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March 19, 2002 (9:59AM)

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RULEMAKINGS AND
ADJUDICATIONS STAFF

March 15, 2002

Charles Bechhoefer, Chairman
Administrative Judge
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Dr. Richard F. Cole
Administrative Judge
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Dr. Charles N. Kelber
Administrative Judge
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Re: **Dominion Nuclear Connecticut, Inc.**
Millstone Nuclear Power Station, Unit 3
Docket No. 50-423-LA-3

Administrative Judges:

On Monday, March 18, 2002 — in accordance with the schedule established by the Atomic Safety and Licensing Board in this Subpart K proceeding — Dominion Nuclear Connecticut ("DNC") will be filing its "Summary of Facts, Data and Arguments on Which Dominion Nuclear Connecticut Will Rely at the Reopened Proceeding Subpart K Oral Argument." This filing will include a written summary and sworn testimony in the form of affidavits. As required by the Licensing Board's February 4, 2002 Notice of Filing Schedules and Oral Argument, DNC intends to make the filing by e-mail, with conforming paper copies by first class mail.

In addition to the written summary and the affidavits that will be filed on the 18th, DNC's filing will incorporate five exhibits. Three of the five exhibits are over-sized and are not easily convertible to electronic form. Therefore, to assure in-hand delivery of all exhibits by the March 18 service date specified by the Licensing Board, DNC is filing today, herewith, all five of the exhibits and is serving parties by Federal Express for delivery on Monday, March 18th.

Template= SECY-028

SECY-02

(In addition, DNC is serving this letter and two exhibits today by e-mail.) The five exhibits to DNC's filing are:

Exhibit 1 — Millstone Unit 1 Spent Fuel Pool Map

Exhibit 2 — Millstone Unit 3 Reactor Core Map

Exhibit 3 — Millstone Unit 3 Spent Fuel Pool Map

Exhibit 4 — *Millstone Unit 1 Fuel Rod Accountability Project,* Number M10063, Final Report, approved October 1, 2001

Exhibit 5 — *Root Cause Investigation, Loss of Accountability of Two Fuel Rods at Millstone Unit 1* (CR# M1-00-0548), approved October 25, 2001

(Exhibits 1 to 3 are the exhibits in paper form only.) A copy of the service list is attached.

Please contact me if there are any questions.

Sincerely,

David A. Repka

David A. Repka
Counsel for Dominion Nuclear Connecticut, Inc.

Enclosure: Certificate of Service

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of:	)	
	)	Docket No. 50-423-LA-3
Dominion Nuclear Connecticut, Inc.	)	
	)	ASLBP No. 00-771-01-LA-R
(Millstone Nuclear Power Station,	)	
Unit No. 3)	)	

CERTIFICATE OF SERVICE

I hereby certify that copies of Dominion Nuclear Connecticut, Inc.'s EXHIBITS 1 through 5 for its forthcoming filing in the captioned proceeding have been served on the following by placement with Federal Express, this 15th day of March 2002, for delivery on March 18, 2002, except for parties indicated by an asterisk (*), which are being served today by deposit in the United States Mail, first class.

Charles Bechhoefer, Chairman
Administrative Judge
Atomic Safety and Licensing Board
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
(e-mail: cxb2@nrc.gov)

Dr. Richard F. Cole
Administrative Judge
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Office of the Secretary*
U.S. Nuclear Regulatory Commission
Washington, DC 20555
Attn: Rulemakings and Adjudications Staff
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Office of Commission Appellate Adjudication*
U.S. Nuclear Regulatory Commission
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David A. Repka
Counsel for DNC, Inc.

THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED AT THE RECORD TITLED:

EXHIBIT 1

"MILLSTONE UNIT 1 CURRENT (planning simulation) SPENT FUEL POOL, CYCLE 15 UNIT 1 08/02/01"

WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER

EXHIBIT 1

NOTE: Because of this page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.

DATE:
02/27/01
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Millstone Unit 3
Current (planning simulation) Unit 3 Core, Cycle ~~7~~ 8
Cycle 8 - Verified 2/26/01

