of generic value to utilities considering fuel consolidation activities.
- Design, fabricate, and demonstrate advanced fuel consolidation equipment that could be made commercially available to utilities within the U.S.
- Demonstrate equipment to handle, volume-reduce, and package waste bundle scrap.

SUMMARY OF PROGRAM AND SCHEDULE

A detailed outline of the program is given in the Program Overview Report (1). The program was divided into three phases, as follows:

- Phase I - concept development, equipment design, and methods development, testing and preliminary analysis. Phase I was begun in November 1982 and essentially completed in March 1984.
- Phase II - equipment fabrication, checkout testing, seismic and structural analysis, licensing and cold demonstration. Phase II was essentially completed in April 1987.
- Phase III - hot demonstration at Millstone Unit 2. Phase III was essentially completed in October 1987 (some equipment modification and packaging for storage occurred in 1988).

Northeast Utilities (NU) was the prime contractor for the program and undertook the evaluation of the spent fuel pool and building to accommodate the increased fuel capacity, as well as the licensing of the pool for consolidated fuel storage and the submittal of a 10CFR50.59 safety evaluation of consolidating spent fuel in the pool.

Combustion Engineering Inc., (C-E) provided the consolidation system concept and performed methods development, analysis and testing together with equipment design, development, construction and testing. C-E also provided technical supervision and the consolidation equipment operating crew for the hot demonstration.

Structural Dynamics Technology (SDT) was the consultant to NU for the seismic and structural analysis of the spent fuel pool and building.

Table 1-1 lists the program tasks and the organization responsible for performing each task. There are five volumes of EPRI technical reports on the program, and Table 1-1 indicates which volume covers the work performed in each task. The EPRI technical report volumes are:

- I. Methods Development, Testing and Design Analyses (NP-5945)
- II. Consolidation Concept Development (NP-6722)
- III. Storage Area Analysis (NP-6551)
- IV. Cold and Hot Demonstrations (in publication)
- V. Licensing (in publication)

Section 3 outlines the activities recorded in these volumes, and provides a good indication of the overall scope of the program.

SCOPE OF REPORT

This final report summarizes the results of the Fuel Consolidation Demonstration Program, discusses the lessons learned, and presents an overall perspective of the program and the present status of the consolidation system developed in the program. In addition it briefly describes the contents of the five EPRI technical report volumes, and reports on activities which occurred after the end of the hot demonstration on October 7, 1987.

Table 1-1

SUMMARY OF PROGRAM TASKS

Task No.	Task	Implementing Organization	Relevant EPRI Technical Report Volume
1	Consolidation Concept Development	C-E	II
2	Criticality Analysis and Test	C-E	I
3	Thermal Hydraulics Analysis and Test	C-E	I
4	Seismic and Structural Analysis* and Test	C-E	I
5	Consolidation Tooling and Equipment Design, Fabrication, and Test	C-E	II (Appendix A)
6	Reactivity Monitor Design Evaluation	C-E	I (Appendix B)
7	Spent-Fuel Storage Pool/Auxiliary Building Area Analyses	NU, C-E and SDT	III
8	Consolidation Procedures and Training (see Task 9)	C-E	IV
9	Cold Demonstration at C-E Windsor (includes Task 8)	C-E	IV
10	Licensing SAR Submittal	NU with C-E support	V
11	Hot Demonstration at Millstone Unit 2	NU with C-E support	IV
12	Generic Application of Consolidation Equipment to Non-C-E Fuel	C-E	II

*Except for the structural and seismic analysis of the spent fuel pool and auxiliary building, which was part of Task 7.

Section 2

RESULTS

The quantitative results of the fuel consolidation demonstration program are specifically applicable to the Millstone Unit 2 spent fuel storage facility and to 14 x 14 fuel of C-E's design. The analytical design methods which were developed, however, are generic to all PWR installations, and since Millstone Unit 2 and C-E fuel designs are typical of U.S. PWR practice, the design and performance of the consolidation equipment are representative of what can be effected at other PWR nuclear power plants.

SYSTEM DESIGN PHILOSOPHY

The philosophy of the fuel consolidation system design evolved early in the program. Initially the concept was simply an extension of the fuel reconstitution operations and tooling, and envisaged a group of individual tools lined up along the side of the spent fuel pool and manipulated by several operators. As this was discussed among the program participants a consensus developed that, although suited to a short duration reconstitution effort, such a concept had shortcomings when applied to a long production campaign of fuel consolidation. A particular concern was the possibility of errors resulting from the repetitive nature of the operations.

The eventual approach agreed upon by Northeast Utilities, EPRI, Baltimore Gas and Electric and C-E was to develop an integrated system such that the consolidation process could be operated and controlled from a central console which would require the attention of only two operators. The system was to be simple enough to gain the confidence of trained and qualified personnel, while control logic and interlocks would be employed to minimize the likelihood of operator error. Emphasis was to be placed on the positive control of fuel rod position; avoidance of fuel rod damage caused by the consolidation equipment; avoidance of radioactive contamination of the pool water due to uncontrolled release of fuel rod crud; safety; reliability and a high degree of process feedback to the operators.

The system was also to be partially automated to achieve an acceptable production rate (the target set for the hot demonstration was the consolidation of one fuel assembly per shift). Taking into consideration that the first system would be a prototype that might be operated by utility operators, utility maintenance personnel or the system design engineers, the controls and interlocks should be able to be adjusted to the level of expertise and background training of all three levels of potential operators. The interlocks should be established to be as forgiving as possible while keeping the operators out of trouble. The utilization of one or more programmable controllers would facilitate meeting these requirements.

CONSOLIDATION PROCESS

The fuel consolidation equipment is designed to operate in the nine-foot square cask laydown pool in the northeast corner of the Millstone Unit 2 fuel storage pool, which is shown in Figure 2-1. The layout of the equipment is shown diagrammatically in Figure 2-2. Consolidation is performed in batches of ten spent fuel assemblies, and Figure 2-3 is a flow diagram of the process for one batch.

A batch of fuel assemblies is brought through the cask pool gate opening by the spent fuel handling machine, which deposits nine assemblies in the temporary storage rack and one assembly in the fuel disassembly station of the lower work platform (LWP). The cask pool gate is then lowered into position. Consolidation takes place in the lower work platform and an X-Y table traversing the top plate of the platform aligns the fuel manipulating equipment accurately with the five LWP work stations in which fuel rods may be processed. The consolidation equipment is serviced by a hoist assembly traversing the cask laydown area.

Fuel assemblies are taken apart in the disassembly station by cutting off the upper end fitting and then removing fuel rods singly or up to one 14-rod row at a time by means of a multiple rod pulling tool (MRPT). Rod pulling forces are maintained between preset limits. Fuel rods are then deposited in an interim transfer canister (ITC) at the next work station. The ITC has channels that guide the rods into a close-packed triangular array at the bottom. Damaged fuel rods are deposited in the damaged fuel rod storage after being separated from the row in the separation/recovery station.

Figure 2-1. View of cask laydown pool. The spent fuel pool is in the background and the gate separating the two pools is in the rear wall of the cask pool. The upper end of the MRPT mast can be seen to the left of the gate, and the upper end of the RTT to the left of the MRPT mast.

Figure 2-2. Fuel Consolidation Equipment Layout

Figure 2-3. Process Flow Chart for Batch of 10 Fuel Assemblies

After all rods have been pulled, the lower end fitting is cut from the grid cage/guide tube assembly which is then transferred to the compaction station. The upper and lower end fittings are deposited in an end fitting storage box (EFSB).

Fuel rods in the ITC from two intact assemblies are transferred by gravity into a consolidated fuel storage box (CFSB) located in the fuel transfer station. Descent of the rods is controlled by a telescoping cylinder acting on the bottom of the ITC floor, which is also transferred into the box. A deadweight type of rod transfer follower tool (RTT) positioned on top of the ITC serves to verify that all fuel rods have been transferred. The close-packed triangular rod array results in a compaction ratio of 2:1. A cover with an accountability tab is locked on to the CFSB which is then deposited in the temporary storage rack.

As described above, fuel assembly end fittings are placed in storage boxes at the end fitting storage station. Grid cages and guide tubes have a much larger bulk volume and are compacted hydraulically before discharged into compacted waste canisters (CWC) at the compaction station. When they are filled, EFSBs and CWCs are placed in the temporary storage rack.

A filtration system is connected to the fuel disassembly, ITC, and fuel transfer work stations to collect and filter out radioactive particulates generated by operations performed at these stations. The MRPT is enclosed by a shroud assembly that provides guidance and alignment and vents released gases to the plant gas handling system.

When the batch of ten intact fuel assemblies have been consolidated, the cask pool gate is removed and the CFSBs, EFSBs and CWCs are transferred from the temporary storage rack into the spent fuel pool by the spent fuel handling machine. Another batch of spent fuel is moved into the cask pool, the gate is replaced and the consolidation cycle is repeated.

The consolidation system is operated from a control console on the work platform of the hoist assembly. Control logic is programmable to allow for changes as experience is gained. A TV system is provided for remote viewing of all consolidation operations.

Most of the components referenced above are shown in Figures 2-4 through 11.

Figure 2-4. Hoist Assembly

Figure 2-5. Consolidation equipment in Windsor mockup pool. Lower work platform in center; work stations from left to right are: fuel transfer (ITC stabilizer frame above) and end fitting storage; ITC with X-Y table; fuel disassembly; and damaged rod storage. Two filter skids with suction manifold are in front of platform. In foreground are temporary storage rack with dummy fuel assemblies and, on right, shroud for MRPT.

Figure 2-6. End view of top plate of lower work platform. Support frame for compactor bolts to plate area in foreground. First work station is damaged rod storage with row of separation/recovery fuel rod tubes to left. Second work station is fuel disassembly, and X-Y table behind that is positioned over ITC station. Rail projecting from left edge of platform is for TV system camera.

Figure 2-7. Lower end of MRPT shroud showing flange for locating in X-Y table, and fuel rod guide bar opening/closing mechanism.

Figure 2-8. View looking up from lower end of interim transfer canister with gate removed, showing corrugated section that rearranges fuel rods into triangular array.

Figure 2-9. Compactor being bolted to lower work platform in cask laydown pit. Two horizontal ram hydraulic cylinders and inlet funnel (covered with plastic sheet) can be seen. Third, vertical, ram with cylinder bolts over square opening into compaction chamber.

Figure 2-10. Consolidation equipment installed in cask laydown pit before flooding. Components in storage locations, clockwise from left-hand wall of pit: rod transfer verification tool with square open framework; single rod pulling tool mast and shroud; multiple rod pulling tool and shroud; temporary storage rack (below cask pit gate); miscellaneous handling tools; lower work platform and compactor.

Figure 2-11. Control console, mounted on platform of hoist assembly. Console has three sections. Left hand section has controls for power supply, TV cameras and compactor; center section has controls for TV cameras and hoist assembly; and right hand section has controls for pool lights, MRPT and X-Y table.

MILLSTONE UNIT 2 SPENT FUEL STORAGE POOL

The arrangement of the Millstone Unit 2 spent fuel storage pool has been redesigned to take advantage of the proposed Revision 2 of NRC Regulatory Guide 1.13, "Spent Fuel Storage Facility Design Basis", which permits credit to be taken for reactivity depletion in spent fuel. This change made it possible to locate spent fuel assemblies substantially closer together in the racks and to divide the pool into two regions, thereby achieving the maximum utilization of the space available for storage.

Region I is the high-enrichment, core off-load region, and its storage rack modules contain a neutron poison insert in each cell. The nominal center-to-center cell spacing is 9.8 inch. Fuel assemblies or consolidated fuel can be stored in every location.

Region II is reserved for fuel that has sustained at least 85% of its design burnup. Fuel assemblies to be consolidated will be taken from Region II. The storage rack modules in Region II do not contain neutron poison inserts and the nominal center-to-center cell spacing is 9.0 inch. Fuel assemblies are stored in a three-out-of-four pattern. The fourth cell of the pattern remains empty to provide the flux trap for reactivity control. A blocking device is used to prevent a fuel assembly being inadvertently placed in the fourth cell. Consolidated fuel can be stored in any unblocked cell in Region II, and also in a blocked cell (after removal of the blocking device) if all the adjacent cells contain consolidated fuel.

ACHIEVEMENT OF PROGRAM OBJECTIVES

Program Implementation and Documentation

The development part of the program had two main aspects. The first was the development of the system for consolidating the fuel and the second was the development or verification of provisions for storing the consolidated fuel in the spent fuel pool.

The fuel consolidation system was developed from a C-E concept based on the company's extensive experience with reconstituting fuel and made use of or adapted much of the tooling proven in reconstitution operations. The five major items of new equipment which had to be developed were: the means of extracting several fuel rods at a time from a fuel assembly—the multiple rod

pulling tool; the means of repacking the fuel rods into a close triangular array - the interim transfer canister; the storage box for consolidated fuel; the means of reducing the volume of the non fuel bearing components - the compactor; and the overall control system. In accordance with the design philosophy discussed above, the original system concept was modified and a considerable effort was expended in developing the control logic and interlock software. The end result was that the consolidation system as built has the capability of being adjusted to a greater or lesser degree of control automation depending on the classification, background and skill of the operators.

NU planned to re-equip the Millstone Unit 2 spent fuel pool in 1986 with high capacity racks for storing intact fuel assemblies, and the fuel consolidation demonstration program developed analytical methods and performed design analyses to demonstrate that the re-racked facility would also be adequate to store consolidated fuel.

Development of the fuel consolidation system culminated in a demonstration (known as the cold demonstration) of the hardware and equipment with dummy fuel bundles in a full scale mockup of the Millstone Unit 2 cask laydown pool at C-E's Engineering Development Laboratory in Windsor Connecticut.

NU requested from the US NRC, and was granted, a partial license amendment to permit the storage of five consolidated fuel storage boxes of consolidated fuel, so that the field demonstration could be performed. The field demonstration (known as the hot demonstration) took place in the cask laydown pool at Millstone Unit 2 and successfully consolidated six spent fuel assemblies. The consolidation equipment worked well except for initial shakedown problems described below, and performed as expected. The non-fuel waste compactor completed one compaction cycle but was unable to discharge the compacted waste due to a malfunction. The compactor was repaired and modified after the demonstration was completed, but no further processing was conducted under this program.

On the basis of the above developments, NU was successful in obtaining a license amendment to consolidate and store consolidated fuel at Millstone Unit 2.

The program was documented in five EPRI technical volumes, a technical manual of the equipment, and detailed procedures for equipment installation, operation and removal. In addition more than thirty technical subtask reports, including test reports, were produced. A licensing plan and two safety analysis reports were prepared for NU's submittals to the NRC.

Feasibility of Fuel Consolidation

The hot demonstration confirmed the technical feasibility of consolidating PWR spent fuel at a nuclear power plant and storing the consolidated fuel in the spent fuel pool.

Consolidation Ratio

A consolidation ration of 2:1 was consistently achieved with spent fuel in the hot demonstration. All 352 fuel rods from each pair of 14 x 14 fuel assemblies were deposited in close triangular array in one consolidated fuel storage box which would occupy one cell in the spent fuel pool storage rack.

Technical Problems

Most of the technical problems in the consolidation of spent fuel and storage of consolidated fuel were identified at the outset of the program and the activities necessary to resolve them were the basis of the program itself. These activities are summarized in the task descriptions provided in the Program Overview Report (1), and the solutions achieved are described in the five EPRI technical report volumes.

During the evaluation of means of disposing of the fuel assembly scrap hardware (a subtask of the consolidation system concept development task) it became evident that disposal of the scrap was a much more significant problem than had been anticipated. On the one hand, storage of all the scrap in the spent fuel pool could result in a major reduction in ultimate spent fuel storage capacity-as much as 20 percent as described in Section 4; on the other hand shipping the lower activation scrap (ZircaloyTM material) off site to a low level waste storage facility as originally contemplated might not be possible due to the isotopic content of the contamination being unacceptable for this type of storage, or if it were possible, could be very costly. The scope of this program did not permit the extensive study necessary to identify the optimum solution to this problem, which is now being addressed by EPRI project RP2813-13.

Two points were overlooked when performing the criticality analysis for consolidated fuel storage, which resulted in additional analysis being necessary. The first point was that when determining the minimum burnup required for fuel to be eligible for storage in the region of the spent fuel pool where credit for burnup is permitted (Region II at Millstone), allowance must be made for the axial variation of burnup along the fuel rods. The second point was that consolidated fuel storage boxes may not always contain their full complement of 352 fuel rods, since damaged rods will have been separated from their rows and deposited in the damaged rod container. This will increase the water to fuel ratio in the CFSB, which may increase the reactivity. In the case of Millstone it was calculated that up to seven rods could be left out of each CFSB in an infinite storage array and still maintain the criticality criterion ($k_{eff} < 0.95$).

Benchmarked Analytical Methods

A 16 neutron energy group calculational model suitable for use in both KENO (a Monte Carlo criticality computer code) and DOT (a two-dimensional neutron transport computer code) was developed. The model was benchmarked against the results of Babcock and Wilcox criticality experiments with fuel rods in three different close pitched triangular arrays.

Licensing

NU obtained a license amendment from the USNRC for the storage of consolidated fuel and the full scale consolidation of spent fuel in the Millstone Unit 2 spent fuel pool.

Initially, NU and C-E presented a position paper to the NRC in December 1983 describing the NU program for re-racking the Unit 2 spent fuel pool and the EPRI fuel consolidation demonstration program. Thereafter NU kept the NRC informed on an informal basis of the progress and results of the two programs. NU was granted an amendment for storing intact spent fuel in the new racks in January 1986.

NU's approach with regard to consolidated fuel was to request a license amendment for storing consolidated fuel and seek NRC approval under 10CFR50.59 for the consolidation process as a plant operation which did not introduce any unreviewed safety question. A safety analysis report for storage and a safety evaluation report for the consolidation process were prepared. NU submitted

the request for consolidated fuel storage to the NRC in May 1986. The 10CFR50.59 safety evaluation of consolidation was submitted in August 1987.