N ←

EXHIBIT 2

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1					H23 68DS	H58 81DS	H47 R542	H06 132DS	H34 48DS	H67 104DS	H07 114DS				
2			H31 127DS	J71 R564	K38 109DS	K51 R541	K56 89DS	K73 R573	K58 56DS	K67 R540	K40 71DS	J61 R568	G26 22DS		
3		G22 13DS	K41 16DS	K68 131DS	K03 R558	J18 70DS	J48 R552	J26 OSS4D	J47 R102	J15 91DS	K11 R563	K50 7DS	K46 90DS	H33 86DS	
4		J81 R534	K71 103DS	J11 R514	J10 82DS	K14 99DS	J49 23DS	K24 R510	J57 136DS	K25 47DS	J12 5DS	J02 R515	K62 115DS	J73 R511	
5	H03 95DS	K47 118DS	K02 R570	J04 117DS	K33 R547	J37 39DS	J23 59DS	J60 27DS	J25 94DS	J56 85DS	K06 R571	J09 77DS	K19 R546	K37 44DS	G23 67DS
6	H57 112DS	K62 R532	J21 55DS	K20 18DS	J55 98DS	K16 R543	J77 110DS	K17 R531	J59 123DS	K10 R560	J54 128DS	K13 29DS	J13 121DS	K63 R549	H30 120DS
7	H60 45DS	K59 130DS	J50 R556	J42 54DS	J32 66DS	J72 92DS	K01 96DS	J76 46DS	K23 43DS	J68 79DS	J22 84DS	J40 19DS	J46 R561	K60 58DS	H70 R537
8	H01 72DS	K74 R574	J29 OSS6D	K09 R512	J69 6DS	K08 R524	J62 34DS	J20 R520	J80 129DS	K30 R569	J64 125DS	K28 R555	J31 OSS5D	K75 R576	G12 25DS
9	H50 R565	K55 64DS	J36 R545	J45 101DS	J33 60DS	J66 31DS	K22 52DS	J74 41DS	K36 33DS	J58 1DS	J24 69DS	J44 102DS	J52 R527	K57 14DS	H61 17DS
10	H35 28DS	K49 R554	J19 83DS	K21 38DS	J53 50DS	K18 R548	J79 107DS	K27 R530	J78 4DS	K07 R509	J35 21DS	K32 53DS	J17 108DS	K66 R550	H40 126DS
11	H28 93DS	K48 113DS	K05 R525	J05 30DS	K12 R557	J38 49DS	J27 135DS	J70 63DS	J28 119DS	J39 51DS	K26 R553	J06 106DS	K15 R562	K39 100DS	H02 133DS
12		J65 R528	K54 9DS	J07 R516	J01 3DS	K29 75DS	J43 65DS	K31 R533	J41 88DS	K35 73DS	J08 32DS	J03 R517	K53 122DS	J67 R506	
13		G27 35DS	K44 87DS	K70 10DS	K04 R567	J16 116DS	J51 R526	J30 OSS3D	J34 R536	J14 80DS	K34 R566	K69 62DS	K45 78DS	H29 74DS	
14			H51 124DS	J63 R551	K42 12DS	K65 R569	K72 61DS	K76 R544	K64 76DS	K61 R572	K43 8DS	J75 R535	H32 11DS		
15					G13 37DS	H69 26DS	H74 105DS	H04 2DS	H48 R539	H64 15DS	H18 134DS				

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Reviewed by: [illegible] Date: 3/2/01

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D-2

Northeast
Utilities System

107 Seldon Street, Berlin, CT 06037

Northeast Utilities Service Company
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Hartford, CT 06141-0270
(860) 442-7747
Fax (860) 444-5466

Frank C. Rothen
Vice President - Nuclear Services

EXHIBIT 4

October 1, 2001

VIA HAND DELIVERY

William R. Matthews
Vice President and Senior Nuclear Executive
Millstone Power Station
Rope Ferry Road
Waterford, CT 06385

Re: Final Report of the Millstone Unit 1 Fuel Rod Accountability Project

Dear Bill:

On behalf of Northeast Utilities, I have enclosed the Final Report of the Millstone Unit 1 Fuel Rod Accountability Project.

Please extend my appreciation to the employees of Dominion Nuclear Connecticut, Inc. for their cooperation and support throughout the Project and my best wishes for their continued success.

Sincerely,

Frank C. Rothen

Millstone Unit 1

Fuel Rod Accountability Project

Project Number M10063

FINAL REPORT

Prepared: *Robert V. Fairbank* Date: *10/1/01*
Robert V. Fairbank
Project Manager

Approved: [signature] Date: 10/1/01
Frank C. Rothen
Executive Sponsor

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

BACKGROUND

On September 1, 1972, Millstone Unit 1 condenser tubes failed and seawater entered the reactor coolant system. Station management requested that General Electric ("GE") help determine the effect of chlorides in the seawater on nuclear fuel components. In October 1972, GE personnel disassembled fuel assembly MS-557 in the Unit 1 spent fuel pool ("SFP" or "pool"), stored all of the 49 fuel rods in seven specially designed eight-rod containers, and shipped the non-fuel irradiated hardware to GE's Vallecitos Nuclear Center in Pleasanton, CA ("VNC" or "Vallecitos"). GE personnel recorded the placement of the rods into the eight-rod storage containers and also noted that one of the fuel rods (a tie rod) had been damaged in handling. Millstone personnel did not record the location of the eight-rod containers within the pool.

In April 1974, GE returned to re-assemble MS-557. They did not, however, return the damaged tie rod or the center spacer capture rod to the reconstituted assembly. GE personnel used a dummy center spacer rod to support the assembly and left a vacancy where the damaged tie rod would have gone. GE records of this work do not reflect what became of the two rods that had been stored separately in an eight-pin storage container in the spent fuel pool since 1972. Likewise, the Unit 1 Reactor Engineer prepared a record of the reconstitution of assembly MS-557, but made no mention of the center spacer capture rod or the tie rod.

In May 1979, the Unit 1 Reactor Engineer asked on-site GE personnel to read the serial numbers inscribed on the end plug of two rods in an eight-rod container to determine their origin. Using the partially legible serial numbers, the Reactor Engineer and GE personnel concluded that the rods were the two rods removed from the MS-557 seven years earlier.

The Reactor Engineer documented this work and created a data card in the Kardex file to document the location of these two rods in the eight-rod storage container. Later maps of the spent fuel pool drawn in February and April 1980, show the two fuel rods from MS-557 in the northwest corner of the pool. A third map, drawn in September 1980, and initialed by the same Reactor Engineer, omits the two MS-557 fuel rods. The team has not found any record prepared after April 1980, that refers to these two rods in any way.

In late-1980, the Reactor Engineer left Millstone and another engineer assumed the Reactor Engineer's responsibilities. Neither the new Reactor Engineer, nor any other individual interviewed by the team (except for the first Reactor Engineer and the Special Nuclear Material ("SNM") accountant at that time), indicated that they had any knowledge of the presence of two separate fuel rods in the spent fuel pool after 1980.

DISCOVERY

During document reviews conducted in connection with the decommissioning of Millstone Unit 1 in 2000, engineers found records from 1979 and 1980, indicating that during those years two fuel rods from MS-557 were being stored separately, i.e., not with their parent fuel assembly. Because these two rods did not appear to be accounted for in current records, the engineers looked for additional information about the disposition of those fuel rods. The most recent records that they found which reflected the location of the fuel rods in the Millstone Unit 1 spent fuel pool were created in 1979 and early 1980.

INVESTIGATION

When the engineers reported to management that their records review and preliminary investigation did not resolve the issue, Northeast Nuclear Energy Company ("NNECO") promptly initiated an internal Condition Report, reported the matter to the Nuclear Regulatory Commission ("NRC"), and initiated an investigation under the direction of Unit 1 management. In December 2000, NNECO retained the support of five industry experts, including engineering and nuclear fuels experts, as well as former senior executives from the NRC. NNECO expanded the search effort in January 2001 by forming a dedicated project team, the Fuel Rod Accountability Project ("FRAP" or "Project"), including over 20 individuals with diverse backgrounds and expertise to conduct the investigation. From January through September 2001, the team conducted an investigation to determine the location of the two fuel rods.

CONCLUSIONS

The Project team reviewed thousands of documents, interviewed almost two hundred knowledgeable individuals, and performed many hours of videotaped underwater inspections of the Unit 1 spent fuel pool. Despite these efforts, the investigation did not yield clear and convincing evidence of the precise location of the two fuel rods. Nevertheless, the investigation has established that the fuel rods are safely located in a facility that is licensed to store or dispose of radioactive material. Specifically, the investigation has determined that the rods are: (a) in an undetermined location in the Unit 1 spent fuel pool; (b) at GE's Vallecitos nuclear fuel facility; or (c) at one or both of the low-level radioactive waste ("LLRW") disposal facilities in Barnwell, South Carolina ("Barnwell") or the Hanford reservation in Richland, Washington ("Hanford"). Even if inadvertently shipped to a LLRW facility, the presence of the rods does not pose a danger to the health and safety of workers, the public, or the environment.

Although the evidence developed in the investigation was not sufficiently clear and convincing to conclude that the fuel rods are in one specific location, the evidence was substantial enough to permit some qualitative assessment of opportunities for inadvertent shipments. In this regard, the likelihood that the rods remain in the Unit 1 spent fuel pool is low. A detailed inspection of the accessible areas of spent fuel pool did not locate the rods. But the best reasonable efforts of the inspection team were not able to examine all areas of the pool or all areas where smaller sections of the rods might have been placed if they were segmented. Moreover, for safety reasons, the team did not disassemble each of the 2884 fuel assemblies in the pool to conduct a rod-by-rod inspection.

Similarly, the likelihood that the fuel rods are at GE's Vallecitos nuclear facility is low. The official records and inspection procedures implemented for SNM at that facility provide confidence that, if shipped, the records would reflect the presence of the rods. Nevertheless, there remain several important – and unanswered – questions about a 1980 shipment to that facility that prevent the investigation from removing this location as a possible location of the rods.

One of the three shielded shipments from Unit 1 to the Hanford LLRW facility in 1985 provided some small opportunity to inadvertently ship the fuel rods. But there is no direct evidence and little circumstantial evidence available to support a conclusion that the rods were actually shipped.