The storage amendment request did not include any information on the consolidation process. From the initial NRC questions, however, it appeared likely that the NRC would not grant the storage amendment without a detailed review of the process, therefore, in May 1987 NU asked for partial approval to allow the performance of the hot demonstration. Approval for the storage of five consolidated fuel storage boxes of consolidated fuel was given in June 1987.

Further NRC questions at the end of October 1987, on both the consolidation process and consolidated fuel storage, were resolved in November 1987, and in February 1988 the NRC issued an "Environmental Assessment and Findings of No Significant Impact."

A licensing amendment to allow full scale consolidation and storage of spent fuel at Millstone Unit 2 was issued by the NRC in March 1988. No public hearing had been requested or held.

Non-Proprietary Codes for Licensing

One new computer code, CFCGEN, was developed in the program. This code is non-proprietary and generates a lumped mass stick model of a fully loaded consolidated fuel storage box for use in seismic analysis. Two existing thermal hydraulic codes, VIPRE and GFLOW, were evaluated but both were found to need economically unjustifiable modification for application to spent fuel pool conditions. In general, C-E proprietary versions of existing criticality, thermal hydraulic and dynamic structural response codes were capable, with relatively minor modifications, of performing all the necessary program analyses, and considerations of cost and schedule dictated their use.

Topical Reports

The five EPRI technical report volumes described in Section 3 constitute a set of topical reports covering all technical aspects of the program.

Fuel Consolidation Equipment

Several changes were made in the equipment for consolidation from the original concept as the detailed design and development progressed. The most important concerned the multiple rod pulling tool and the interim transfer canister.

The MRPT as originally conceived pulled a 2x6 rod array and was located by pins engaging in a pattern of holes around the fuel disassembly station. Because of the restricted space, it was realized that the locating pin diameters would have to be so small that the pins would easily be damaged. The location concept was therefore changed to the use of an X-Y table. The MRPT was also changed to pull a single row of up to 14 rods, permitting a reduction in the number of movements necessary to remove all the rods from a fuel assembly and transfer them to the ITC.

A mockup of the original ITC concept failed to hold the fuel rods reliably in the desired triangular array, and would have required powered transverse pushers to achieve this. A mockup using tapered corrugated plates as in the present ITC design was tested successfully. The original fuel transfer concept provided for the ITC movable floor and the weight of the fuel rods to be supported by cables during the transfer from the ITC into the consolidated fuel storage box. The risk of floor tilting or cable failure with this design during transfer was judged unacceptable and the telescopic fuel transfer cylinder was adopted to support the floor and fuel rods in place of the cables.

Prototypes of the MRPT gripper head and the ITC in June 1984 achieved a successful demonstration of remotely controlled fuel rod deposition into the ITC and subsequent gravity transfer of fuel rods into a storage canister. Following this demonstration it was decided that a means of verifying that all rods had been transferred was necessary and the rod transfer tool was added to the inventory of equipment.

Fabrication of the equipment for the hot demonstration was authorized in November 1985 and was completed in about a year. As components were received from vendors they were assembled and tested in C-E's Windsor laboratory. Concurrently, a full-scale mockup of the Millstone Unit 2 cask laydown pool was constructed in the laboratory and the equipment was set up in it. In December 1986 a successful cold demonstration of all the main steps of fuel

consolidation was conducted in the mockup pool with dummy fuel assemblies. The 2:1 consolidation ratio was achieved.

An operating procedure for the hot demonstration was written and was verified step-by-step on the equipment in the mock-up pool during January and February 1987. NU operating personnel were trained on the procedure and equipment by operating the system during procedure verification.

Four components were significantly modified as a result of experience gained with the consolidation equipment during the checkout and cold demonstration periods. The X-Y table drive was changed twice. The first change was from the original rodless cylinders, which did not achieve the required positional accuracy, to a linear nut drive. The latter in turn was replaced because it ran noisily and developed incipient wear and corrosion. The replacement system utilized recirculating stainless steel ball screws. The fuel transfer cylinder bottom support was modified to improve the working clearance of the piston through the bottom opening of the CFSB. X-Y table position readouts on the main control console were inconsistent with the actual table locations, so a TV camera-based X-Y table position calibration system was added. The locking design for the CFSB cover was modified because with the original cover, removal of the latching tool after installing the cover caused the accountability tab to be bent over, giving a false indication of tampering with the CFSB.

The consolidation equipment was delivered to Millstone early in July 1987 and installed in the cask laydown pool of Unit 2. The hot demonstration was successfully performed in September 1987, six spent fuel assemblies being consolidated in a 2:1 ratio. Brief summaries of the demonstration and the results obtained are given below. After the demonstration, part of the equipment was removed in October 1987 and the remainder in May, 1988. One fuel rod channel in the ITC was found to be blocked during the hot demonstration, and the ITC was inspected and repaired in May 1988, as described in Appendix B.

Equipment to Handle Waste Bundle Scrap

Studies were performed on the quantity, isotopic content and activity of the grid cage/guide tube assemblies (Zircaloy) and end fittings (austenitic stainless steel); the economic influence of these factors, shipping regulations and waste volume reduction; and industry experience in the safe

handling of Zircaloy. It was concluded that only the relatively low activity Zircaloy components should be considered for disposal off-site, in a shallow landfill low level waste facility. More recent published information on radioactive isotopes not acceptable for such a facility may even preclude this disposal option. Furthermore, regulations restricting curies per unit volume would dictate little or no compaction, the opposite of what is desirable for minimizing shipping costs, or for storage in-plant.

Volume reduction methods for the grid cage/guide tube assemblies were then investigated (volume reduction of the relatively dense end fittings was not considered), both by discussions with equipment vendors and experimentally. Packaging of the end fittings and compacted grid cage/guide tube assemblies either together or separately was considered. Packaging of the end fittings with granulated Zircaloy assemblies gave the best volume reduction but was rejected because the pyrophoricity of Zircaloy is greatest for fine material. It was elected to package the end fittings separately. Shearing was preferred for the volume reduction of the Zircaloy assembly, but it was evident that existing equipment designs would require costly development to adapt them to operate under water in a radioactive environment. Accordingly, the concept adopted comprised shearing the assembly into short sections and compressing several sections into a briquette by hydraulically operated rams. It was anticipated from fuel material test results that the residual ductility of the irradiated Zircaloy would be sufficient that the briquetted material would remain intact and that there would be minimal generation of fines.

As the design of the compactor was developed, a delivery system to move the compacted waste canisters from the compactor discharge to a point accessible to the consolidation system hoist was added, together with a transfer cylinder to position the movable floor of each CWC so as to sandwich the Zircaloy briquettes between the floor and the compactor ram during discharge to prevent them from impacting and breaking up. During checkout tests after fabrication of the compactor, difficulty was experienced in synchronizing the dual hydraulic drive motors for the discharge gate. The system was changed to a single motor driving the two lead screws by a chain and sprockets.

The compactor performed successfully in the cold demonstration and achieved a compaction ratio of 15:1 for the grid cage/guide tube assemblies.

As previously indicated, in the hot demonstration the first compaction cycle successfully compacted about half of a complete grid cage/guide tube assembly, but then the compactor discharge gate jammed after it had opened only about 20 percent of full opening. The waste was eventually cleared from the compaction chamber but the gate could not be repaired during the demonstration. Examination of the waste revealed that the guide tubes had flattened as expected, but that the grid cages had broken up into fragments, indicating brittle behavior. The volume reduction achieved for the half grid cage/guide tube assembly was estimated to be 18:1. The compactor was inspected and repaired in May 1988, as described in Appendix B, when it was found that metal fragments lodged in washholes in the gate had caused the jamming. The gate was replaced with a new design which had no washholes.

Because of the inability to repair the compactor before the end of the hot demonstration, it was not possible to verify the grid cage/guide tube assembly compaction ratio or to determine the actual scrap capacity of a compacted waste container.

DEMONSTRATION AT MILLSTONE UNIT 2

Operation of Equipment

Consolidation of spent fuel in the cask laydown pool began on August 31, on completion of equipment installation and pre-operational checkout. The entire operation was performed in accordance with a detailed operating procedure and was conducted under standard plant administrative rules and quality control requirements. Ten spent fuel assemblies, each having attained at least 85% of its designed burnup and having been stored for ten years since removal from the reactor (the specified minimum for consolidation was five years) were made available by NU for the demonstration. Six of the assemblies had guide tubes which had been repaired by sleeves. All of the fuel was from the Unit 2 first fuel cycle.

The equipment generally worked very well, the control system was reliable and the interlocks were effective. The only problem with adverse consequences was the jamming of the compactor discharge gate in the first compaction cycle. Although the compactor was satisfactorily repaired later, as described in Appendix C, the jamming and the tight schedule prevented a complete demonstration of non-fuel bearing waste volume reduction. Minor problems occurred with the interim transfer canister and the lower guide tube cutting

tool, but these were overcome without serious difficulty and only resulted in some delay. The gripper force required to pull fuel rods from an assembly was consistently higher than normally anticipated for spent fuel; instead of the expected 30-35 lbs per rod, 50-100 lbs was routinely necessary. The MRPT gripper force "override" control mode was used to provide the higher forces. The higher breakaway forces were attributed to the fact that the fuel assemblies had only been in the reactor for one fuel cycle so that the radiation-induced relaxation of their Zircaloy retention grid springs was considerably less than that for normal 3-cycle spent fuel.

Much of the delay caused by equipment problems was incurred during the initial period, as might be expected for the first-time operation of a new system under actual plant conditions. After the upper guide tubes of the first fuel assembly had been cut and the upper end fitting removed, fuel rod pulling began. One of the MRPT fuel rod grippers would only partially open. It was found that the stroke of the gripper air cylinder was being restricted by foreign material in the cylinder. This was probably a result of development testing in Windsor before filters had been incorporated in the pneumatic system. All the gripper cylinders were replaced. After the gripper problem had been rectified, fuel rods were observed to be binding in the MRPT guide bars as they were being lowered into the ITC. This was attributed to slight misalignment of the split fuel rod gauging holes in the guide bars. The guide bars were replaced with a spare pair after modifying it by slightly enlarging the diameter of the gauging holes and incorporating lead-ins at both ends of each hole. Diagnosing and rectifying these problems (neither of which had occurred during the cold demonstration) took about five days to accomplish. Pulling of the fuel rods from the first assembly and depositing them in the ITC then proceeded without further incident. After the fuel rods had been pulled from the first assembly, difficulties were experienced with the lower guide tube cutting tool, whose cutter bit would not come out properly, and with the lower end fitting removal tool, which would not grip the end fitting. Temporary substitutes for these two tools were employed to complete the disassembly. At first it was thought that the cutter problem was due to working with irradiation hardened Zircaloy, but it was later resolved by making a minor dimensional change in the cutter holder. The problem with the removal tool was solved by changing the sequence of engaging the tool with the end fitting and turning on the air supply to the expanding collet gripper mechanism.

The only significant problem experienced in disassembling the second spent fuel assembly was that one of the fuel rods (no. 7L) hung up while being deposited in the ITC, evidently due to an obstruction in the ITC channel. The ITC has eight spare channels, however, so the procedure for the disassembly of the second fuel assembly of each pair of assemblies was changed to deposit rod 7L in a designated alternate channel. This slightly increased the disassembly time in that rod 7L had first to be separated from its row in the separation/recovery station, and then be picked up again individually by the MRPT for depositing in the designated ITC channel. It was also necessary to remove the follower rod corresponding to the blocked ITC channel from the RTT. The blocked ITC channel was repaired after the demonstration (see Appendix C).

Transfer of the fuel rods from the first two spent fuel assemblies into a CFSB proceeded smoothly, and with the installation of the CFSB cover the first 2:1 consolidation of irradiated fuel with production type equipment was completed.

The second pair of spent fuel assemblies was disassembled and consolidated in a 2:1 ratio into a second CFSB without further significant problems, although the substitute tooling for cutting the lower guide tubes continued to be used.

The first four assemblies consolidated did not have sleeved guide tubes, but the next two each had four guide tubes that had been repaired by sleeving in the upper section. Previous cutter testing had shown that cutting through a sleeve and the tube wall together was difficult and unreliable, and a combination pneumatic/hydraulic sleeve removal tool had been developed. This tool was used to remove the sleeves from each of the fifth and sixth assemblies before disassembling it by the same procedure as for the unsleeved assemblies. While functionally testing the sleeve removal tool before starting to pull sleeves, a hydraulic fitting inside the tool failed, causing a leak of hydraulic fluid into the compressed air system and resulting in several hours' delay to repair the fitting and clean up the leakage. Disassembly of the fifth spent fuel assembly was completed without incident. The equipment also performed as designed during the disassembly of the sixth assembly, but one fuel rod (no. 2L) stuck in the assembly and had to be left behind when its row was pulled. It was later pulled out individually by the MRPT (which was gently wiggled manually to assist breakaway) and transferred to the damaged rod station. The rod was found to have a cladding blister. Consolidation of the fuel rods from the fifth and sixth fuel assemblies in

a 2:1 ratio was completed with their transfer from the ITC into a CFSB and the installation of the CFSB cover.

At this point the Technical Management Committee (TMC) of the program partners agreed that 2:1 consolidation had been satisfactorily demonstrated with spent fuel. Only two days remained for continued operation of the equipment due to the need to clear the spent fuel pool operating floor for the receipt of new fuel for the December 1987 refueling shutdown of Unit 2. Furthermore, the visibility in the cask laydown pool (and the spent fuel pool) had gradually deteriorated to the extent that it was deemed inadvisable to move fuel. It was therefore decided not to consolidate the remaining four spent fuel assemblies and the demonstration ended on September 24. The loss of pool water clarity and the measures taken to restore it are described below (see "Pool Water-Radioactivity and Clarity", and Appendices A and B).

The failure of the compactor while compacting the grid cage/guide tube assembly after removal of fuel rods from the first fuel assembly has already been described in this section (see "Achievement of Program Objectives"). A special tool shaped like a hockey stick was made up before final equipment shutdown and successfully used in conjunction with the compactor rams to clear the waste material from the compaction chamber through the 2-inch opening left by the rammed discharge gate (see Appendix C for the inspection and repair of the compactor). The consolidation filtration system was effective in capturing radioactive crud and particulates from the disassembly process to maintain the activity in the cask pool water at its normal low level. Based on flow indications, two filter cartridges were replaced after the first two fuel assemblies had been consolidated, and two more cartridges would have been replaced before starting to disassemble the seventh fuel assembly.

Pool Water - Radioactivity and Clarity

The spent fuel pool water was isolated from that in the cask laydown pool to prevent the possible spread of radioactive contamination due to consolidation into the spent fuel pool. The cask gate was removed after the cask laydown pit was flooded, to permit fuel to be moved into the cask pool for consolidation. The gate was then reinstalled, and it remained in position during consolidation. The total gamma activity in both pools remained practically constant at a very low level throughout the equipment operation (consolidation demonstration) period, the spent fuel pool activity being actually slightly higher than that in the cask laydown pool. The maximum

recorded value in the cask pool was approximately $7 \times 10^{-4} \mu\text{Ci/ml}$, compared with a starting value of $5.2 \times 10^{-4} \mu\text{Ci/ml}$.

Visibility in the spent fuel pool water began to deteriorate during the equipment installation phase before the cask pool was flooded. It was first observed as a cloud moving across the pool at the time the spent fuel handling machine was load tested on September 20 after having been upgraded for the weight of a full consolidated fuel storage box. At this time the turbidity measurement was 0.15 N.T.U. (NU tries to maintain it at 0.20 NTU or less). After the cask pool was flooded on August 27 and the demonstration phase began on August 31 the turbidity measurements in the spent fuel pool rose fairly rapidly and reached a peak of 1.3 NTU on September 11, the corresponding value for the cask pool water being 2.5 NTU. After a few days the turbidity began to decline, falling to a value of about 1.0 NTU in the spent fuel pool at the end of September when the demonstration ended, partly due to the poor visibility.

It was evident early in September that the reduction in visibility might restrict the movement of fuel in the spent fuel pool and that the plant spent fuel pool purification system was unable to remove, at an acceptable rate, whatever was causing the turbidity. Because of the forthcoming refueling shutdown NU immediately began a program of water sample analysis both at Millstone and at outside laboratories to determine the potential causal factors, and also began to evaluate methods of restoring pool water clarity. These activities and the reverse osmosis cleanup method subsequently adopted by NU are described in Appendix A.

One of the several suspected causal factors (others were iron oxides and microorganisms) was the presence of organic hydrocarbons in the water, and a possible contributor to these was the hydraulic fluid UCON WS-34 employed in several fuel consolidation system components. During the initial fill of the system on site it had been necessary to top off the hydraulic system reservoir with between two and five gallons of fluid, and some of the deficiency might have been due to spillage or leakage into the cask laydown pit. This did not cause concern at the time since UCON WS-34 is miscible in water, and had been used successfully by C-E and others for several years in underwater servicing operations.

The actual cause of the spent fuel pool water turbidity had not been identified (although microorganisms had been ruled out) before it became necessary to select the pool cleanup method. Millstone Chemistry developed a coagulant method using NALCO 7107 and successfully demonstrated it on a pilot plant scale. Associated Technologies Incorporated (ATI) of Charlotte, North Carolina proposed a system utilizing reverse osmosis technology. NU decided upon the latter system, based on reduced financial risk, lower estimated cost and lower estimated radioactive waste generation. Before the cleanup operation began on November 23, 1987, the spent fuel pool water turbidity had fallen to 0.63 NTU. The cleanup operation further reduced the turbidity to 0.30 NTU by the time it was terminated on December 28, 1987 after processing a total of approximately 1.27 million gallons of water.

The effort to identify the cause of the loss of pool water clarity continued during and after the cleanup operation. It was initially suspected that UCON WS-34 might be acting to stabilize the suspension of particulate materials already present in the water. However the manufacturer of the hydraulic fluid, Union Carbide, indicated that WS-34 is basically polyalkylene glycol and has too low a molecular weight to be an effective dispersant. A simple poolside sludge disposal test performed by C-E during the clean up operation, using deposits from the floor of the pool and various concentrations of WS-34, failed to demonstrate the formation of a stable suspension. The Duratek Corporation of Greenbelt, Maryland, one of the outside laboratories contracted by NU, determined (by a precipitation method) that WS-34 was present in a very low concentration (20-30 mg/l) in the cask pit water, but showed experimentally that the ultraviolet-visible (UV-Vis) spectrum of the cask pit water was representative of that of a WS-34/water solution of a much higher concentration (@25,000 mg/l). Millstone Chemistry, Duratek and C-E all agreed that WS-34, by itself, could not be responsible for the turbidity in the spent fuel pool.

Duratek then irradiated a 200 mg/l solution of WS-34 at a dose rate of 7000 R/hour. The resulting solution was turbid with a UV-Vis spectrum resembling that of the cask pit water. Duratek concluded that the combination of radiation and WS-34 could produce the turbidity characteristics found in the Millstone Unit 2 spent fuel pool. Reports of both the C-E sludge dispersal test and the Duratek tests are reproduced in Appendix A. Duratek's conclusion was reinforced by independent work performed later in 1988 for NU by C-E to evaluate a series of hydraulic fluids for use in a hydraulic crane,

considering the possibility of fluid leakage into the refueling pool water. The work included irradiation testing and WS-34 was included in the series as a benchmark. When WS-34 was irradiated after dilution the solution demonstrated a similar increase in turbidity. This evaluation was not part of the fuel consolidation demonstration program but is described in Appendix B because of the relevance of the results for WS-34.

FUEL TRANSFER AND COMPLETION OF EQUIPMENT REMOVAL

On the completion of the hot demonstration in October 1987 the fuel and non-fuel bearing waste were left in the cask laydown pool until the visibility in the spent fuel pool water had been restored. The cask pit gate was removed on December 7, 1987 and this material, consisting of three full consolidated fuel storage boxes, four intact spent fuel assemblies, two full end fitting storage boxes and one box containing two end fittings, one compacted waste canister containing approximately half of a compacted grid cage/guide tube assembly, and five and one half uncompact grid cage/guide tube assemblies, was moved into the spent fuel storage pool. The spent filter cartridges in the filtration skid were also removed from the cask laydown pool and placed in a lined 55 gallon drum which was transferred to the radwaste storage area. They were later shipped offsite with other spent filters for burial.

Removal of the fuel consolidation equipment left in the cask laydown pool in October 1987 was deferred until after the refueling shutdown in early 1988. The first components to be removed then were the compactor and interim transfer canister, both of which had to be inspected and repaired before packaging for storage. This removal operation began on May 6, 1988 with the compactor.

Compactor Inspection and Repair

It will be recalled that the compactor discharge gate had jammed partially open during the demonstration, and that this was thought to be due to Zircaloy chips being forced into washholes in the gate and becoming wedged into the gate openings. The compactor was unbolted from the lower work platform, washed down and then transferred by the cask crane into the adjacent cask washdown pit. During the transfer it was apparent that significant damage not previously observed had occurred to the gate mechanism in the lead screw drive area when the gate jammed, and it was necessary to order replacement parts

additional to the new discharge gate (without washholes) which had already been procured.

A detailed inspection in the cask pit on May 9 confirmed that Zircaloy chips in the washholes had caused the jamming, and revealed that the lead screw also had fractured. Contamination levels were up to 10 mr/hr smearable. The available replacement parts were installed at this time, and a new lead screw was installed on May 16 to complete the repair. In all, the parts replaced were: the modified gate; hydraulic motor; drive chain; drive assembly; drive plate; and lead screw. In addition, the vertical cylinder and top plate assembly were removed to inspect the internal wear plates. No wear or damage was found and the cylinder and plate assembly were reinstalled. Appendix C gives details of the compactor inspection and repair.

Interim Transfer Canister Inspection and Repair

One of the fuel rod paths in the interim transfer canister had been found to be obstructed during the demonstration about 45 inches from the top. Inspection and repair of the ITC began in the cask washdown pit, immediately after the repair of the compactor. The contamination level was about 1 mr/hr smearable.

An external visual examination of the ITC showed nothing abnormal, as did a visual examination of the lower corrugated section. Each fuel rod path was then visually inspected from the top of the ITC while illuminated by a light at the bottom. All of the 360 paths passed inspection except the one which had appeared to be obstructed. An edge of one of the spacer grids, at approximately 45 inches from the top, was protruding about 0.050 inches into this path. Anticipating such a problem, a special repair tool consisting of a T-handled rod with a collar which could be positioned anywhere along the length of the rod had been fabricated. A button-head screw standing proud of the collar would act like a cam when the rod was rotated, and when positioned correctly should smooth down the protrusion. This tool worked successfully and removed the obstruction in a few rotations. It was felt that a similar path-by-path internal visual inspection of the ITC should be performed prior to any fuel consolidation campaign. Details of the ITC inspection and repair are given in Appendix C.

When the ITC repair was completed, both the ITC and the compactor were decontaminated to conform to the Millstone site unrestricted long term storage

requirement of less than 150 mr/hr by hydrolazing followed by spraying with a penetrating decontamination solution (Envy) and a hand wipedown with Masselin cloth. They were then lifted out of the cask washdown pit and packed in LSA boxes for storage. Radiation levels outside of the boxes were less than 100 mr/hr for the compactor and about 2 mr/hr for the ITC.

Removal of Remaining Consolidation Equipment

The components remaining in the cask laydown pit - the lower work platform and attachments, the temporary storage rack and the filtration skids - were handled in a similar manner as for the compactor and ITC except that no repairs were needed. Gross decontamination was performed by washdown in the cask laydown pit, and final decontamination to long term site storage levels was carried out in the cask washdown pit where the background radiation level was lower. The equipment was packed in LSA boxes, and the work was completed on July 1, 1988.

Radiation levels before, during, and after decontamination were as follows:

- Equipment in cask laydown pit, fuel removed, flooded, before decontamination, on contact readings 100 mr/hr to 3 R/hr (compactor 2-3 R/hr).
- As above, but cask laydown pit pumped down, lower work platform and compactor 1 to 10 mr/hr smearable.
- After hosedown in cask laydown pit, hydrolazing in cask washdown pit, followed by handwiping with Envy spray and Masselin cloth, average 50kdpm/100 cm² from smear (goal was less than 100kdpm/100 cm²).
- Decontaminated equipment in LSA boxes, on contact outside box (allowable 150 mr/hr)
 - compactor less than 100 mr/hr (highest equipment reading)
 - lower work platform 10-50 mr/hr
 - long tools (e.g., MRPT) 2 mr/hr
 - hoses 10 mr/hr
 - filter tools 3 mr/hr

FUEL CONSOLIDATION PERFORMANCE TIME

Time to Consolidate a 10-Assembly Batch

Based on actual experience with the last two spent fuel assemblies processed during the hot demonstration, the average time to consolidate two spent fuel assemblies with the procedure and equipment as used in the demonstration was calculated to be 20 hours. The process step times were estimated by the

operating crew supervisor where time records were incomplete, and were adjusted to eliminate the delays caused by problems judged to have been resolved by the corrective actions which were taken during the demonstration. Thus the average time to consolidate ten fuel assemblies would be 100 hours for a mixture of sleeved and unsleeved assemblies. The program target for the consolidation of two assemblies was 16 hours, and NU believes that this can be achieved and even improved upon by the incorporation of the equipment and procedure modifications recommended in the Cold and Hot Demonstration Reports. This is discussed in the next sub-section.

Some additional steps have to be taken into account in order to arrive at the total processing time for the batch. These are:

- Transfer of four end fitting storage boxes (EFSB's, each having a capacity of five upper or lower end fittings) as they are filled, from lower work platform to temporary storage rack, and replacement with empty EFSB's, 1 hour per exchange.
- Transfer of compacted waste canisters (CWC's) as they are filled, from compactor to temporary storage rack, and replacement with empty CWC's. As previously discussed, the waste capacity of a CWC was not determined because of the malfunction of the compactor. However, if the estimate that a grid cage/guide tube assembly compaction ratio of 18:1 was achieved is assumed correct, each CWC will hold 4.5 compacted grid cage/guide tube assemblies. For most batches there would be two CWC exchanges per batch, and every fourth batch would require three exchanges, 1 hour per exchange. (Note that the compaction itself is performed in parallel with consolidation).
- Exchange of filter cartridges twice and three times for alternate batches (one exchange per four fuel assemblies consolidated), 3 hours per exchange. With two filter skids in operation, it should be possible to perform the exchange in parallel with consolidation.
- Transfer of the batch consolidated fuel and compacted waste from cask laydown pool to spent fuel storage racks, and vice versa for the next batch of spent fuel to be consolidated, including opening and closing of cask pit gate, 12 hours. The first batch of a campaign will require an additional transfer from the spent fuel pool to bring the initial spent fuel assemblies into the cask pool. On the average, these steps add a total of about 19 hours for any batch of a campaign except the first, for which they add 31 hours.

This results in a total average processing time for a mixed batch of five unsleeved and five sleeved spent fuel assemblies of about 120 hours, using the equipment and procedure utilized in the hot demonstration.

Time and Crew Size Required for a Typical Annual Production Campaign

In the report of the hot demonstration (5), NU projects an overall average consolidation rate of eight hours per assembly, based on use of the present equipment with the direct loading system for the ITC movable floors, which was completed too late to be used in the hot demonstration, together with other recommended improvements documented in the report of the cold demonstration (5). These improvements are also summarized under the heading "Lessons Learned" later in this Section. Thus, the estimated operating time for a typical annual campaign consolidating 150 spent fuel assemblies is 1200 hours, plus say 200 hours for cask pit to spent fuel pool transfer operations and equipment servicing, making a total of 1400 hours.

Ideally, the work would be performed on one eight-hour shift per day, five days per week, resulting in a campaign of about 35 weeks. Equipment installation, preoperational testing, and removal after the campaign are not included in this period. However, as discussed further below, these activities would be considerably reduced in comparison to the hot demonstration if the in-pool equipment were usually left in place between campaigns.

For the consolidation station, NU recommends a crew consisting of one supervisor, two technicians, one health physics technician, and one quality control technician.

For the compaction/end fitting station (which would be separate from the consolidation station), NU recommends 2 technicians and a health physics technician (when required). The crew supervisor above would serve both locations. In addition, one plant spent fuel handling machine operator and one reactor engineer would be required for the movement of fuel assemblies, consolidated fuel storage boxes, waste storage boxes, and grid cage/guide tube assemblies (for compaction) to and from the spent fuel pool.

PERSONNEL EXPOSURE

Experience During Hot Demonstration Activities

The total personnel exposure recorded in the radiation work permits for the installation of equipment, preoperational testing, operation (fuel consolidation), removal and repair of equipment, and decontamination for transport offsite or long term unrestricted storage on site, was

6.895 man-rem, and the overall average Effective Dose Rate (EDR) was 2.1 mrem/hr. Effective dose rate is defined as total personnel dose divided by total personnel exposure manhours, and was calculated from the manhour and direct reading pocket dosimeter data recorded on the radiation work permits (RWP's). In NU's experience, direct reading dosimeter data averages about 7 to 10 percent higher than thermoluminescent dosimeter (TLD) data. The direct reading dosimeter data relating to the overall hot demonstration effort in 1987 and 1988 is given in Table 2-1. A further breakdown of the dosimeter data is given in Volume IV Table 7-3 for the 1987 activity and in Table 2-2 of the present report for the 1988 activity.

The EDRs during the equipment removal phases are relatively higher than they would normally be partly because of the compactor and ITC repairs, and also because it was an NU requirement for the demonstration that the equipment be decontaminated afterwards to a level which would permit long term storage on site in an unrestricted location (see discussion under "Removal of Remaining Consolidation Equipment" earlier in this Section). This decontamination requirement was very stringent and was imposed because the equipment is not expected to be needed for a production campaign before 1994. Storage between production campaigns could be in an area where access is controlled, reducing the time and effort necessary to be expended on equipment decontamination.

Predicted Exposure During Production Campaign

The exposure of personnel in a typical annual fuel consolidation campaign at Millstone Unit 2 may be divided into three parts:

- (a) exposure received during reinstallation of equipment,
- (b) exposure received during consolidation, and
- (c) exposure received during decontamination and removal of equipment.

Parts (a) and (c) of the exposure can be greatly reduced by leaving the consolidation equipment in the cask laydown pool in place between campaigns, which is feasible except when the pool is required for loading the shipping cask. At present Millstone Unit 2 ships items such as spent in-core detectors every second or third refueling. The equipment on the operating floor must be removed at the end of each campaign to permit bringing in new fuel, but this equipment does not get contaminated and the background radiation level is very low, in contrast to the high radiation level in the cask pit when drained due

to the proximity of Table 2-1 spent fuel in the spent fuel pool. Following a campaign after which the cask pool equipment does have to be removed, the in-pool reinstallation time should be much shorter than that required for the hot demonstration, which was extended by the difficulties experienced in draining the pool and the need to complete the hoist assembly rail installation before starting work in the cask pit.

If the in-pool equipment is left in place except when the shipping cask has to be used, there are three possibilities for parts (a) and (c) in a campaign:

1. Only operating floor equipment is reinstalled and afterwards removed.
2. Operating floor equipment is reinstalled and afterwards removed; in-pool equipment is afterwards removed and decontaminated.
3. In-pool and operating floor equipment is reinstalled; only operating floor equipment is afterwards removed.

Table 2-1

HOT DEMONSTRATION PERSONNEL EXPOSURE IN 1987-88

<u>Activity</u>	<u>Total Dose</u> <u>man-rem</u>	<u>EDR</u> <u>mrem/hr</u>
Spent fuel pool preparations, equipment installation and pre-operational testing (1987)	3.255	1.94
Fuel consolidation (1987)	0.530	0.56
Operating floor equipment removal and decontamination (1987)	0.180	1.55
In-pool equipment removal, compactor and ITC repair, and decontamination (1988)	2.930	4.69
Total Dose and Effective Dose Rate (EDR)	6.895	2.10

Table 2-2

EXPOSURE DISTRIBUTION IN POST-HOT DEMONSTRATION ACTIVITY, 1988

<u>Activity and Personnel Group</u>	<u>Group Dose Man-rem</u>	<u>Group Manhours</u>	<u>Effective Dose Rate¹ mrem/hr</u>
Removal of in-pool equipment, repair of compactor and ITC, equipment decontamination			
- C-E	0.100	10	10
- NU	0.645	162	4
- NU Subcontractor	2.185	453	5
Total Dose and Manhours, and Overall Effective Dose Rate:	2.930	625	5

¹Note: Effective Dose Rate =
$$\frac{\text{Personnel Group Dose}}{\text{Personnel Group Manhours}}$$

Projecting the exposures for parts (a) and (c) from the hot demonstration data is difficult because there is no way to determine what proportion of the total dose was due to a particular short term activity and therefore to identify specific doses caused by first-time activities not likely to recur in a production campaign. However, the following total dose assumptions appear reasonably conservative.

Part(a): For operating floor equipment reinstallation, use Table 2-1 data for removal since the operations are approximately equivalent, i.e., 0.180 man-rem. For in-pool equipment reinstallation reduce Table 2-1 data for installation (minus 0.180 man-rem for operating floor equipment) by 50 percent to reflect reduced installation time and eliminate exposure caused by in-situ modifications to tool racks and other in-pool equipment to correct interferences or increase clearances. Use 1.538 man-rem.

Part(c): For operating floor equipment removal, use Table 2-1 data, i.e., 0.180 man-rem. For in-pool equipment removal and decontamination, reduce the corresponding Table 2-1 data (minus the C-E dose of 0.150 man-rem received during the compactor and ITC repairs) by 30 percent to reflect the less-severe decontamination requirements. Use 1.981 man-rem.

Thus the total exposure for parts (a) and (c) in case (1) is 0.360 man-rem, in case (2) is 2.161 man-rem, and in case (3) is 1.898 man-rem.

During the consolidation of 150 spent fuel assemblies, based on the crew size and campaign time indicated above, NU estimates an accumulated dose of 3.9 man-rem for personnel at the consolidation station, 0.77 man-rem for personnel at the compactor station, and 0.41 man-rem for fuel and waste transfer, making a total of about 5 man-rem. Details of this estimate are given in the report on the hot demonstration (5).

In summary, the total dose for a consolidation campaign during a year when the shipping cask will not be used is projected at 5.44 man-rem. The dose for a campaign preceding the use of the shipping cask is projected at 7.24 man-rem, and the dose for the campaign following that is projected at 6.98 man-rem. It should be noted the analysis is based on data from equipment with very limited service, and it can be expected that dose rates may increase with repeated use. On the other hand, the dose rate increase may be offset by corresponding improvement in operating time efficiency.

LESSONS LEARNED

This overview of the results of the Fuel Consolidation Demonstration Program would be incomplete without citing the lessons learned from the program and also recognizing that there were a few significant programmatic deficiencies. Many of the following points have already been touched upon elsewhere in this report and in the reports of the cold and hot demonstrations.

Probably the most important lesson, from the point of view of consolidation providing increased spent fuel storage capacity, is the significance of the end fittings relative to the grid cage/guide tube assemblies in occupying storage space if it proves necessary to retain all fuel assembly scrap on site. Attention initially was focused on the grid cage/guide tube assemblies because without compaction they comprise over 90 percent of the envelope volume of a fuel assembly and were more amenable to underwater compaction methods than the comparatively rugged end fittings. Additionally there was a possibility of shipping the grid cage/guide tube assemblies offsite for burial as low level waste. However, a compaction ratio of about 14:1 (exceeded in the cold demonstration but not able to be confirmed in the hot demonstration) reduces the volume of the grid cage/guide tube assembly from one spent fuel assembly to about the same as that of the uncompacted end fittings from that

assembly. Thus if the end fittings are not also compacted the overall scrap volume reduction ratio is only 7:1 and, for example, 120 fuel assemblies require 60 cells for storing the consolidated fuel rods and 17 cells for storing the scrap, if all of the scrap has to be stored on site and in the fuel racks. If the scrap is stored in supplementary racks above the fuel racks, the need to be able to transport fuel assemblies over the supplementary racks severely restricts their height, with a corresponding reduction in the amount of scrap each supplementary cell can store. Calculations for Millstone Unit 2 (see Section 4 of this report) indicate that supplementary racks to hold the scrap (including uncompacted end fittings) from all the consolidated fuel assemblies that could be stored in the existing fuel racks would occupy virtually the entire spent fuel pool area and would tend to block access to the full core reserve cells. The space required to store end fitting scrap could be substantially reduced by cutting off the fuel grid from the lower end fittings, cutting off the stub tubes from both upper and lower end fittings, and then disassembling the upper end fittings. As the uncertainty of being able to ship the grid cage/guide tube assemblies off site increased and the incentive for reducing the volume of the end fitting scrap began to be realized, consideration was given to developing special tooling for this purpose, but the necessary budget was not available. In hindsight, this was a programmatic deficiency.