Of the four possible locations, the LLRW facility at Barnwell, SC had the most significant opportunity to receive the rods. In particular, three shipments in 1988 contained the segments of about 90 Local Power Range Monitors ("LPRMs") that had been cut into pieces many years earlier and stored in containers in the spent fuel pool. These items, which are very similar in appearance to the fuel rods, were most likely cut in late 1979, shortly before the fuel rods disappeared from later spent fuel pool maps. Because the workers cutting the LPRMs lacked experience with reactor components, the workers may have mistakenly cut the fuel rods believing them to be LPRMs, and placed them in a container with the LPRMs. Many, if not all, of the LPRMs in that container were shipped to Barnwell in 1988.

Having concluded that the LLRW facility at Barnwell had a significant opportunity to receive the fuel rods does not mean that there is clear and convincing evidence that the rods are there. The evidence simply does not support that conclusion. In fact, there is no evidence, either in the form of documents or from interviews, that actually places the fuel rods in any of the off-site shipments to Barnwell or any other facility. The identification of the 1988 shipments to Barnwell as a potential explanation for the disposition of the fuel rods must be read in that context and not regarded as an established fact.

THE UNIT 1 SPENT FUEL POOL

The team performed focused, as well as comprehensive, inspections of the spent fuel pool. Fuel specialists used video cameras and radiation monitors to inspect thousands of fuel assemblies and other items in the pool. Inspectors used these devices remotely from the refuel deck floor or a refuel bridge that travels over the length of the pool. A crawler-mounted camera inspected the entire pool floor.

The results of the inspections revealed that there is a low likelihood that the fuel rods remain in the spent fuel pool. Indeed, the comprehensiveness and quality of the inspections strongly suggests that the fuel rods are not in the pool. The inspections addressed both the most likely places that the rods would be stored, as well as the places that full-length rods (or large segments of fuel rods) could be stored. But the best reasonable efforts of the inspection team were <u>not</u> able to examine all areas of the pool or all areas where segments of rods might have been placed. Indeed, if the fuel rods were cut – and there is evidence that they could have been – there remain many areas in the pool where smaller segments could be housed that could not have been seen during the inspections. Additionally, safety considerations, pragmatism, and prudence precluded a rod-by-rod inspection of the more than 167,000 fuel rods in the pool. Only after all of the spent fuel assemblies and other material have been inventoried and removed from the spent fuel pool can the question of the two rods' presence in the pool be finally determined.

THE GE FACILITY AT VALLECITOS

So too, the fuel rods are very likely not at the GE Vallecitos facility. Nevertheless, one shipment of spent fuel rods from Unit 1 in April 1980 contains discrepancies in the GE shipping and receipt documents, as well as in certain NRC documents. Additionally, after this shipment occurred, there are no known records that refer to the fuel rods.

To be sure, the shipping and receipt records for that April 1980 shipment, as well as the established GE procedures and practices, provide strong evidence that the rods are not at GE Vallecitos. Indeed, the contents of the shipping container were examined at Vallecitos and there is no indication that the examination revealed the presence of the two fuel rods from MS-557. Moreover, the official record of this SNM shipment, the DOE/NRC Form 741, does not indicate that the rods were shipped. The GE receipt records for certain non-fuel items in that shipment, however, are inconsistent with the shipping records. The inconsistency does not establish that the rods were shipped, but multiple discrepancies in the shipping records preclude unconditional reliance on the documents. More important, an unexplained difference exists between the weight of the SNM shipped (2.4 kg), and the entries on two NRC records that indicate that GE received 8.8 kg of spent fuel. The difference between these amounts is slightly less than the weight of the SNM in the two fuel rods.

These facts are sufficient to maintain the Vallecitos facility as a possible location of the rods. The loading of the segmented test rods in this shipment on May 5, 1979, and the unexplained movement of MS-557, the parent assembly of the two fuel rods, on that same day, creates another potential link between this shipment and the two fuel rods. The disappearance of the two fuel rods from all known documents immediately after the April 1980 shipment, and the disappearance of the two rods from the memories of those who should have seen or remembered the rods, adds to the uncertainty about this shipment. Again, the compilation of these matters does not establish that the rods are at Vallecitos. The possibility that they are, however, cannot be dismissed.

THE LLRW FACILITY AT HANFORD

There is no credible evidence, and certainly no clear and convincing evidence, proving that the fuel rods were shipped to the U.S. Ecology LLRW facility at Hanford. An opportunity for the inadvertent shipment of the rods, however, existed to some small degree in three shipments in 1985. The likelihood of an inadvertent loading of the rods in the first two shipments, however, is not significant. The loading of the first shipment by experienced GE personnel and the relative certainty regarding the identity of items bearing any resemblance to fuel rods in the second shipment, reduce considerably the opportunities for either of these shipments to have contained the fuel rods. And for the third shipment, only the inclusion of the hot sections of eight local power range monitors ("LPRMs") of uncertain origin causes this shipment to stand apart somewhat from the other two shipments to Hanford. Mistaking a fuel rod for an LPRM hot section is possible because of the similarities in appearance between an LPRM and a fuel rod. The identity of the items described as segments of LPRM hot sections in the third shipment cannot be established with certainty because the source of these items cannot be determined. A possibility exists that workers who were unfamiliar with reactor hardware may have cut the fuel rods by mistake in late-1979, when cutting a large build-up of LPRMs stored on the walls of the spent fuel pool. If the workers made such a mistake and stored the cut rods with cut LPRMs, and if the LPRM sections chosen for this shipment included cut rods, there is a chance that the rods, or a piece of the rods, could have been inadvertently included in this shipment. Given the relatively small quantity of LPRM sections in this shipment, however, the opportunity is not substantial.