The second most serious programmatic deficiency was perhaps the decision to locate the consolidation equipment for the hot demonstration at Millstone Unit 2 in the cask laydown area of the spent fuel pool. At the time it seemed advisable to be able to isolate the consolidation area from the main pool because of potential failures in the process and to prevent the spread of contamination throughout the spent fuel pool. However, these events did not occur and the shape and restricted dimensions of the cask pool severely limited the options of the equipment designers. As a result, some of the demonstration system components are more site-specific than they need have been, and their design would probably have to be modified for use at a different plant. The consolidation equipment could have been designed to be located in the spent fuel transfer canal, and probably will be in future installations.

The scope of the hot demonstration at Millstone was planned for consolidating a maximum of ten spent fuel assemblies. Because of equipment installation delays and the approach of the next refueling shutdown only six assemblies

were actually consolidated. Nevertheless, even if the planned maximum number of assemblies had been consolidated, it would have been insufficient to determine the maximum production rate capability of the consolidation system as designed. A planned program of say 50 assemblies, with a pause after the first ten were consolidated to make minor adjustments or repairs, would have provided a much wider experience base, enhanced confidence in the reliability of the equipment, and probably enabled the compactor to be repaired and fully demonstrate the waste reduction capability and canister storage capacity. Of course, such an extended demonstration would have had to be started earlier in the year and carried out on a two-shift basis.

A very significant lesson learned from the hot demonstration is the importance of detailed planning of the site preparation work well in advance of the actual demonstration or production campaign. For example, Millstone is a three-unit site, and it was not sufficiently recognized ahead of time that the work schedule of another unit might impact the schedule for Unit 2. In fact, a shutdown of Unit 1 severely restricted the availability of craft labor at the time the Unit 2 site preparation work had been planned to start. Also, like Millstone, many utilities have an engineering planning organization which is separate from and located away from the organization responsible for operating the plant. Continuous close coordination between these organizations and any external contractors to be involved in the demonstration or campaign is essential during advanced planning to avoid delays, piecemeal agreement on utility/contractor interface arrangements, repetitious information exchanges, and the extra costs resulting from all of these.

An important lesson learned from the hot demonstration was that there was no evidence of the generation or spread of "hot particles" (highly radioactive particles too small to detect by dosimetry but hazardous in case of skin contact).

Areas for improvement of the consolidation system as designed for the demonstration program have been identified. Most of these have already been discussed in the reports on the cold and hot demonstrations (5). The most significant are:

- Achievement of higher throughput rates and reduced operational impact by streamlining the process and operating procedure, guided by detailed time and motion studies.

- Reduction of tool changing time by modifying equipment layout and designing multiple purpose tools. In the hot demonstration, tool changing and other ancillary operations took at least as much time as the actual rod pulling and transfer operations.
- Additional reduction of process time by positioning the compactor away from the lower work table to allow compacting to proceed independently of rod consolidation. Also consideration of simultaneous rod consolidation operations on two spent fuel assemblies.
- Provision for remote rotation of the multiple rod pulling tool (required during the rod pulling sequence) by the addition of a self propelled turntable to the X-Y table. At present the MRPT has to be lifted off the X-Y table and rotated manually.
- Aiding the detection of plugged filter cartridges by providing an indication of differential pressure measurement at the control console.
- Further investigation is necessary to assess what design modifications to the compactor and compacted waste handling equipment may be necessary in view of the unexpectedly brittle behavior of the Zircaloy grid cage material in the hot demonstration after only one cycle in the reactor.

Section 3

EPRI TECHNICAL REPORTS

The work accomplished in the Fuel Consolidation Demonstration Program and the results obtained are documented in five volumes of technical reports published by EPRI. Volumes I, II and IV each contain two or more subtitled design reports, each of which covers the program task with the corresponding title shown in Table 1-1. Volume III covers program task 7 only. As indicated in Table 1-1, tasks 5 and 6 are reported in appendices and task 8 is reported as a part of task 9. These volumes cover the program to the end of the hot demonstration with spent fuel at Millstone Unit 2 on October 7, 1987. Program related activities occurring since that date are described in the present report.

This section itemizes the activities reported in the four technical volumes.

VOLUME I: METHODS DEVELOPMENT, TESTING, AND DESIGN ANALYSES (2)

This addresses methods for fuel consolidation and storage criticality, thermal hydraulics and seismic/structural analysis, both in their development and application in design. Laboratory experiments performed to support their development are also described.

Criticality Analysis and Test

- Extent of generic application.
- Summary descriptions: Millstone Unit 2 spent fuel storage racks, Regions I and II; consolidated fuel storage boxes; consolidation equipment; reactivity monitoring.
- Description of Babcock and Wilcox criticality experiments with closed-pitched triangular arrays of fuel rods, used for benchmarking computer model.
- Evaluation and verification of 16 neutron energy group homogenized fuel module calculational model in both KENO and DOT computer codes for design and licensing criticality analysis.
- Fuel rod packing density test for consolidated fuel storage.

- Spent fuel storage analyses for normal conditions: intact fresh fuel assemblies in Region I; correlations between initial enrichment and required burnup for safe storage ($K_{eff} < 0.95$) in Region II for intact spent fuel assemblies and consolidated fuel; minimum permissible number of fuel rods in less-than-full consolidated fuel storage box; intact spent fuel assemblies in temporary storage rack; fuel consolidation operations in lower work platform.
- Analyses for accidents postulated to occur during fuel handling operations including consolidation.
- Analysis of reactivity effect due to axial burnup distribution (Appendix A to Volume I).
- Evaluation of two concepts for reactivity monitors (Appendix B to Volume I).

Thermal Hydraulics Analysis and Test

- Extent of generic application.
- Evaluation of CEP00L, VIPRE and GFLOW thermal hydraulic codes for use in consolidated fuel storage thermal hydraulic analysis, including sample problem (Appendix C to Volume I).
- Selection of CEP00L for design analysis, definition of "worst row" of fuel storage cells.
- Modification of CEP00L model to allow for intact fuel assemblies mixed with consolidated fuel, and for coolant flow through storage cell bypassing fuel rods.
- Design analyses: predicted maximum coolant temperatures in spent fuel pool in normal and accident conditions for intact fuel assemblies and consolidated fuel.
- Analysis of conduction heat transfer in a consolidated fuel storage box using ANSYS code.
- Methods verification test with test section housing 19 electrically heated rods.

Seismic and Structural Analysis and Test

- Extent of generic application.
- Description of structural details of spent fuel storage racks, temporary storage rack, and consolidated fuel storage box.
- Description of computer codes used: SAP IV, CESHOCK, CFCGEN, CE/MARC.
- Approach to fuel rack analysis.
- CFSB mechanical tests: lateral deflection; forced vibration; local bending stiffness.

- SAP IV computer models of spent fuel rack and temporary storage rack.
- CESHOCK computer model of CFSB and correlation with mechanical test results.
- Development of computer code CFCGEN to generate lumped mass stick model of CFSB.
- Computer model - mechanical test comparison results.
- Coupled spent fuel rack/CFSB/spent fuel pool computer models.
- Design parameter sensitivity studies.
- Final spent fuel rack design.
- Seismic design analyses of spent fuel and temporary storage racks: lateral and vertical seismic; vertical impact and tipping; floor loads.
- Structural design analyses of spent fuel and temporary storage racks: with and without tipping; accidental drops.
- Structural analysis results for racks.
- Seismic and structural analyses of consolidation equipment: lower work platform; hoist assembly.

VOLUME II: FUEL CONSOLIDATION SYSTEM (3)

This volume describes the consolidation and storage system design which formed the basis for detailed design of the equipment comprising the system. Detailed design, fabrication and testing of the equipment are described in an appendix. Also described in this volume is the applicability of the consolidation system to other light water reactor fuel designs.

Consolidation Concept Development

- Extent of generic application.
- Identification of consolidation system components.
- Summary descriptions: Millstone Unit 2 spent fuel pool; system and equipment design requirements; system design support studies (see below).
- Description of consolidation process.
- Description of individual consolidation components, consolidated fuel storage box, spent fuel racks.
- Study of the disposal of fuel assembly scrap and waste.
- Study of the safe handling of Zircaloy.

- Study of methods of volume reduction of fuel assembly materials after removal of fuel rods.
- Description of equipment as fabricated: design changes, principal performance and instrumentation data (Appendix A to Volume II).
- Description of control system as built, layout of main control console and function of individual controls (Appendix A to Volume II).
- Summary of safety interlocks (Appendix A to Volume II).
- List of fuel consolidation equipment drawings (Appendix A to Volume II).

Application of Consolidation Equipment to Non-C-E Fuel

- Review and tabulation of published data on fuel assemblies manufactured by Babcock and Wilcox, Exxon (now Advanced Nuclear Fuels), General Electric and Westinghouse for both pressurized and boiling water reactors.
- Comparison of fuel assembly design configurations, dimensions and assembly details.
- Assessment of adaptability of individual consolidation components to above fuel designs: hoist assembly; X-Y positioning table; guide tube cutter; fuel rod removal; compactor; interim transfer canister; grappling.
- Findings: PWR fuel assemblies; BWR fuel assemblies.

VOLUME III: STORAGE AREA ANALYSES (4)

This addresses the radiological effects - dose rates to the public and to plant personnel - of consolidating fuel, and also the impact on the spent fuel pool cooling and purification systems of the increased quantity of fuel storage in the pool. In addition, a seismic and structural analysis of the spent fuel pool, containing its full capacity of intact assemblies and consolidated fuel, and the surrounding auxiliary building structure is presented in an appendix.

- Extent of generic application.
- Description of consolidation process
- Description of Millstone Unit 2 spent fuel pool.
- Description of computer codes used: ISOSHLD and ORIGEN.

Radiological Evaluation of Fuel Consolidation

- Description of events considered: doses to general public due to accidents; dose rates to plant personnel during normal consolidation operations; dose rates to plant personnel in disposing of waste material.
- Accident analysis: site boundary dose rate due to dropped CFSB.
- Normal operation dose rate analyses: spent fuel pool area; intact assembly or ITC above work platform.
- Accidental crude release to cask pool water: dose rate to plant personnel: time to cleanup cask pool.
- Accidental fission gas release to auxiliary building atmosphere: dose to plant personnel.
- Waste handling analyses: dose rates due to grid cage/guide tube assembly and spent filter cartridge.
- ALARA evaluation for typical fuel consolidation campaign.

Spent Fuel Pool Cooling and Purification

- Description of factors considered: decay energy of spent fuel as function of time; fuel storage capacity; capability of existing cooling system; size of fuel consolidation area; amount of fuel in work platform; heat generated by consolidation equipment.
- Determination of maximum storage cell utilization.
- Design bases for pool cooling system: normal operation; abnormal operation with full core offload and assistance of one shutdown cooling heat exchanger.
- Cooling requirements in the cask laydown pool.
- Spent fuel decay energy calculations (Appendix A to Volume III).
- Calculation of performance of spent fuel pool cooling system heat exchangers in two separate cases with single active failures in the system, for the normal operation and abnormal operation design bases.
- Cask laydown pool cooling and filtration provisions.
- Discussion of results.

Seismic/Structural Analysis of Spent Fuel Pool and Auxiliary Building (Appendix B to Volume III)

- Report of seismic/structural analysis of capability of auxiliary building and spent fuel pool to withstand increased loads caused by increased storage of spent consolidated fuel.

VOLUME IV - COLD AND HOT DEMONSTRATIONS (5)

This volume describes the cold demonstration of the integrated consolidation system with dummy fuel in a mockup pool at C-E's Engineering Development Laboratory in Windsor, Connecticut, and the hot demonstration with spent fuel at Millstone Unit 2.

Cold Demonstration at C-E Windsor

- Extent of generic application.
- Description of Millstone Unit 2 cask laydown pool.
- Description of mockup of cask laydown pool constructed in Windsor Laboratory.
- Preparation of consolidation equipment and installation in mockup pool.
- Tests on subsystems: handling tools; lower work platform components; control subsystems; main control console.
- Development of consolidation system operating procedure.
- Cold demonstration: upper end fitting removal; pulling and consolidating fuel rods; loading a CFSB; compacting non fuel bearing waste; handling a damaged fuel rod; common mode failure.
- Verification of operating procedure and qualification of operators.
- Recovery of broken fuel rod.
- Break in hydraulic line to fuel transfer cylinder.
- Test of filter system with synthetic crude.
- Achievement of 2:1 consolidation ratio.
- Achievement of 15:1 waste compaction ratio (target 10:1).
- Modifications to components, controls and operating procedure as a result of cold demonstration.
- Improvements to components recommended in critique of cold demonstration and incorporated before hot demonstration.
- Recommended improvements deferred due to insufficient time for evaluation and/or implementation.

Hot Demonstration at Millstone Unit 2

- Comparison of planned and actual schedules.
- Development of on-site procedures: interface requirements; system installation; preoperational checkout; equipment removal; additional amendments to operating procedure; drawings and specifications list.
- Layout of equipment in cask laydown pit and on operating floor.
- Installation of equipment: unloading and unpacking; cask pit pump down; hoist rails and embedments; placing components in the cask pit; cabling and hose hookup.
- Comparison of planned and actual installation schedules.
- Preoperational equipment checkout; weighing all handling tools dry and in water; mapping hoist position coordinates for all locations to be reached in pool; verifying X-Y table position readouts.
- Flooding cask pool and moving in the spent fuel assemblies.
- Fuel assembly data and personnel for equipment operation (consolidation) phase.
- Day-by-day account of consolidation events, problems and resolutions; shutdown after consolidating six fuel assemblies; deferral of fuel movement and of repairs to ITC and compactor.
- Removal, decontamination and packaging of all consolidation equipment on operating floor level.
- Six fuel assemblies consolidated, to ratio of 2:1.
- Average times, estimated from step times recorded during demonstration: pulling fuel rods from one intact assembly; consolidating fuel rods from two intact assemblies.
- Personnel exposures received during installation, preoperational checkout, equipment operation and equipment removal.
- Radiological survey data for: end fittings and grid cage/guide tube assembly; MRPT; filter cartridges.
- Cask pool temperature variation.
- Spent fuel pool water analyses: boron; total gamma activity; turbidity.
- Videotape of compacted grid cage/guide tube material.
- Estimated average time to consolidate two spent fuel assemblies in a production campaign. Time study and possible tool modifications recommended to reduce tool handling time.
- Recommended crew size for production campaign.

- Estimated operating personnel exposure in typical production campaign.

VOLUME V - LICENSING (6)

This volume describes the two-step approach followed by NU in obtaining a license amendment to consolidate fuel and store the consolidated fuel in the Millstone Unit 2 spent fuel pool. The first step, in May 1986, was to request an amendment to store consolidated fuel in the new racks then being installed in the spent fuel pool. The second step, in August 1987, was to submit a 10CFR50.59 safety evaluation report of the consolidation process.

Consolidated Fuel Storage

- Licensing amendment requested.
- Proposed revisions to Technical Specifications.
- NU Safety Analysis Report to NRC:
 - Description of spent fuel rack design.
 - Nuclear and thermal hydraulic considerations.
 - Mechanical, material and structural considerations.
 - Assessment of need and environmental impact.
- NRC requests for additional information, and NU responses:
 - On reracking (in rounds 1-6).
 - On pool cooling and consolidated fuel storage (in rounds 1-6).
- NRC actions:
 - Safety Evaluation of amendment request.
 - Licensing amendment.
 - Approved Technical Specifications.

Consolidation Process

- NU Safety Evaluation Report of process to NRC:
 - Overview of consolidation process.
 - Proposed plant design changes.
 - Prevention or mitigation of fuel damage in normal consolidation operations.
 - Radiological evaluation.
 - Civil structural evaluation of placement of consolidation equipment.
 - Nuclear/criticality considerations.
 - Thermal hydraulic considerations.
 - Accident analyses.
 - 10CFR50.59 summary.

- NRC request for additional information and NU response (one round).
- NRC actions:
 - Safety Evaluation of amendment request.
 - Licensing amendment.
 - Revised Technical Specifications.

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Section 4

PROGRAM ASSESSMENT AND SYSTEM EVOLUTION

ASSESSMENT OF PROGRAM

In concluding the Fuel Consolidation Program, it seems appropriate to try to assess the extent to which the program has established the viability of the demonstrated system as an option for utilities to consider in increasing their capacity for storing spent fuel. The following discussion considers the consolidation of fuel rods, the volume reduction of the non-fuel bearing component (NFBC) scrap, licensability, and the factors limiting the ultimate spent fuel pool storage capacity achievable with consolidation. For most PWR plants, the most significant limiting factor may be the disposition of NFBC scrap, and one approach toward overcoming this limitation for Millstone 2 is described.

Fuel Rod Consolidation

The program has demonstrated that rod consolidation at a 2:1 ratio is practical and safely controllable with equipment which can easily be adapted to different pool layouts. At Millstone Unit 2 a typical annual campaign (assuming consolidation is begun before the new spent fuel racks are filled) is expected to be 150 spent fuel assemblies. The present equipment, with improvements as referenced in Section 2 under the heading "Time and Crew Size Required for a Typical Annual Production Campaign", is projected to take about 35 weeks of five single-shift workdays each. C-E's second generation version of this consolidation system, which is described below, is designed to consolidate two spent fuel assemblies per shift, including fuel and waste transfers. Personnel exposure is relatively low even with the demonstrated system, and would be reduced if the time saving modifications were adopted.

Volume Reduction of Non Fuel Bearing Components

Compaction of the grid cage/guide tube assemblies was not adequately demonstrated under plant conditions because of the compactor jamming in the hot demonstration after compacting the first half assembly. Elimination of the compactor gate washholes is expected to prevent the recurrence of jamming

but this needs to be confirmed in service. The formation of small Zircaloy particles due to the less than anticipated ductility of the grid cage material means that the design of the compacted waste canister (CWC) system should be modified to prevent jamming of the movable floor and in particular to prevent the escape of Zircaloy particles into the water of the spent fuel pool. It is recommended that the movable floor be eliminated (and the cylinder which raises it up through the CWC), replacing it with a fixed floor which has no water flow holes since the grid cage/guide tube assemblies do not require cooling. This will result in considerable cost savings for CWCs, but the effective compaction ratio may be somewhat reduced since the waste will then drop into the CWC and may not pack as well. The first half-assembly in the hot demonstration was estimated to have been reduced 18:1 in volume in the compactor. The performance of the compactor in the cold demonstration was also satisfactory, and it is felt that with the modified gate that has been installed it will perform satisfactorily in plant service in the future.

Volume reduction of the end fittings was not seriously pursued in the program for budgetary reasons, since this would require an additional item of equipment (e.g., saw or heavy duty shear) to be developed and the end fittings are relatively dense compared to the grid cage/guide tube assemblies (the incentive for reducing the volume of end fittings is perhaps greater for C-E fuel because of their design). As noted in Section 2, this omission is now recognized to have been a mistake, and the development should be pursued.

Licensability

Both the consolidation of fuel assemblies and the storage of consolidated fuel in the spent fuel pool are licensable by the USNRC. NU obtained an amendment to the Millstone Unit 2 operating license which permits them to consolidate and store fuel up to the maximum theoretical capacity of the spent fuel pool, and this is expected to be sufficient to be able to maintain full core removal capability with the expiration of the operating license. NU did not experience any significant difficulties in obtaining the amendment, no doubt in part because the NRC was kept fully informed of the progress of the demonstration program. Full utilization of the maximum authorized fuel storage capacity at Millstone, however, depends on not using any of the spent fuel rack cells for storing NFBC scrap. This is discussed below.

Limiting Factors

A variety of factors were identified during the program as having an impact on the increase in capacity of the spent fuel pool that can be achieved by fuel consolidation. Some of the more important are:

- Number of years' cooldown time required before fuel may be consolidated - with annual refueling of one third of the core, each addition or reduction of a year's cooldown time decreases or increases the storage available for fuel assemblies in consolidated form by two thirds of the core. Five years' cooldown was selected for the demonstration program, but the thermal hydraulic analysis of Millstone fuel suggested that three years could probably be shown to be acceptable.
- Fuel storage pool and existing rack design - capability to withstand the additional weight and seismic loading. This was not a problem at Millstone Unit 2, either for the pool and auxiliary building, or for the racks, which were new and designed for this loading.
- Capacity of existing spent fuel pool cooling system - capability to handle the additional heat load. Depending on the capacity margin in the original cooling system design, as the amount of fuel stored approaches its maximum there may be some difficulty in maintaining the normal pool water temperature at or below 140°F in the event of a single failure in the system. This is the normal operation design basis maximum temperature predicated by the NRC (7) on considerations of personnel comfort and safety. If the problem does occur it will only be for a short period following the discharge of spent fuel during refueling, since this accounts for two thirds of the maximum normal spent fuel pool heat load and decays quite rapidly. For Millstone Unit 2 it was shown that there would be several hours following a failure of a single train of the cooling system to set up supplementary cooling through a shutdown heat exchanger before the pool water temperature reached 140°F.
- Spent fuel pool working area radiation level - increase due to additional storage of spent fuel. From NU's experience this should not be a problem. The background radiation level at Millstone 2 has been found to be mainly influenced by pool waterborne contamination, and is almost independent of the quantity of stored fuel. The experience to date suggests that radiation readings rise when the pool water is disturbed by refueling operations, and afterwards subside.

- Disposition of the non-fuel bearing component scrap - at Millstone Unit 2, if no NFBC scrap is deposited in the spent fuel racks, consolidation increases the pool capacity from 1112 (intact) fuel assemblies to 1965 assemblies, an increase of 853 assemblies (as noted in the next subsection, intact fuel assemblies in Region II of the pool have to be stored in a 3-out-of-4 cell pattern, whereas consolidated fuel can be stored in any Region II cell). Full core reserve (217 assemblies) is maintained, 1375 assemblies are consolidated, and the remaining 373 intact assemblies have less than 5 years' cooldown or are damaged and unsuitable for consolidation. Conversely, if all the NFBC scrap has to be stored in the spent fuel racks and full core reserve is maintained, the total fuel capacity is reduced to 1587 assemblies (assuming 18:1 compaction ratio for grid cage/guide tube assemblies and no compaction of end fittings), so that the capacity increase due to consolidation is reduced by 44 percent and the reduction in total fuel capacity is 20 percent.

Options for storing NFBC scrap at Millstone are discussed below.

Non-Fuel Bearing Component Scrap Storage at Millstone Unit 2

One option (Option 1) being considered by NU is the storage of compacted waste canisters (CWC's) on top of consolidated fuel storage boxes (CFSB's) or intact fuel assemblies in the spent fuel storage racks. The upper ends of the CWC's might be supported laterally against tipping and seismic motions by an eggcrate gridwork suspended from the edges of the pool and bearing against the sides of the pool. Figure 4-1 shows the dimensional relationships.

A major potential difficulty with this option is that the CWC's containing the compacted Zircaloy grid cage/guide tube assemblies (GGA's) should contain no cooling flow slots and therefore would block flow of coolant through the fuel in the cells beneath them. An ANSYS analysis made in the thermal hydraulic program task (2) for a single consolidated fuel storage box in a fuel rack cell that was fully blocked at the top indicated that the fuel rods could be cooled by lateral conduction to the box walls. However, this analysis assumed convection cooling of the outside of the box between the box and the cell wall. This analysis may not be valid for multiple cells. The actual Option 1 geometry and conditions would have to be modeled in a new ANSYS analysis to determine whether or not conduction cooling would be adequate.

Figure 4-1. Dimensional Relationships for Storing NFBC Scrap Over Spent Fuel Racks

An alternative arrangement (Option 2) is shown in Figure 4-2. The CWC's are stored in separate freestanding racks above the spent fuel racks with sufficient clearance to obviate interference with natural circulation fuel cooling. The CWC storage rack modules could be supported from the fuel support bars by columns extending up through empty cells of the spent fuel racks or could be free standing on the top of the rack. This slightly reduces fuel storage capacity. The level of the tops of the CWC racks would have to be the same as the level shown in Figure 4-1 for the tops of the CWC's to permit fuel handling over the racks, otherwise the rack modules would have to be positioned in the pool in a sequence such that fuel would not have to be transported over them, which may not be feasible. Therefore, the maximum height of a CWC for Option 2 would probably be about 22 inches compared with 36 inches for Option 1, with a corresponding reduction in scrap capacity. A scoping estimate indicates that whereas Option 1 could be accommodated within Region II of the spent fuel racks, Option 2 would require approximately the area of Regions I and II combined, and would block access to the full core reserve cells in the Region I spent fuel rack.

A compromise arrangement (Option 3) would utilize two designs of CWC, one without coolant slots for the GGA's and one with coolant slots for the end fittings. The end fitting CWC's would sit on top of fuel in the spent fuel racks as in Scheme 1 and the GGA CWC's would initially be deposited in empty cells in the spent fuel racks. It is assumed that the end fitting CWC's with cooling slots would not inhibit fuel cooling. This arrangement would permit 1238 fuel assemblies to be consolidated before the spent fuel racks were filled, giving a total fuel capacity of 1828 assemblies, with 69 spent fuel rack cells filled with GGA CWC's. By this time the regional low level waste repositories should be in operation, and if the regulations permit shallow burial of the Zircaloy material, a cost/benefit evaluation could be made of shipping the compacted GGA's to a repository and thereby freeing 69 fuel rack cells. This would allow consolidation of 124 more fuel assemblies, increasing the total fuel capacity to 1952 assemblies and leaving only 7 fuel rack cells occupied by GGA CWC's. Only one more GGA shipment would then be needed to bring the total spent fuel pool storage capacity up to 1964 assemblies. A total of 550 fuel rack cells would have end fitting CWC's stored on top of CFSB's or intact assemblies. The number of such cells would be materially reduced if a method of compacting end fittings were developed.

Figure 4-2. Freestanding Upper Level Storage Rack for NFBC Scrap

Any in-pool storage design for the NFBC scrap will of course require the appropriate analyses to verify adequate cooling of the fuel, and the structural and seismic integrity of the racks and gridwork. Potential accidents will have to be reviewed and re-analyzed if necessary. If the compacted grid cage/guide tube assemblies are to be shipped, radioisotopic scans of the material should be considered, since shipments are curie-limited and activity estimates based on nominal chemical composition have an uncertainty of about 50 percent. Precautions must also be evaluated with regard to the pyrophoricity of Zircaloy particles, especially during the drying out period, because the pyrophoricity of Zircaloy fines is greatest when they are moist.

Intact spent fuel assemblies have to be stored in a 3-out-of-4 pattern in Region II, the fourth cell remaining empty to serve as a flux trap. A removable cell block in the empty cell prevents the inadvertent deposition of a fuel assembly in the cell. Consolidated fuel can be stored in all Region II cells (subject to replacing the intact assembly positions in a pattern first) hence the cell blockers eventually have to be removed. This is not considered a problem however since the blockers are stainless steel tubes and can easily be decontaminated and disposed of as scrap, or repositioned in the tops of cells already containing consolidated fuel but not designated also to contain end fitting CWC's.

SECOND GENERATION CONSOLIDATION SYSTEM

In planning for the design and fabrication of C-E's second generation version of the fuel consolidation system, the experience gained in the demonstration program and the recommendations made for improvements were critically reviewed. The major design objective was to increase the production rate to consolidate two spent fuel assemblies in one 10-hour shift to improve unit operating costs and plant scheduling, while retaining as many of the proven features of the demonstration system as possible. This was achieved with the following principal refinements:

- Multiple purpose tools are used to reduce tool changeout time.
- Lift rigs have been eliminated. Handling is accomplished with dedicated equipment.
- Two fuel disassembly stations enable disassembly operations to be performed on two fuel assemblies in sequence with one tool set-up.

- Fuel rod pulling speed is increased to 10 feet per minute from 7 feet per minute.
- The upper guide tube cutting tool is capable of cutting both the tube wall and the sleeve in a single pass.
- The layout of the work platform has been optimized based on the results of detailed time and motion studies of several different arrangements. Rod consolidation operations are conducted in parallel whenever possible. The compactor has its own stand and is located away from the work platform so that compaction can proceed independently of consolidation.
- The recommended location for the equipment is in the fuel transfer canal at the end of the spent fuel pool, eliminating the need for a temporary fuel storage rack.

Figure 4-3 illustrates the general arrangement of the system, and Figure 4-4 shows a typical layout of the equipment in the spent fuel pool. The consolidation equipment is oriented along a line which is parallel to the side of the pool except for side-by-side fuel disassembly stations. This allows easy access and direct observation by operators from the operating platform. All major equipment is located in the lower frame which provides a solid base for stability. When work stations are being reloaded by the utility fuel handling crew, the X-Y table is moved out of the path of the fuel handling crane. Similarly, the rod transfer tool is stored out of the fuel handling crane path when consolidated fuel storage boxes are removed. The fuel disassembly station layout is such that the upper end fittings can be removed while rods are being transferred to the consolidated fuel storage box. Compacting can be conducted at any time using the auxiliary crane.

Two jib cranes with hoists are provided for handling and are located at the side of the transfer canal to clear existing equipment. The main jib is below the cask handling crane but above the auxiliary jib. The auxiliary jib is below the main hoist but above the festoon cable system for the fuel handling machine. Both jibs cover the entire work area, but are separated sufficiently to allow work to continue simultaneously.

The compactor is located on its own platform just beyond the consolidation work frame. Lower end fittings are cut from the grid cage/guide tube assemblies at this point before the assemblies are loaded into the compactor inlet tunnel.

Figure 4-3. C-E Second Generation Fuel Consolidation System

Figure 4-4. Typical Layout of Second Generation System in Spent Fuel Pool

Most of the elements of the demonstrated system are retained virtually unchanged in the second generation system. These include: the multiple rod pulling tool, the interim transfer canister, the fuel transfer station (except for duplication), the rod transfer tool, the separation/recovery station, the damaged fuel rod station and the filter system. The compactor and the X-Y table are modified only to the extent necessary to eliminate the use of hydraulic fluid in the pool. This is done to alleviate any utility concern over the possible effects of hydraulic fluid leakage. The compactor ram cylinders are actuated with de-ionized water, and the de-ionized water system is equipped with a variable speed high pressure water pump as well as the present medium pressure pump. The X-Y table is propelled by electric motors.

Modular construction is adopted for the work station frame to reduce installation and removal time. There are three mating sections, each within the handling capacity of the plant's cask handling crane. The work station frame performs the same function as the lower work platform in the demonstration system.

The layout of the complete system at the plant site is designed to minimize the need for removing and reinstalling equipment between consolidation campaigns, thereby minimizing the cost, schedule and personnel exposure impact of these operations.

FUEL CONSOLIDATION ECONOMICS

For a given consolidation system design the main factors influencing the cost are the following:

1. The total number of consolidated fuel assemblies over which the equipment cost can be spread.
2. The number of times and extent to which the equipment has to be removed from the pool and then reinstalled, after the first installation.
3. The cost of provisions, if any, made to store or dispose of NFBC scrap so as to use all spent fuel rack cells for spent fuel storage (and full core reserve) only.
4. The number of fuel assemblies consolidated per campaign.
5. The cost of replacement spare parts and maintenance schedule requirements of the system.
6. The labor force utilized to perform the operation (plant personnel, contractors, or combination of both).

7. The schedule upon which the operation will be performed (normal, extended or accelerated).

The schedule will establish the cost of the operation, i.e., overtime, and the degree to which plant resources must be available to support the operation.

The following charts provide NU's economic breakdown of the costs to consolidate spent fuel at Millstone Unit No. 2. The chart provides both a current and future projection of the relative costs.

Table 4-1
MILLSTONE UNIT NO. 2

MAN-HOUR ASSUMPTIONS/CONSOLIDATION OF 2 SPENT FUEL ASSEMBLIES

<u>Current Technology</u> (In Rack Waste Storage @ 10:1)	<u>Future Technology</u> (Above Rack Waste Storage @ 10:1)
Fuel-rod Related Activity	
• 5 men x 18 hours = 90 MH	• 5 men x 16 hours = 80 MH
Compaction/End Fitting Station	
• 3 men x 8 hours = 24 MH	• 3 men x 8 hours = 24 MH
Plant Operations Support	
• 2 men x 4 hours = 8 MH	• 2 men x 4 hours = 8 MH
Filter Changes (not critical path)	
• 5 men x 1 hours = 5 MH	• 5 men x 1 hours = 5 MH
Movement of Loaded Waste Canisters (not critical path)	
• 1.2 MH (based on 10:1)	• 1.2 MH (based on 10:1)
Total Man-Hours	
• 128.2 MH	• 118.2 MH

Table 4-2
1990 \$ COST/INCREMENTALLY STORED BUNDLE

	<u>Current Technology</u>	<u>Future Technology</u>
Labor ¹	\$5,609	\$5,171
Consolidated Fuel and Waste Canisters	4,636	4,636
Cost and Disposal Filters	<u>624</u>	<u>624</u>
Sub-total	\$10,869 0.83 ²	\$10,431 + 1,000 ³
Total/Incremental Space	\$13,043	\$11,431

¹Labor Rate = \$25.00/hour × 1.75 (overhead factor)

²Efficiency Factor for in rack waste storage:

$$\frac{1}{1 + \frac{CF}{VR}} = 0.83$$

where, CF: Consolidation Factor = 2:1, and
VR: Volume Reduction Ratio = 10:1

³Above rack waste storage

NU COMMENTARY

Fuel consolidation has progressed to the point of being a proven and useful technology.

Many technical obstacles have been overcome in the development and testing of the consolidation system process.

Additionally, a significant amount of generic testing and analytical development work was performed in support of the licensing submittal for the storage of consolidated spent fuel.

The technology has been shown to be a safe and cost-effective option for nuclear utilities. Positive encouragement may now be offered to others in the

nuclear industry with respect to the viability of this option for both near- and long-term spent fuel storage requirements.

Accordingly, the Department of Energy should clarify that non-fuel bearing waste components resulting from consolidation will be accepted by DOE on the same schedule as standard intact fuel assemblies and with no additional cost. This clarification could result from a rule-making proceeding on the disposal contract or amendment to the Nuclear Waste Policy Act (NWPA), whichever is likely to occur earlier. By taking this action, DOE will remove the remaining obstacle to fulfilling the potential of this technology. We look forward to DOE's related encouragement and expedition of the development of this technology, as contemplated under NWPA.

Section 5

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Appendix A

MILLSTONE UNIT 2 SPENT FUEL POOL WATER CLEANUP

INTRODUCTION

During the Hot Demonstration in September, 1987, the water in the Millstone Unit 2 spent fuel pool lost its clarity. A refueling outage was scheduled for December 15, 1987. The fuel in the pool would have to be visible for this operation, requiring the turbidity of the water to be reduced to less than 0.1 NTU.

This appendix describes the intensive effort which was mounted to : (a) establish the cause of the visibility loss, (b) evaluate methods of restoring visibility, and (c) perform the pool cleanup operation. The task was coordinated by the NU project engineer for the Fuel Consolidation Demonstration Program and involved the participation of NU's Millstone Chemistry and Unit 2 Operations Engineering Departments, the Radwaste Systems Engineering Department, C-E and several subcontractors to NU.