THE LLRW FACILITY AT BARNWELL

There is no clear and convincing evidence that the fuel rods were shipped to the Chem-Nuclear facility at Barnwell, but the evidence available indicates that the opportunities for the inadvertent shipment of the rods to Barnwell are higher at this facility than any of the other three possible locations. Of the 16 shielded shipments to Barnwell that were investigated by the Project, two TN-8L cask shipments and the one CNSI 3-55 cask shipment to Barnwell in May 1988, stand out as having the most significant opportunity to contain the fuel rods.

In these three shipments, records indicate that WasteChem workers loaded the segments of somewhere between 90 and 98 items, described as LPRM hot sections. Other records establish, however, that there were less than 90 LPRMs in the spent fuel pool available for shipment. Thus, the shipments included a substantial quantity of LPRM-like material presumed to be LPRMs, but which were probably not LPRMs, given the total number of LPRMs that had been removed from the core and stored in the spent fuel pool. That disparity suggests the possibility that the fuel rods – or other LPRM-like items – were inadvertently included among the LPRM hot sections.

The evidence is clear that, regardless of the precise number of LPRMs included in those shipments, the vast majority of these LPRMs were from the 1979 LPRM cutting campaign discussed previously. The records also show clearly that neither NNECO nor WasteChem knew precisely the identity or characteristics of the items they considered to be LPRMs, which they had retrieved from old containers that had been stored in the pool. If the contractors from 1979 mistakenly cut the fuel rods, believing them to be LPRMs, and placed them in containers with LPRMs, it is likely that those cut rods were included in one or more of the May 1988 shipments. As discussed earlier, however, this evidence is not sufficiently clear and convincing to support a conclusion that the fuel rods were included in these, or any other shipments.

Theft or Diversion

The investigation found no evidence or data of any sort suggesting that the rods had been stolen or diverted. Not a single interview or document provided any indication of theft or diversion. Nevertheless, the team conducted an investigation to search for any indication of the failure of the multiple physical, technical, and administrative barriers, which protect the fuel from this possibility. The investigation found no such failure.

The barriers to theft and diversion are many and interlocking. First, the nature of the rods themselves makes theft inherently risky. They cannot be handled without the person taking special precautions to guard against receiving a high and potentially lethal dose of radiation. This means that if a person tried to remove the rods from the spent fuel pool without placing the rods in a properly shielded cask, the person would receive a very substantial, and potentially lethal, dose of radiation.

Second, if someone were to try to steal the rods without the necessary shielding, multiple radiation alarms on the refuel floor and various other radiation alarms throughout the reactor building would sound, signaling the presence of radiation and triggering various systems' responses, as well as a response from Control Room, Site Security, and Health Physics personnel.

Third, if a thief were to try to use a cask of some sort to hold the spent fuel rods, the task of bringing the cask into the reactor building and loading the cask on the refuel floor would be cumbersome and obvious. Among other things, this activity would require the use of heavy equipment and a crane, the acquiescence of supervision, and the breach of multiple security barriers and Health Physics checkpoints. Additionally, various security barriers and work procedures exist that restrict access only to persons authorized to be in the locations and trained to perform specific work in those locations.

Fourth, any unauthorized work around the spent fuel pool would be subject to discovery by workers, Health Physics technicians, supervisors, operators, and contractors in the area, all of whom are trained to report suspicious activity, particularly unusual activity associated with nuclear fuel. Health Physics personnel, in particular, carefully monitored the placement in, and removal of any item from, the spent fuel pool.

Fifth, security barriers, security alarms, Health Physics checkpoints, and other measures exist to ensure that unauthorized material does not leave the refuel floor, the reactor building, or the site.

Wholly apart from the various radiation, security, and personal barriers that exist to prevent theft, there would be little or no reason for someone to incur the expense, the extraordinary risk, and potential consequences associated with stealing two spent nuclear fuel rods. The fissile material contained in those rods is far less than that needed to achieve criticality or to create a nuclear device or weapon.

Additionally, the two spent fuel rods have no economic value. In fact, the radioisotopes found in the fuel rods are largely available in numerous commercial applications around the world and exist in businesses and locations far less secure than a nuclear power plant.