BACKGROUND

The following is a brief chronology of events that led to loss of clarity in the Unit 2 fuel pool:

- Before 8/25/87 Reports of high chlorides;
Very green tint with reduced visibility;
Fuel consolidation crew reported the reduced visibility occurred from east to west; and
Drained the cask pit, placed fuel consolidation equipment into the cask pit, and then filled the cask pit.
- 8/25/87 Plant added 10ft³ of anion resin to the fuel pool demineralizer.
- 8/26/87 Fuel pool's visibility improved to almost crystal clear.

- 8/28/87 Removed the cask laydown gate and moved fuel into the cask laydown area for the fuel consolidation demonstration. At this point, the water from the fuel pool and the cask laydown area mixed.
- 8/31/87 The fuel pool started to lose visibility—water had a black tinge.
- 9/15/87
 (on or about) Total visibility was lost in the fuel pool.
- 9/22/87 The cask pit clarity was lost and the fuel consolidation demonstration was shutdown. During the consolidation process of about 25 days, a 500 gpm Tri-Nuclear 1 and 5 micron filter system was in use. Clarity in the cask pit was maintained by filtration for seven days longer than in the fuel pool.

Experience at Other Plants

From examination of other published plant experience (i.e., Ft. Calhoun and TMI) there were two common factors that disrupted fuel pool clarity. These factors were the presence of iron oxide and microorganisms. The Ft. Calhoun study emphasized that other pools have had microorganisms and have had hydraulic fluid spills, but have not had a clarity problem. (The microorganisms use the hydraulic fluid as a food source.) The common thread that did cause the clarity problem was iron oxide. Ft. Calhoun's source of iron oxide was a carbon steel bucket containing cut up in-core detectors which had been in the pool for a number of years. Prior to restoring the clarity to the fuel pool, Ft. Calhoun removed the source of iron oxide. After Ft. Calhoun restored clarity to the pool, samples indicated that the hydraulic fluid still remained in the pool. A coagulant method was not successful in removing the hydraulic fluid, but it did remove the iron oxide colloids and reestablished pool clarity. After about six months, Ft. Calhoun tested the pool water and determined that the glycol had left the pool. It was thought that it degraded to lower molecular weight compounds by radiation and/or microorganisms, and was removed by volatilization. TMI's clarity problems are similar to Ft. Calhoun's. TMI used WS-34 and a borated ester as a hydraulic fluid. This hydraulic fluid sustained significant growth rates in RCS-7 (microorganism). TMI has not been able to stop the organic growth or get rid of the source of iron oxide, and frequently experiences clarity problems in the fuel pool.

INVESTIGATION OF CAUSE OF TURBIDITY

As noted in Section 2, it had been necessary to top off the hydraulic system reservoir of the consolidation equipment with between two and five gallons of WS-34 during the initial fill on site, possibly due to spillage or leakage into the cask laydown pit. It therefore appeared that the presence of WS-34 in the pool water, possibly in combination with microorganisms and particulates, could be a factor in the loss of water clarity, although C-E and others had used WS-34 for several years in underwater servicing operations without any effect on water visibility. A plant chemistry measurement of 10 ppm total organic carbon (TOC) in the spent fuel water was calculated to be consistent with the dilution of five gallons of WS-34 in the pool, and the concurrent TOC level of 94 ppm in the cask pit water strengthened the suspicion that the contaminant was WS-34.

Initial Pool Water Analyses

In September, 1987, Millstone sent samples of the fuel pool water and the WS-34 hydraulic fluid to an outside laboratory with a request to identify the contaminant (suspected to be WS-34). The laboratory was unsuccessful in doing so, and was unable to detect the presence of polyalkylene glycol, the major constituent of UCON WS-34.

Millstone also performed a microbial analysis in accordance with a TMI procedure and found no living organisms. No test was made for iron oxide, but there were known sources and generators of iron oxide in the pool such as the galvanized stud buckets that held spent in-core detectors, residue from the cutting of the thermal shield, and possible carbon steel liners. In addition, the color of the fuel pool water had been described as green, which could indicate the existence of iron oxide.

Sludge Dispersion Test

To evaluate the suggested ability of WS-34 hydraulic fluid to promote a stable suspension of particulate material already present in the spent fuel pool water, C-E performed a simple test in December 1987 using actual deposits from the bottom of the pool and various concentrations of WS-34 in spent fuel pool water. Turbidity measurements were taken of each combination for a period of 165 hours. Two samples were exposed to radiation in the pool from a spent fuel assembly, and behaved the same as the corresponding unirradiated samples. It was concluded that the test did not demonstrate that WS-34 in the pool

water would support a stable suspension of the debris from the bottom of the pool. The test report is contained in Attachment 1 to this appendix.

Duratek Analysis and Testing

Continuing the effort to identify the cause of the turbidity, NU contracted with the Duratek Corporation of Greenbelt, Maryland for further analysis of the problem. The work was completed in early 1988 and Duratek's report is contained in Attachment 2 to this appendix.

Four liters each of cask pit water and fuel pool water were provided to Duratek. The samples were analyzed for total organic carbon, presence of WS-34 by calorimetric method based on precipitation with iodobismuthate, and ultraviolet - visible (UV-Vis) spectrum in comparison with the spectra of 1 and 2 percent solutions of WS-34. It was concluded from these analyses that the WS-34 fluid itself was not responsible for the problem.

A solution of 200 mg/l WS-34 was then irradiated for 23 hours and its UV-Vis spectrum analyzed. This spectrum resembled that of the cask pit water, from which it was concluded that the combination of radiation and UCON WS-34 would produce the turbidity characteristics found in the fuel pool. Particle sizes were estimated and filtration effectiveness tests conducted with a 0.1 micron cellulose acetate filter and with a 50-200 mesh carbon bed specially designed to remove organics. Neither filtration method was recommended for plant use.

The principal conclusions of the report were:

1. Polyethylene glycols were present in the cask pit water in concentrations of 20-30 mg/l. Polyethylene glycols are the major constituent of UCON WS-34 hydraulic fluid.
2. The polyethylene glycol level in the cask pit represented only approximately 20% of the total organic carbon present in the cask pit.
3. UCON WS-34 itself could not be responsible for the turbidity since it displayed neither the proper spectral features nor intensity of absorbance in the UV-Vis region.
4. The turbidity was most likely caused by irradiation of the water solution of the WS-34 fluid. Such solutions displayed both the proper intensity and spectral features.

5. The irradiation of WS-34 fluid produced particles in the 0.05-0.15 micron size range. The irradiation apparently caused the WS-34 fluid to agglomerate either by chemical reaction which causes increased polymerization or by intermolecular interactions, perhaps due to charge attraction.
6. Fuel pool clean up efforts must be directed at removing both the turbidity causing species and any remaining UCON WS-34 fluid, as the latter would transform to the former in time.

Conclusion (4) was supported by independent work performed by CE for NU later in 1988 to evaluate a series of hydraulic fluids for use in a hydraulic crane at Millstone Unit 2. The evaluation included irradiation testing and WS-34 was included in the series as a benchmark. When WS-34 was irradiated after dilution it demonstrated a similar increase in turbidity. If irradiated first and then diluted, however, the turbidity did not increase. This hydraulic fluid evaluation is described in Appendix B.

Development and Evaluation of Cleanup Methods

Because of the necessity of restoring visibility in the spent fuel pool by December 15, 1987, the method of achieving this had to be selected before the cause of the turbidity could be determined. This meant that there was a considerable risk involved in the selection. The objectives established for the cleanup system were based on the review of experience at Fort Calhoun and TMI, and the results then available from the investigation into the cause. These objectives were:

- Remove iron oxide
- Remove WS-34
- Remove fractions of WS-34 produced by radiological effects.

Bench-Top Testing

Millstone Chemistry Department performed some bench-top tests to gain some insight on the potential effectiveness of different removal methods.

The simplest approach tried was to filter out the turbidity and to remove the organic by use of activated carbon. Listed below are the results of the initial testing.

Fuel Pool Water = 11.3 ppm TOC, 1.4 NTU

<u>Liters Processed</u>	<u>TOC (ppm)</u>	<u>NTU</u>
1	0.60	0.10
2	1.32	0.20
3	1.24	0.20
4	2.04	0.26
5	1.93	0.35
6	2.57	0.14
7 Coagulant Only	3.40	0.20
Coagulant & Demin	1.27	0.14
8	1.30	0.14
9	N/A	0.20
10	1.30	0.20

Average TOC reduction = 86.6%

Average turbidity reduction = 84.6%

Because this system showed no signs of rapid exhaustion it was decided to scale up to a 2 gpm pilot system based on the bench top testing. As mentioned earlier however, bench top testing for a better coagulant was continued because of the small micron size of the microfloc. By the time the pilot system was set up, a better coagulant producing 2x the size microfloc was ready for use. Initial testing of this coagulant (NALCO 7107) had produced a microfloc 4x the size of the 8103 coagulated microfloc.

Pilot Testing of Coagulant Method

Figure A-1 is a diagram of the pilot system. The system was installed in the Unit 2 Auxiliary Building. The differential pressure needed to produce flow through the system was obtained by taking a sample off the discharge of the fuel pool cooling pump and then returning the sample back to the suction side of the pump.

In the initial testing it was evident that the one micron filter was not working. Testing of the influent to the filter showed that a microfloc had failed to form and even a .22 micron filter was ineffective in reducing turbidity. It was thought that better mixing of the coagulant (NALCO 7107) with the influent was necessary, and a mixing vessel was fabricated.

Installation of the mixing vessel produced a microfloc that could be almost entirely removed by a 0.40 micron filter. This was now identical to what was being achieved in the laboratory. What may seem as an inconsistency in the data was brought about by using a different lot of NALCO 7107. Initially, the

7107 sample left by a NALCO representative produced a microfloc greater than one micron. Because there was only approximately 50 mls of the original sample, a liter of new NALCO 7107 (same chemical, different lot number) was purchased from NALCO for the pilot plant testing. Surprisingly, this lot would not produce the same size microfloc as the original sample. Nevertheless, 7107 remained the best coagulant. Testing of the pilot plant using a 0.40 micron filter produced the following results.

<u>Sample Position</u>	<u>Parameter</u>	<u>Results</u>	<u>% Reduction</u>
0.4 micron filter	NTU	.10	90.0%
	TOC (ppm)	3340	65.9%
Carbon	NTU	0.06	94.0%
	TOC (ppm)	0.370	96.2%
IRN-938	NTU	0.06	94.0%
	TOC (ppm)	0.210	97.8%
Mixed Bed	NTU	0.06	94.0%
	TOC (ppm)	0.107	98.9%

These results obtained from the pilot plant testing were actually 10% better than what was achieved in the preliminary bench top testing. However, the problem of early filter clogging was still present. After approximately 200 gallons had passed through the 0.4 micron filter the flow had been reduced by 75% (i.e., from 2 gal/min to 0.5 gal/min). Some additional filter capacity in a full scale system might be obtainable if it had a variable pressure capability (the filters were rated at 15 psi pressure differential whereas the maximum available in the pilot plant was 10 psi). However, the increased filtration capacity would, most likely, not be relatively significant. A rough estimate (on the conservative side) for the total number of filters needed to treat one volume of fuel pool water (which should produce a 50% improvement in fuel pool clarity) is 500 filters.

If the pilot plant data was an accurate indicator of what could be expected from full scale operation, it would be necessary to alleviate the filter plugging problem. One possible solution would be to simply backwash the filters. This would effectively eliminate the filter change out problem but would present a radioactive waste concern.

- A: COAGULANT ADDITION TANK (1:100 DILUTION OF NALCO 7107)
- B: MIXING VESSEL
- C: FLOW METER
- D: HOLD UP TANK (1 ft³ CAPACITY)
- E: 0.4 MICRON FILTER
- F: 2 TANKS CONTAINING ACTIVATED CARBON (1 ft³ CAPACITY EACH)
- G: TANK CONTAINING IRN 938 (0.25 ft³ CAPACITY)
- H: TANK CONTAINING MIXED BED RESIN (1 ft³ CAPACITY)
- I: 0.22 MICRON FILTER

Figure A-1. Diagram of Coagulant System Pilot Plant

A possible solution to the backwashed radioactive waste problem would be to collect it in a settling tank. If the backwashed coagulated material settled, a dewatering process could ultimately consolidate the waste and make it much more manageable. If the backwashed coagulated material would not settle of its own accord, it might be made to settle out by either adjusting the pH or adding a coagulant aid. There would be a lot more flexibility to treat the waste than what is available when working with fuel pool water. Figure A-2 presents a flow diagram of a plant scale system based on the coagulant method.

Alternatives to Coagulation

Millstone Chemistry Department briefly considered an oxidation process on the premise that the contaminant was organic and could possibly be oxidized to CO₂, or at least ionized to a point where it could be removed by ion exchange resin. Possible oxidation processes that could be tried were ultraviolet light, ozone, and hydrogen peroxide. However, it was felt that there was already more ionization energy available in radiation from the spent fuel than would be introduced by the processes mentioned above. It was also uncertain whether elimination of the organic contaminant would result in removal of the turbidity.

A third method considered was the use of reverse osmosis (R.O.) technology. Associated Technologies Incorporated (ATI) of Charlotte, North Carolina was contacted on the feasibility of using R.O. technology to clean up the fuel pool. ATI was confident the R.O. could do the job but indicated some uncertainties and disadvantages, as follows:

1. Membrane life: There was no way to tell how the organic contaminants might effect membrane performance. There was the chance that the membrane might quickly foul and need to be replaced. At a cost of \$30,000 per membrane change out, it would be a considerable gamble. ATI's best guess however, was that polyalkylene glycol would not foul the membrane and might actually help to keep it clean.
2. Reject water: For a R.O. process to work it was necessary to "reject" a portion of the influent water. ATI recommended a 10% reject flow for operation of its R.O. This meant that to treat 4-5 fuel pool volumes, as would be necessary to return the pool to its original clarity, it would be necessary to reject 1.40 to 1.75 x 10⁵ gallons to Radwaste. That was approximately half the entire volume of the fuel pool.

(ESTIMATED PROCESS VOLUME)
1,750,000 gal

Figure A-2. Flow Diagram of Coagulant System for Pool Cleanup

3. Boron removal: It was estimated that the boron rejection rate would be approximately 25%. It would therefore be necessary to add approximately 8.34×10^3 lbs of boric acid for each volume of fuel pool water that was processed.
4. Expense: Based on an operating expense of 11¢/gallon processed, an estimated cost for cleaning up the pool would be between \$150,000 - \$200,000. It was noted, however, that if the filters for the coagulation system could not be backwashed the price for that system would probably exceed \$200,000.

Figure A-3 is a flow diagram of the R.O. system which was considered, and subsequently adopted, for the cleanup of the fuel pool.

Cleanup System Evaluation

The Millstone Chemistry coagulant system and the ATI reverse osmosis system were evaluated by Radwaste System Engineering to recommend which process should be used for the fuel pool cleanup operation. Millstone Unit 2 Operations Engineering confirmed that both systems were compatible with plant operations and facilities.

The two systems were evaluated on the following factors:

- Technical capability
- Estimated cleanup cost
- Estimated discharge volume to radioactive waste system
- Degree of risk to NU.

Three vendors, including ATI, that normally provide water processing to the nuclear industry were invited to submit proposals. Two vendors offered equipment and manpower based on the Millstone Chemistry coagulant system, and ATI offered its R.O. system. None would quote a fixed price for the overall operation because of uncertainty as to the contaminant, the cause of the turbidity, and the total volume of water which would have to be treated to clarify the pool water and leave it free from contaminants. ATI did offer to provide an effluent of 0.1 NTU at a fixed price per gallon.

Figure A-3. Flow Diagram of ATI Reverse Osmosis System for Pool Cleanup

The advantages and disadvantages identified for each process were as follows:

Coagulant	Removes iron oxide. Would probably remove WS-34.	Not demonstrated to be capable of removing a wide range of organics. Only demonstrated on pilot scale. Estimated cleanup cost \$200 - \$300K. Estimated waste disposal volume 600 cu. ft. Entirely NU's risk; end condition of pool and total water volume to be processed unknown.
ATI Reverse Osmosis	Removes iron oxide. Removes WS-34 and carbon chains produced by radiological breakdown. Waste disposal volume most likely zero—reject flow should be dischargeable from plant. Vendor willing to accept process liability (price per gallon); reduces NU's risk.	Estimated cleanup cost \$150 - \$200K, but if reject flow dischargeable, would be additional cost to process, transport and dispose.

The ATI reverse osmosis system was recommended for the pool cleanup operation.

Other recommendations made were:

- Remove sources of iron oxide from the pool.
- Future hydraulic fluid should be demineralized water only
- Plant testing program should include:
 - elemental analysis
 - total organic carbon
 - microbial
- All interfacing systems should be reviewed for detection and removal of iron oxide producers.
- Ensure no organics are introduced into the pool.

Fuel Pool Cleanup

The ATI reverse osmosis system was selected on October 29, 1987; the equipment was delivered to site on November 16, and was set up and leak tested by November 22.

The cleanup operation began on November 23, the subsequent chronology of events being as follows:

- November 30: After processing approximately one pool volume, clarity had increased to the point where the tops of the racks were visible.
- December 3: The process was realigned to the cask pit alone.
- December 7: Cask pit processing was secured due to poor performance, and the cask pit gate was removed.
- December 8: R.O. system operation was terminated due to high radiation levels that could not be reduced by flushing with pool makeup water.
- December 10: It was decided to replace the first stage membranes.
- December 14: The R.O. resumed operation on both fuel pool and cask pit water.
- December 28: The spent fuel pool water processing was completed. The cask pit gate was re-installed to isolate the fuel consolidation equipment from the fuel pool.
- December 29 - 31: The R.O. equipment was removed.

The total volume of water processed was approximately 1.27 million gallons.

Figure A-4 shows the relationship between the total organic carbon (parts per billion) in the fuel pool and the gallons of water processed. The TOC was reduced from 4420 ppb to less than 400 ppb. At approximately 1 million gallons the cask pit was opened to the spent fuel pool.

Figure A-5 shows the relationship between fuel pool turbidity (NTU) and the gallons of water processed. The turbidity was reduced from 0.63 to 0.30 NTU. At approximately 1.25 million gallons fuel was moved into the pool and the transfer canal was vacuumed.

Figure A-6 shows the relationship between fuel pool chlorides (parts per billion) and the gallons of water processed. Chlorides were reduced from 388 ppb to less than 50 ppb.

Figure A-4. Spent Fuel Pool (SFP) Cleanup
Total Organic Carbon (TOC) vs. Gallons Processed

Figure A-5. Spent Fuel Pool (SFP) Cleanup
Turbidity vs. Gallons Processed

Figure A-6. Spent Fuel Pool (SFP) Cleanup
Chlorides vs. Gallons Processed

Visibility was restored sufficiently for fuel movement after about 0.5 million gallons of water had been processed. Fuel movement and transfer canal vacuuming in preparation for the refueling outage caused turbidity to increase, but visibility was not lost. Operation of the normal spent fuel pool purification system successfully removed the turbidity caused by those activities.

Lessons Learned

1. The existing Millstone Unit 2 spent fuel pool purification system cannot remove organic carbon type impurities.
2. The reverse osmosis system was effective in removing the organic contaminants in concentrations of less than 5 ppm.
3. The R.O. system did not effectively remove organic concentration in the range found in the cask pit. (90 ppm)
4. Future use of this type of system should include a membrane cleaning process that should be demonstrated to be effective in reducing membrane radiation levels and extending membrane performance.

Changes in Operating Practices to Prevent Recurrence

1. Analysis of total organic carbon was added to the weekly spent fuel pool sampling program.
2. Cask pit water is being directly discharged to the watered waste system instead of to the fuel pool as previously.
3. The use of hydraulic fluids other than water is eliminated.

RESULTS

MILLSTONE II SPENT FUEL POOL

SLUDGE DISPERSION TEST

(DECEMBER 1987)

PURPOSE

The Spent Fuel Pool (SFP) at Millstone Point Unit II developed a turbidity problem in September 1987. The site personnel thought that the turbidity may have resulted from the leaking of a miscible hydraulic fluid (Union Carbide WS-34) that was used in the C-E fuel consolidation equipment. Union Carbide claimed that WS-34 should not be capable of supporting a stable suspension of particulate matter, thereby not contributing to a turbidity problem. C-E designed a simple test exposing actual deposits from the bottom of the fuel pool to various concentrations of WS-34. The purpose of this test was to establish to what extent WS-34 was responsible for the suspension of the debris within the SFP.

OVERVIEW

The test was designed to expose an excess of the SFP deposit, simulating the condition of the fuel pool bottom, to varying amounts of WS-34. The amounts of WS-34 were selected to differentiate to what extent the hydraulic fluid could influence the formation, and decay of, a stable suspension of SFP particulate matter. If there was no change in the turbidity in any of these combinations it would be concluded that the WS-34 would not support a stable suspension. If all

the combinations produced a stable suspension, then the test would be inconclusive since the SFP deposits had been previously exposed to WS-34 and further additions of WS-34 may have had no influence.

PROCEDURE

Eight liters of SFP water with excess deposit from the bottom of the SFP were collected by NNECO personnel. The pool-side test set up consisted of eight one liter erlenmeyer flasks containing 1000 ml of SFP water/deposit mixture, ensuring an excess of particulate matter. In addition, three one liter erlenmeyer flasks were prepared as control samples; one contained 1000 ml DI water and the other two were filled with 1000 ml of RWST water. The WS-34 hydraulic fluid was added to each flask per the test matrix in Table 1. To evaluate the effects of the radiation field on the formation/decay of a stable suspension, two samples were placed adjacent to a fuel bundle in the SFP. These samples consisted of 1000 ml of the SFP water/deposit mixture and WS-34 per Table 1 (Flask 10 and 11), housed within polyethylene bottles. Flasks 1-7 were placed in a constant temperature bath set at 100°F, Flasks 8 and 9 were kept at pool side (ambient temperature) and polyethylene bottles 10 and 11 were placed adjacent to spent fuel bundles in the SFP.

Table 1

Flask	WS-34
(SFP Water)	
1	0 ppm
2	10 ppm
3	20 ppm
4	50 ppm
5	100 ppm
6	1000 ppm
10*+	50 ppm
11*+	1000 ppm
(RWST Water)	
7	1000 ppm
8	0 ppm
(DI Water)	
9	0 ppm

* Polyethylene bottles located adjacent to the fuel bundle in the SFP.

+ Samples not included in Test 2.

After mixing the WS-34 and the SFP deposit in each flask, an initial set of samples were taken and analyzed for turbidity and total organic carbon (TOC). Subsequent samples were taken according to the sample schedule in Table 2, withdrawn using a pipet so as not to agitate the test solutions. The control samples (8 and 9) and those in the radiation field (10 and 11) were only sampled at the beginning and end of the test.

Table 2

<u>Flask #</u>	<u>Sample Time</u>	<u>Analysis</u>
1-11	T ₀ (initial)	Turbidity, TOC
1-7	T ₄ (4 hrs.)	Turbidity
1-7	T ₈ (8 hrs.)	Turbidity
1-7	T ₂₄ (24 hrs.)	Turbidity
1-7	T ₄₈ (48 hrs.)	Turbidity
1-11	T ₇₂ (72 hrs.)	Turbidity, TOC

DISCUSSION

Two tests were performed, as described herein. The first test used debris taken from the bottom of the transfer canal. The deposits were noted to have a distinctly reddish color (thought to mainly consist of Fe₂O₃). The initial turbidity of these test solutions was around 200 NTU. The test was continued past the design 72 hour duration, with the final data point obtained at the 165 hour point. The results of this test are plotted in Figure 1. The turbidity

level of about 25 NTU after 165 hours. The samples in the radiation field did not exhibit any difference than the non-radiated samples. Since the actual SFP turbidity problem occurred at a turbidity level of only 1.4 NTU this first test was thought to have been too severe, indicating the need for a second test.

The second test was basically the same as the first with a few exceptions. First, samples located near the fuel bundles were not included during this test since there was no difference in turbidity decay in radiated vs non-radiated samples noted during the first test. Secondly, the SFP debris was taken from the fuel pool bottom rather than the transfer canal. This deposit was not reddish, as during the first test, but rather a black or dark gray color. The SFP water/deposit mixture was added to a liter of clean SFP water until 1.5 NTU turbidity was achieved. The addition of WS-34 was per Table 1, with the exception of samples 10 and 11 which were not included. The sampling schedule from Table 2 was also employed during the second test. The results of Test 2 are shown in Figure 2. Most of the test combinations exhibited similar settling rates. The settling rate in Flask 6 (1000 ppm WS-34 in SFP water) did seem to stop at about 0.5 NTU.

Figure 3 contains the data from some of the control samples. Flask 7 from both tests was RWST water (which is the source of makeup water for the SFP) with 1000 ppm WS-34 and Flask 8, Test 2 (the turbidity of Flask 8 at the end of Test 1 was not obtained) was RWST water only (no WS-34). First, this data and plot show that the RWST water has a turbidity greater than DI water (0.3-0.4 NTU vs <0.1 NTU). Secondly, there was an increase in turbidity in the RWST water without any added WS-34. The third observation is that both flasks with WS-34 added became more turbid during the course of the test compared to the flask without WS-34.

CONCLUSIONS

The test results did not demonstrate that WS-34 would support a stable suspension of the debris from the bottom of the MP-2 SFP. NNECO conducted a

Millstone Point II Spent Fuel Pool Test #1

Figure 1

Millstone Point II Spent Fuel Pool Test #2

Figure 2

Millstone Point II RWST Water (SFP Test)

Figure 3

(150T 430) 12W/11 110109 and 110110

CLIMATE DATA

CLIMATE DATA

CLIMATE DATA

CLIMATE DATA

CLIMATE DATA

Attachment 2
to
Appendix A

ANALYSIS & TESTING

MILLSTONE II

FUEL POOL WATER

By: Herbert Sutter, Ph.D.
Technical Director

Date: February 19, 1988

DURATEK CORPORATION

A Subsidiary of National Patent Development Corporation

EXECUTIVE SUMMARY

Duratek has performed analysis and testing of the fuel pool and cask pit water from Millstone II in an attempt to determine the cause of the turbidity that began to appear in the fall of 1987.

Its conclusions are as follows:

(1) Polyethylene glycols, the major constituent of UCON WS-34 hydraulic fluid, are present in the cask pit water in concentrations 20-30 mg/l;

(2) The polyethylene glycol level in the cask pit is only 20% of the total organic carbon level;

(3) The turbidity problem is most likely caused by irradiation of the WS-34 fluid which provides agglomerated particles of size 0.05-0.15u.

(4) Fuel pool cleanup efforts must remove both the turbidity causing species and the WS-34 fluid since the latter will transform to the former under irradiation.

Analysis Of The Turbidity Problem In The Millstone II Fuel Pool

INTRODUCTION

In the fall of 1987, a turbidity problem developed in the fuel pool of the Millstone II nuclear power plant. It was believed that the problem might have originated with the leakage of approximately 5 gal of UCON WS-34 hydraulic fluid (Union Carbide Corp.) into the pool during cutting operations in the late summer of 1987. The turbidity began to appear approximately one month after the termination of the cutting operation. Millstone II personnel conducted extensive tests on the fuel pool water and determined the following:

- (1) the turbidity was not due to biological organisms;
- (2) filtration down to 0.22u did not remove the turbidity;
- (3) coagulation using a flocculating agent followed by 0.22u filtration lowered the turbidity.

Millstone II then contracted with Duratek Corporation for further analysis of the problem. The goals of the Duratek Corporation work were:

- (1) to, if possible, confirm the presence of UCON WS-34 fluid in the cask pit and fuel pool water;
 - (2) determine what was producing the turbidity;
 - (3) look at possible methods for removing the turbidity
- four liters each of cask pit water and fuel pool water were sent to Duratek Corporation at the Vitreous State Laboratory of the Catholic University of America. All testing was performed by Duratek personnel.

EXPERIMENTAL

TOC Analysis:

The two samples were analyzed for total organic carbon (TOC) using a Dohrmann DC-80 TOC analyzer. The results are given below. UCON WS-34 fluid is a polyalkylene glycol. Its major constituent is polyethylene glycol. The ethylene oxide repeating unit in the polymer has the formula C_2H_4O and a formula weight of 44.05 of which 24.02 is carbon. Thus maximum UCON WS-34 concentrations can be calculated by assuming all the TOC is WS-34 and multiplying the TOC values by $(44.05/24.02)$. These maximum values are also given below:

Sample	TOC (mg/l)	Maximum WS-34 (mg/l)
cask pit	82 ± 3	150 ± 6
fuel pool	8.9 ± 1	16.3 ± 0.2

As previously noted by Millstone personnel, the cask pit values are almost a factor 10 higher than the fuel pool values.

UCON WS-34 Determination:

A colorimetric method based on the precipitations of the fluid with iodobismuthate was used in an attempt to determine the level of the WS-34 present in the cask pit. This method results in the precipitation of all polyethylene glycol materials with greater than five ethylene oxide units. The test is sensitive down to WS-34 levels of 20 mg/l. As can be seen above, it is not sensitive enough to be used on the fuel pool water. When used with the cask pit water, a small amount of the typical bright orange precipitate was formed corresponding to a level of WS-34 of roughly 20-30 mg/l. Despite numerous efforts, the level could not be quantified since it was right at the detection limit. The test absolutely confirms the presence in the cask pit of polyethylene glycols which are the major constituent of the WS-34 fluid. However, the test also yields a maximum level of 30 mg/l which corresponds to a TOC level of only 16 mg/l. The WS-34 level can account for no more than 20% of the TOC in the cask pit.

Optical Properties:

The ultraviolet-visible (UV-Vis) spectrum of the cask pit solution was measured relative to water and compared to that of solutions that were 1 and 2% in UCON WS-34. The major feature of

the spectrum is a shallow absorbance at 340nm. It has a maximum absorbance of 0.040 in the one cm cell. The 1% (10,000 mg/l) solution of UCON WS-34 had an absorbance at 340nm of 0.017 and the 2% (20,000 mg/l) solution an absorbance of 0.032. Thus, for the absorbance at 340nm to be due to the WS-34 fluid, the concentrator would have to be approximately 2.5% (25,000 mg/l). This is more than 150 times that possible given the TOC level and about 1,000 times higher than that measured by the colorimetric method. Furthermore, the shape of the UCON-WS-34 spectrum does not match that of the cask pit water. The absorbance centered at 340nm is primarily responsible for the turbidity. Thus, we have a second indication that the WS-34 fluid itself is not responsible for the problem.

Irradiation Experiments:

A solution of 200 mg/l UCON WS-34 was irradiated for 23 hours with a Co-60 source at a dose rate of 7,000 R/hr. The resulting solutions was turbid with a shallow UV-Vis absorption figure centered at 340nm. In other words it resembled the cask pit water. The absorption at 340nm was 0.831, about 20 times that of the cask pit water. It thus appears that the combination of radiation and UCON WS-34 will produce the turbidity characteristics found in the Millstone II fuel pool.

Particle Size Determination:

A plot of log absorbance vs log wavelength for the irradiated WS-34 solution yielded a straight line with a slope of -2.4. According to light scattering theory this indicates that the average particle size, d , is slightly smaller than the wavelength region tested, 340-500nm (0.34-0.5u). For particles where $d >$ wavelength the slope would be -2; when $d \ll$ wavelength the slope would be -4. Accordingly this experiment predicts the particle size to be 0.05-0.15u).

The irradiated solution, spent fuel pool water and cask pit water were each filtered through a 0.1u cellulose acetate filter and the DF of the filter measured using both the TOC and UV-Vis method. The results are given below:

Sample	DF	
	TOC	UV-Vis
fuel pool	0.77	0.43
cask pit	1.11	2.38
irradiated UCON WS-34	1.81	2.98

The results indicate that fine filtering of 0.1u is more effective at removing turbidity elements than TOC. It also shows

that the turbidity elements are distributed around 0.1u and can be produced by the irradiation of WS-34 fluid. Work continues on varying the irradiation time and dose of the UCON WS-34 fluid in an attempt to match the spectrum to the cask pit sample.

Carbon Column Tests:

Cask pit solution was passed through a bed of Dura-C 100 carbon (50-200 mesh carbon especially designed to remove organics) (a) by itself; (b) doped with 15 mg/l of Nalco 8103 coagulant; and (3) doped with 50 mg/l of Nalco 8103. The Nalco 8103 coagulant had been used to coagulate turbidity due to spilled hydraulic fluid at the Fort Calhoun reactor. The decontamination factor of the column was measured by the TOC and UV-Vis methods. The results show clearly that the Nalco 8103 has a negative effect on DF measured either way. In other words the Nalco 8103 causes increased TOC and turbidity over just the plain carbon treatment. The Nalco 8103 also causes very early breakthrough of the carbon indicating that it is coating the carbon and rendering it ineffective. It is also clear from the test that carbon filtration would not be an especially effective way for removing turbidity.

CONCLUSIONS

The results given in the experimental section lead to the following conclusions:

(1) Polyethylene glycols are present in the cask pit water in concentrations of 20-30 mg/l. Polyethylene glycols are the major constituent of UCON WS-34 hydraulic fluid.

(2) The polyethylene glycol level in the cask pit represents only approximately 20% of the total organic carbon present in the cask pit.

(3) UCON WS-34 itself cannot be responsible for the turbidity since it displays neither the proper spectral features nor intensity of absorbance in the UV-Vis region.

(4) The turbidity is most likely caused by irradiation of the water solution of the WS-34 fluid. Such solutions display both the proper intensity and spectral features.

(5) The irradiation of WS-34 fluid produces particles in the 0.05-0.15 μ size range. The irradiation apparently causes the WS-34 fluid to agglomerate either by chemical reaction which causes increased polymerization or by intermolecular interactions perhaps due to charge attraction.

(6) Fuel pool clean up efforts must be directed at removing both the turbidity causing species and any remaining UCON WS-34 fluid as the latter will transform to the former in time.

Appendix B

MILLSTONE UNIT 2 PEDESTAL CRANE HYDRAULIC FLUIDS EVALUATION

During the preparations for the December 1987 refueling outage a pedestal crane inside the Unit 2 containment with a hydraulically actuated extension boom was discovered to have a corroded carbon steel hydraulic fluid reservoir tank. It was decided to change to a different fluid for future operations, and because of the relatively large capacity of 150 gallons of fluid, there was concern that the replacement fluid be compatible with the refueling pool water in case of leakage.

Candidate hydraulic fluids for the crane were evaluated by C-E for NU in 1988. Although the evaluation program was not a part of the Fuel Consolidation Demonstration Program, UCON WS-34 was included as a benchmark for the candidate fluids so that their results could be correlated to the actual in-plant experience with WS-34 during the fuel consolidation hot demonstration.

Evaluation included irradiation testing. Each fluid was irradiated in two separate tests to a total dose of 5.1 to 5.6 Mrads and before and after turbidity measurements were taken. In the first test the fluid was irradiated undiluted and was then diluted to 0.3 percent in water. In the second test the fluid was diluted to the same concentration and then irradiated. There was no appreciable effect on the turbidity of WS-34 in the first test, but in the second test, which resembled the conditions of the fuel consolidation hot demonstration, the turbidity of the 0.3 percent solution of WS-34 increased from 0.33 to 5.5 NTU, and would be expected to cause a visibility problem. This result appears to confirm the conclusion of the Duratek report in Appendix A that irradiation of WS-34 while in the spent fuel pool was the probable cause of the loss of pool clarity.

The C-E report to NU of the pedestal crane hydraulic fluid evaluation is provided for information in the remainder of this appendix.

Based upon the results of the final candidate hydraulic fluids, NU selected UCON CC-746 for use in the Millstone 2 Pedestal Crane. Subsequently, CE informed NU that the CC-746 hydraulic fluid was acceptable for use in the Millstone 2 Fuel Condolidation System.