Finally, persons in the plant would have no motive to divert or improperly dispose of the rods in some unauthorized manner or in some unauthorized location, even if they could overcome the barriers. The presence of two fuel rods in a spent fuel pool has essentially no impact on the unit, its operations, or the costs of conducting business, either in the short or long-term. Moreover, the barriers and difficulties associated with an unauthorized disposal do not differ in substance from the barriers that prevent theft.

In short, a person attempting the theft or diversion of these rods would be risking almost certain detection and life-threatening health effects for items of virtually no value. Moreover, there is simply no evidence that the two fuel rods were stolen.

HEALTH AND SAFETY CONSIDERATIONS

Because the only possible locations for the fuel are facilities designed and licensed to store or dispose of nuclear material, the two fuel rods pose no identifiable risk to public health or safety. Although the Hanford and Barnwell low-level waste facilities are not authorized to accept spent nuclear fuel, they are licensed to receive and dispose of all of the radionuclides contained within that fuel. In fact, both facilities have significantly higher quantities of these radionuclides in their current inventories.

Wastes shipped to LLRW facilities are stored in liners transported by specially designed and licensed shipping casks. These low-level waste shipments are surveyed at the shipper's location before departure to ensure that radiation levels meet federal Department of Transportation and NRC standards designed to ensure the protection of public health and safety during shipment. The radiation levels of the fuel rods, if shipped, would fall well below those safety thresholds. Indeed, if shipped, the radiation levels of the fuel rods would have been lower than the radiation level of some of the other irradiated material authorized to be included in the shipment.

Upon arrival at the low-level waste disposal facilities, the liners were removed from the shipping cask and quickly deposited in burial trenches and covered with earth to shield workers and the public from radiation.

The presence of the two fuel rods does not introduce any different radioactive element than already exists in significantly greater quantities at either facility. The analysis supporting the scientific evaluation of each facility assumes that the sites will dispose of these same radionuclides in higher quantities than both rods contain. Accordingly, the two rods do not present a challenge to the effectiveness of these facilities' ability to protect public health and safety, worker safety, or the environment.

2.0 INTRODUCTION

During reconciliation and verification of the Millstone Unit 1 spent nuclear fuel records in connection with decommissioning activities at Millstone Unit 1 in 2000, engineers uncovered records calling into question the precise location of two irradiated fuel rods. These fuel rods, filled with ceramic pellets containing uranium, measure approximately 13 feet in length, one-half inch in diameter, and are clad in a zirconium alloy tube. A picture of a fuel rod appears in Section 1 of the Appendix. The records indicated that the two irradiated fuel rods had been separated from a fuel assembly that had been disassembled for inspection by GE in 1972. A 1979 memorandum indicated that in May 1979, personnel from Northeast Nuclear Energy Company ("NNECO"), the operator of Millstone Unit 1, and GE physically verified the identity of the displaced rods. The records also indicated that the rods would be stored in the northwest corner of the Unit 1 spent fuel pool until they could be moved to another fuel assembly.

By mid-November 2000, the engineers at Unit 1 who discovered the 1979 records determined that they could not identify the location of the two fuel rods. Accordingly, on November 16, 2000, they prepared a Condition Report (CR M1-00-0548), thereby entering the issue into the site's Corrective Action Program. NNECO made timely notifications to the Nuclear Regulatory Commission ("NRC") and other stakeholders. Also, in accordance with NRC reporting requirements, on December 14, 2000, NNECO submitted a formal telephonic report to the NRC describing the information then available about the fuel rod accountability issue. NNECO submitted a Licensee Event Report, LER 2000-002, and a Supplement to that report on January 11, 2001, and March 30, 2001, respectively.

2.1 Background

On September 1, 1972, Millstone Unit 1, a nominal 652 MW (electric) GE boiling water reactor ("BWR"), experienced condenser tube failures that resulted in an introduction of seawater into the condensate system.[1] Chlorides in the seawater caused a breakdown of the condensate demineralizers and a subsequent chloride intrusion into the reactor coolant system. Part of GE's effort to determine the effects of the chloride intrusion on nuclear fuel components included the October 1972 disassembly and inspection of fuel assembly MS-557.[2] Following disassembly, GE placed all forty-nine fuel rods from MS-557 in GE eight-rod containers and stored them in the Unit 1 SFP.[3] During handling in 1972, a tie rod (serial number BP0406) received damage to its upper end plug.[4] Neither it, nor the original center spacer rod (serial number BK0136) were re-used when, in May 1974, GE re-assembled MS-557.[5] GE records indicate that, after disassembly in 1972, workers stored both the damaged tie rod and the center spacer rod in the spent fuel pool in one eight-rod container with no other fuel rods.[6] A cross-sectional view of a GE BWR fuel assembly appears in Section 1 of the Appendix.