A Report to

NUSCO

on

**The Analysis of Hydraulic Fluids For the
Millstone II Pedestal Crane**

**Combustion Engineering, Inc.
1000 Prospect Hill Rd.
Windsor, CT 06095**

1.0 Introduction

A pedestal crane supplied by Allied Systems of Portland, OR was installed inside containment at Millstone Nuclear Station, Unit II to relieve scheduling pressures on the polar crane during outages. The pedestal crane is similar to a "cherry picker" in design with a 2 section extension boom and an inventory of 150 gallons of hydraulic fluid. As a result of this large inventory of fluid there is concern that the fluid chosen be compatible with the pool chemistry and also meet the purity criteria established by the NUSCO Consumable Materials Control Program. During the initial cycle of operation, Plurasafe P1210, a thickened high water content fluid manufactured by BASF Wyandott was used in the crane. At the beginning of an outage in the latter part of 1987 it was found that the carbon steel hydraulic fluid reservoir tank had corroded. The fluid was changed and the system was able to operate for a short time before the friction brake seized.

This program was undertaken by C-E to evaluate hydraulic fluids for the crane. At the same time the crane manufacturer was planning modifications that would be compatible with the fluid chosen by NUSCO from this program.

2.0 Conclusion

No recommendation or selection of fluid is made in this report. The data collected on all of the fluids and the test procedures are presented for NUSCO's use in making a final decision on the fluid to be used. Other factors being considered by NUSCO are input from the crane manufacturer on fluid compatibility with the seals and other materials in the crane and pool chemistry compatibility tests being developed by NUSCO and Millstone II chemistry personnel. C-E is not privy to these data.

3.0 Results

All of the data are presented in the attached table. In addition, copies of all of the manufacturer's technical data and Material Safety Data Sheets were previously given to NUSCO shortly after they were received from the manufacturers.

The radiation exposures were carried out at Isomedix, Inc. in Whippany, NJ using a Co^{60} source. The radiation rate was at 5×10^5 rads/hour for a total dose of 5.1 to 5.6 Mrads.

3.1 Fluid Type

There are a number of different types of fluids represented in this study. The 95/5 fluids are additive packages which are designed to be diluted with 19:1 with water. Thus they are 95 % water and 5 % additive. The additives consist of corrosion inhibitors, anti-bacterial agents and lubricants. The

water/glycol fluids are ethylene glycol and water with corrosion inhibitors and anti-bacterial agents. The high water content fluids (HWCF) use a high molecular weight water soluble polymer as a thickening agent. The solids concentration of these fluids are generally in the 10% range so that the water content is approximately 90%. The polyethylene glycol is a pure organic liquid with no water or other diluents.

3.2 Possible Nutrient

The polyethylene glycol, HWCF and 95/5 fluids are composed of materials that are not considered nutrients. They also contain additives that prevent micro-organism attack on the fluids in the reservoirs. The ethylene glycol portion of the water/glycol fluids is a nutrient. Although these fluids contain additives that prevent micro-organism attack on the fluids in the reservoirs, these additives may not render the ethylene glycol non-nutrient when diluted as in a spill. Therefore the table lists the water/glycol fluids as possible nutrients.

3.3 Viscosity

The viscosity data is presented for the crane manufacturers' use in determining an appropriate fluid. The tests were run using a Brookfield Model RVT-D rotating spindle viscometer with the UL adaptor (for low viscosity fluids). The results from the Brookfield are reported as centipoise (cps). This is converted to SSU by means of the standard conversion factor and the density.

3.4 Acid or Base Number

The acid or base number of the fluids were determined by titration using ASTM D974-64. The changes after radiation are not considered significant.

3.5 Elemental Analysis

The analyses were run at National Spectrographic Laboratories in Cleveland, OH utilizing the same procedures as under the NUSCO Consumable Materials program. Most of the fluids have acceptable chemistry according to the standards set by NUSCO and C-E for consumables. The exceptions are the Microzol CA which has a high Zn additive to prevent plating out of the polymer on higher temperature surfaces. The Microzol CA (1080 ppm) and the Compenol (312 ppm) have high sulfur contents.

3.6 Turbidity

The measurements were made on an H F Instruments Model DRT-100 Turbidity Meter.

The first set of measurements were made on the hydraulic fluids diluted to 0.3% concentration. This concentration was determined to be the worst case if the entire inventory of hydraulic fluid in the crane (145 gallons) spilled into the minimum volume of the refueling pool (47,737 gallons). The first line of the table lists the turbidity when the fluid was diluted to 0.3% and measured without radiation exposure. The second line shows the turbidity when the fluid was irradiated as received and then diluted to 0.3% prior to measurement. The higher turbidity of the Cimdraulic MP unirradiated is due to the additives precipitating out of solution upon dilution. This has been noted by the manufacturer in the technical literature on this product.

The second set of measurement were made on hydraulic fluids mixed with a finely divided magnetite to simulate pool debris which could be held in suspension by the surfactant action of the hydraulic fluids. The same fluids as in the previous set were used with the magnetite added and shaken. After a resting period of 14 hours, a sample was taken and measured. Due to its high turbidity Microzol T30 was eliminated from further testing.

The final set of measurements were made on hydraulic fluids diluted to 0.3% concentration prior to irradiation both with and without magnetite.

Table 1
Properties of Hydraulic Fluids

Fluid	Cindraulic HP	Compenol	Moughto- Safe 620	Microzol CA	Microzol T30	UCON CC 746	UCON WS-34
Manufacturer	Cincinnati Millicron	R L Schaefer	E.F.Moughton	Lubrizol	Lubrizol	Union Carbide	Union Carbide
Fluid Type	95/5 with Additives	Water/Glycol	Water/Glycol	95/5 with Additives	Thickened MMCF (3)	Thickened Glycol/Water	Polyalkene glycol
Possible Nutrient?	No	Yes (1)	Yes (1)	No	No	Yes (1)	No
Density at 100 F (g/cc)							
As Received	0.99	1.05	1.06	0.99	1.00	1.06	1.01
Irradiated (2)	0.99	1.05	1.06	0.99	1.00	1.07	1.01
Viscosity at 100 F. (cps)	100 rpm	50 rpm	50 rpm	100 rpm	50 rpm	50 rpm	50 rpm
As Received	1.2	51.3	47.4	1.2	64.9	47.2	41.0
Irradiated (2)	1.2	50.3	49.8	1.2	35.8	53.9	37.6
% Change	-	-1.9	+5.1	-	-44.8	+14.2	-8.3
Viscosity at 100 F (SSU)							
As Received	29.9	226.3	207.0	29.9	299.9	206.1	188.4
Irradiated (2)	29.9	221.7	217.6	29.9	166.8	233.2	173.1
% Change	-	-1.9	+5.1	-	-44.8	+14.2	-8.3

(1) Glycol based fluids contain biocides which prevent biological attack on the fluid, however the biocide may not be effective in preventing attack on the glycol when highly diluted as would be the case in the event of a spill.

(2) Radiation exposure: 5.1 to 5.6 Mrad

(3) MMCF = High Water Content Fluid

Table 1 (Continued)
Properties of Hydraulic Fluids

Fluid	Cindraulic NP	Compenol	Houghto- Safe 620	Microzol CA	Microzol T30	UCON CC 746	UCON US-34
(A)cid or (B)ase Number							
As Received	(B)0.83	(B)2.47	(B)1.06	(B)0.56	(B)1.23	(B)1.32	(A)0.43
Irradiated (2)	(B)0.79	(B)2.18	(B)1.29	(B)0.64	(B)1.96	(B)1.26	(A)0.61
Elemental Analysis (ppm)							
Chlorine	<10	38	<10	<10	100	28	<10
Fluorine	<10	<10	<10	<10	16	<10	<10
Bromine	<10	<10	<10	<10	<10	<10	<10
Iodine	<10	<10	<10	<10	<10	<10	<10
Sulfur	38	312	<10	<10	1080	<10	<10
Nitrite	<10	<200	<10	<10	<10	<10	<10
Nitrate	16	<200	<13	<26	18	<10	<10
Mercury	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Lead	<10	<10	<10	<10	<10	<10	<10
Copper	<10	<10	<10	<10	<10	<10	<10
Zinc	<50	<50	<50	<50	1200	<50	<50
Tin	<10	<10	<10	<10	<10	<10	<10
Cadmium	<50	<50	<50	<50	<50	<50	<50
Carbonate(%)	<.050	0.064	<.050	<.050	-	<.050	<.050
TOC (mg/l)	9060	86300	83300	7300	46300	73500	224000

Appendix C

INSPECTION AND REPAIR OF
INTERIM TRANSFER CANISTER AND COMPACTOR

This appendix consists of the failure report (C-E Document Number TR-ESE-762) made to NU in June, 1988 on completion of the repairs to the ITC and compactor.

COMBUSTION ENGINEERING, INC.
ENGINEERING AND TECHNOLOGY DEPARTMENT

FAILURE REPORT
FOR
FUEL CONSOLIDATION
COMPACTOR
AND
INTERIM TRANSFER CANISTER

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1.0 SUMMARY

During the Fuel Consolidation Hot Demo in September, 1987, two specific problems arose which could not be corrected at that time and were covered by the equipment warranty. These were the inability to place a fuel rod in a particular location of the Interim Transfer Canister (I.T.C.) and the inability to open the gate of the Compactor.

On May 4, 1988, a team of Engineers and Technicians arrived at Millstone Unit II for the purpose of inspecting, evaluating and repairing the I.T.C., the Rod Verification Tool, which had to be modified in the field to accommodate the I.T.C., and the jammed Compactor gate mechanism. During the week of May 16, the I.T.C., and the Compactor were repaired and turned back over to NUSCO as fully operational.

The Rod Verification Tool could not be located or made available for refurbishment.

2.0 INTERIM TRANSFER CANISTER

2.1 BACKGROUND

The removal of the fuel rods from the second fuel bundle and their transfer to the Interim Transfer Canister (I.T.C.) commenced on September 9, 1987 as part of the Fuel Consolidation Hot Demo. The pulling of the fuel rods from the first fuel bundle and their transfer to the I.T.C. had been completed normally.

The fuel rod pulling of the second fuel bundle began normally, however when the fuel rods of the first pick were lowered into the Interim Transfer Canister (I.T.C.), they could not be fully inserted. Utilizing the T.V. Systems, it became apparent, by the fuel rod deflection, that the outside fuel rod was hitting solid on something inside the I.T.C.. Utilizing the hoist encoder, it was determined that the obstruction was 45.2" down from the top of the I.T.C.. The binding or blocking of this fuel rod transfer location did not seriously effect the Hot Demo as the I.T.C. had eight unused locations and with minor procedural modification, the program was allowed to continue.

2.2 DISCUSSION

Commencement of the inspection of the I.T.C. began on May 16, 1988 in the cask wash down pit. Due to the extremely high contamination levels on the equipment, 20 mR smearable with localized hot spots of 3-5 R and NUSCO's refusal to perform

any decontamination until the equipment was inspected, repaired and ready to be placed in its storage containers, the full respirator and plastics stay time was limited on both radiological and safety concerns to one-half hour.

The inspection consisted of a full visual exam both externally and internally.

The external examination showed nothing abnormal.

The internal examination consisted of two phases. The first phase being the unwrapping of the I.T.C. and visually inspecting the lower corrugated section. No wear, scratches or any abnormalities were observed.

The second phase of the internal examination consisted of positioning a light at the lower end of the I.T.C. and then looking through the top plate and visually inspecting the entire array of 18 x 20 locations. The inspection consisted of looking down the entire internal length of each location and inspecting for any debris and/or internal obstructions.

All the 360 paths passed inspection except one. That location was in fact the same location that created the problem during the Hot Demo. An edge of one of the spacer grids, approximately 45 1/4" down from the face of the top plate, was protruding into the path approximately 0.050". Knowing the rough elevation of the jam from the Hot Demo, it had already been determined that, if the obstruction was not foreign material, the only other solution could be that an edge of the spacer grid at that elevation had to be the problem. With that in mind, a special tool was brought to Millstone to correct the protrusion.

The tool is basically a stainless steel rod with an adjustable collar to allow positioning at various levels, a "T" handle to allow handling and rotation and button head screw in the lower section. The screw is positioned and sized such that the tool can be lowered into the I.T.C. with the screw in the corner of the fuel rod path and then rotated at the proper elevation. When rotated, the screw acts as a cam and comes into contact with any protrusion.

With much appreciated assistance from NNECO Construction Services and Myrock, the I.T.C. was rigged, raised and positioned at the side of the cask wash down pit. The tool was then lowered into the I.T.C. until the proper elevation was reached. Various attempts were made to feel the protrusion with the tip of the tool but were unsuccessful. The tool was then rotated into the protrusion a few times until the obstruction could no longer be felt. See Photo #1.

2.3 CONCLUSIONS:

The obstruction in the guide path of one of the locations in the I.T.C. was caused by the fuel rod catching one of the edges of a spacer grid. The obstruction was significant enough to catch a fuel rod but not significant enough to catch the tool. If a fuel rod could be rotated, as with the Single Rod Pulling Tool, then that location could have been utilized. The rod bow must have been just right to bend the rod into the wrong direction. When the I.T.C. is utilized for future Consolidation Programs, it would be fruitful to modify the installation procedure to require an inspection of each guide path just to verify that the I.T.C. did not experience any abnormal bending which might affect the internals or any foreign material became trapped in the paths.

3.0 COMPACTOR

3.1 BACKGROUND

During the Fuel Consolidation Hot Demo in September, 1987, the Compactor's gate mechanism experienced a malfunction and would not fully open to release the compacted material into the Waste Storage Canister. The Television system was positioned to monitor the various attempts to open the gate. Observations and conclusions at the time of the Hot Demo indicated that the gate was stuck partially open due to Zircaloy chips being forced into the wash holes and becoming wedged into the gate opening as the gate was opened.

3.2 DISCUSSION

On May 4, 1988 a team of engineers and technicians arrived at Millstone II for the purpose of inspecting, evaluating and repairing the Fuel Consolidation Compactor. On the afternoon of May 6, the Compactor was moved from the Cask Pit to the Cask Wash-down Pit. During the transfer, it was observed that significant damage had occurred to the Compactor gate mechanism in the lead screw drive area. These general observations indicated the damage was much more severe than originally expected. Since it was the end of the scheduled eight-hour working shift, access to the equipment for a more detailed inspection was not feasible until Monday. Based upon the amount of damage that was visible, vendors were immediately contacted and requested to work the weekend to provide the following equipment as documented on Drawing No. E-FUEL-501-078, Rev.03:

- 1) Item # 50, Lamina Motor # A37
- 2) Item # 7, Chain 3/8 pitch S>S>
- 3) Item # 29, E-FUEL-501-082, Item #10
 - a) Item # 10, Gate Drive Assembly (modified)
 - b) Item # 11, Gate Drive Plate (modified)

On Monday, May 9, the crew arrived back on site to inspect the Compactor. The H.P. survey indicated that the Compactor was severely contaminated, 20 mR smearable with several dose readings in excess of 3 R. With NUSCO's refusal to perform any decontamination until the equipment had been inspected and repaired and ready to be placed in its storage container, the full respirator and plastics stay time was limited on both radiological and safety concerns to one-half hour.

In the planning stage of the inspection and repair program, it became evident that the complete list of requested tools was not provided and therefore, the anticipated shortage was supplemented with tools which were brought down from Windsor.

The hands-on inspection of the Compactor showed that the holes in the gate did in fact become plugged with Zircaloy chips and debris from the Fuel Bundle Skeletons.

Photo #2 was taken looking up at the gate mechanism through the discharge opening. One of the plugged holes can be seen loaded with chips.

Once the plugged holes were drawn into the base plate of the Compactor, the chips became wedged and jammed and prevented the gate from being withdrawn any further. The various attempts to free up the gate during the Hot Demo proved unsuccessful due to this jamming. Since the lead screw mechanism was still free to turn in the nut drive after the gate became jammed, all the rotational torque being applied to the lead screw was translated into an axial load applied to the gate nut drive plate and resulted in bending the 3/8" plate in a concave shape with approximately a 1/4" deformation (photo #3). Simultaneously, the load was transferred into the gate drive assembly bracket and bent the bracket out approximately 15 degrees (photo #4). As this was occurring, the 1/4" dowel connecting the lead screw to the drive sprocket, Dwg. E-FUEL-501-078, Rev. 03, item #6, was sheared. The bending of the gate Drive Assembly Bracket deflected the lead screw downward. This downward force coupled with the rotational force fractured the lead screw at the drive nut to lead screw interface. This fracture was not previously observed or anticipated. (photo #5)

The manufacturer of the original lead screw was contacted and requested to procure the material, manufacture and heat treat a replacement lead screw as expeditiously as possible. After C-E and H-P personnel removed all the visible Zircaloy chips and debris in an attempt to reduce the dose to a working level, the previously manufactured gate and brackets and plates were installed.

On May 16, the crew returned to Millstone to install the new lead screw and complete the repair on the Fuel Consolidation Equipment.

NUSCO personnel requested that C-E proceed one step further in the inspection program than originally scheduled. That is, remove the vertical cylinder and the top plate assembly and inspect the internal wear plates. The cylinder and top plate were removed and no wear or damage was observed. The top plate was reinstalled and torqued by Myrock (photo #6).

3.3 Conclusion

The Compactor gate jam was a result of Zircaloy chips in the gate wash holes. The resulting damage was a result of the gate being jammed and the resulting force from the hydraulic drive being transmitted thru the lead screw into the drive support hardware. In addition the replacing all the damaged hardware, the Lamina Hydraulic motor and the S.S drive chain have also been replaced to ensure that the system has been returned to optimal condition.

The Compactor has been fully repaired and can be relocated back into the Cask Pit to complete the Compaction of the remaining 5 1/2 skeletons to complete the demonstration.

Photo #1. Correcting Protrusion in ITC Using Special Tool

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Photo #2. View of gate mechanism from below, looking up through discharge opening.

Photo #3. Deformation of Gate Nut Drive Plate

Photo #4. Bending of Gate Drive Assembly Bracket

Photo #5. Fractured Lead Screw

Photo #6. Reinstalling and Torquing Top Plate
(View from above)