On May 12, 1979, GE examined the two fuel rods in an eight-rod container and attempted to identify their serial numbers.[7] Because of limited visibility, they were not able to read accurately all of the serial numbers inscribed on the circumference of the end plug of each rod.[8] GE later verbally indicated that the serial numbers, as read, were very similar to those of the two fuel rods orphaned during the 1974 re-assembly of MS-557.[9] Based on this information, NNECO concluded that the two fuel rods were from MS-557.[10] A NNECO memorandum of May 15, 1979, also indicates that the rods would be stored in a fuel rod storage rack in the northwest corner of the SFP until they could be "incorporated in a scavaged (sic) fuel assembly."[11] The Unit 1 Reactor Engineer documented the location of the rods in the fuel history card file and in the memorandum of May 15, 1979.[12] Spent fuel pool maps of February and April 1980 show the rods in the northwest corner of the pool. Later spent fuel maps and documents do not identify the location of the two fuel rods or refer to them in any way.

2.2 NNECO's Initial Investigation

After learning of the fuel rod issue in mid-November 2000, Unit 1 management promptly established a team to locate the rods and initiated an assessment of the expected radiation levels of the two fuel rods. NNECO also conducted a review of records related to Unit 2 and Unit 3 and confirmed the presence of all spent nuclear fuel for those units.

Radiation levels, on contact, for each of the two missing rods were about 2000R/hr in the early 1980's, and approximately 1000R/hr in 2000. Based upon these radiation levels, NNECO concluded that the attempted removal of the rods from the SFP, in anything other than in a shielded cask, would have triggered multiple plant alarms and would have resulted in incapacitating, if not lethal, radiation doses to the individuals involved. Alternatively, introduction or removal of a cask of sufficient size and shielding would require the knowledge and involvement of numerous individuals, including plant managers. NNECO concluded, therefore, that theft or diversion of the two fuel rods was highly unlikely.

Accordingly, Unit 1 management developed a plan to locate the rods that focused on the Unit 1 spent fuel pool and at facilities licensed to accept radioactive material. The action plan addressed likely scenarios that either assumed the fuel rods remained in the spent fuel pool, or assumed that the fuel rods left the site inadvertently as part of a low-level waste shipment, or left the site with authorization as part of an authorized shipment of other fuel. NNECO formed two teams, a spent fuel pool inspection team and a records inspection team.

The spent fuel pool inspection team began their physical inspection tasks looking first in the areas that they thought would have the highest potential for locating the fuel rods or areas that could be inspected promptly. The spent fuel pool inspection team conducted visual inspections of the SFP designed around four possible scenarios: (1) the rods were still in their original GE eight-rod container; (2) the rods had been removed from the original container and placed in a different container; (3) the rods had been placed into a fuel assembly; or (4) the rods were stored in another pool location (e.g., empty fuel storage locations, control rod storage tubes, etc.).

GE supported the pool inspection effort by inspecting fuel assembly MS-557 and confirming that the center spacer rod and tie rod were not in the assembly. GE also inspected SRP-2D, an assembly that was used to house the rods removed from the segmented test rod assembly. NNECO inspectors also inspected a damaged fuel assembly (MS-508), a fuel storage canister, the pool floor, and other SFP locations. The inspections did not locate the two fuel rods.

A description of the key pre-FRAP spent fuel pool inspections appears in Section 2 of the Appendix.

The records inspection team focused on finding and reviewing those documents that might provide information on the disposition of the missing rods. The records review team searched NNECO records at Millstone and off-site, and records from other off-site sources, including GE. Types of records searched included Material Transfer Forms ("MTFs"), shipping records, DOE/NRC Form 741 SNM material transfer forms, SNM inventory records, SFP maps, records of the 1988-89 Unit 1 SFP Re-Rack Project, and other related records. The records review did not identify the location of the two fuel rods.

2.3 Formation of the Fuel Rod Accountability Project

In mid-December 2000, when discovery of the location of the missing rods did not appear imminent, NNECO executives augmented the already substantial search effort. First, NNECO formed an Independent Review Team ("IRT") to explore additional possibilities and provide oversight for the ongoing search effort. The IRT included industry experts with significant special knowledge in subject areas relevant to the search, including BWR fuels and fuel handling, nuclear plant operations and maintenance, nuclear engineering, and state and federal regulatory requirements. A summary of the backgrounds of the members of the IRT appears in Section 3 of the Appendix.

In January 2001, NNECO formed the Fuel Rod Accountability Project, retaining an experienced Project Manager to lead the investigation. Not including the IRT, the FRAP team included over 20 individuals retained to focus exclusively on locating the two fuel rods. These individuals averaged 28 years of professional experience gained at over 84 nuclear facilities, with diverse backgrounds, including nuclear fuel specialists, engineering, management, regulatory affairs, project management, and independent assessment.

In addition to the IRT and the FRAP Investigation Team, NNECO also formed a Root Cause Assessment Team, made up of individuals with substantial experience in root cause determinations and led by a recognized expert in the field. Finally, to oversee and coordinate the effort, NNECO also dedicated an experienced Vice President to serve as executive sponsor for the project. From the outset of the Project, senior management at Northeast Utilities, the corporate parent of NNECO, has provided all necessary resources and funding to staff and successfully complete the Project.

2.4 Final Report

This Final Report provides a summary of the Project, a description of the efforts taken to locate the missing fuel rods, and the results of the investigation. The report is presented in two parts. Section 3.0 contains a description of the investigation and the methodology applied to the investigation efforts. Section 4.0 provides the specific findings and conclusions. The Root Cause Assessment Team is preparing a separate report addressing the causes for the loss of accountability of the fuel rods, the reasons why the loss was not detected earlier, an evaluation of the extent of condition, and recommendations for corrective actions.

3.0 CONDUCT OF THE INVESTIGATION

3.1 Mission Statement, Principles, and Guidelines

NNECO assigned the Project the mission to determine the disposition of two missing spent fuel rods. Specifically, NNECO assigned the Project to:

- Conduct a comprehensive investigation, including physical inspections of the Unit 1 SFP, research and review documents and records, and conduct interviews of potentially knowledgeable individuals;
- Conduct an independent assessment of Project activities; and
- Use appropriate Project support to facilitate communications and interactions with internal and external stakeholders.

The fundamental principles underlying and guiding the Project work included:

- Protection of public health and safety;
- Purpose and commitment consistent with the seriousness of the mission;

- Objectivity in the investigatory process;
- Openness and forthrightness in communications with federal and state regulators, the public, and other stakeholders; and
- Cooperation with potentially affected entities

These principles guided the Project team in completion of all assigned tasks.

This Project and all work under it were organized and governed by a set of approved guideline documents. A high level description of the organization, the responsibilities of various individuals, and purpose of the FRAP is contained in the Project Description. The Project Plan describes the investigation methodology and the roles of the different Project participants. Ten Project Guidelines describe the processes used in different phases and aspects of the Project, including administration and records retention, scenario development, conduct of physical inspections, document investigation, conduct of interviews, and training. A listing of the Project Guidelines appears in Section 4 of the Appendix.

3.2 Summary of Investigative Method

The Project's investigation followed two parallel paths, similar to those initially used by Unit 1 management. One team collected and reviewed documents and conducted interviews. Another team performed detailed physical inspections in the SFP. Section 5 of the Appendix contains a flow chart depicting the investigatory process used by the two FRAP teams.

3.2.1 Collection of Documents

The Project executed a process designed to identify, retrieve, and review all available documentation containing information that might help determine the location of the two spent fuel rods. The search included both electronic document database searches and hard copy document storage locations, on and off-site. With the support of the Nuclear Document Services organization at Millstone, the Project performed electronic searches on the nuclear records databases. This document retrieval system includes the capability to search on key words, dates, functions, organizations and other parameters.

In addition to the database searches, the investigation team sought and collected hard copy documents from various locations. Because Unit 1 was already well into the decommissioning process, some historical records related to fuel handling at that unit had been moved, or in some cases discarded. Possible temporary storage locations were included in the search. Documents were collected from various on-site and off-site sources.

In some cases, these records were official departmental records. In other cases, the team recovered records maintained by individuals in local collections.

Through interviews and record searches, the team attempted to recover all existing, available relevant documentation.

Despite the comprehensive search and retrieval process, many important documents could not be found. For example, the FRAP was unable to find many older editions of maps of the Unit 1 spent fuel pool. Additionally, record keeping requirements and practices at Millstone Unit 1, like the rest of the industry, improved over time. Information that might have been helpful in this investigation, especially information related to movements of the two fuel rods in the 1970s or early 1980s, may never have been recorded.

In addition to Millstone locations and parts of the NU nuclear organization in Berlin, CT and elsewhere, Project members also sought and obtained records from other organizations that performed work at the Unit 1 SFP. These sources included the GE facilities in Wilmington, NC, Morris, IL, San Jose, CA and the Vallecitos Nuclear Center. The Project also received records from contractors who supported clean-up projects in the Unit 1 SFP between 1988 and 2000. Additionally, the FRAP collected waste shipping documents from the operators of the LLRW storage facilities in Barnwell, SC and Richland, WA..

Through an approved guideline, the FRAP established a process to review documents collected for information potentially relevant to the disposition of the two fuel rods, and to disseminate that information to the investigators. The guideline also established a mechanism to identify, collate, file, and maintain the documentation in a form suitable for audit. The guideline established formal requirements for reviewers to document the results of "applicability" reviews of each document. After the broad scope "applicability" review, Project members also performed another review for "relevance" to particular issues. Relevant information was extracted and included in an event timeline, as appropriate.

Later, during the course of scenario development when key questions and dates were identified and better understood, the Project performed another round of applicability and relevance reviews in light of the new information and the more mature scenario descriptions. Relevant information was subsequently linked with the one or more scenarios to which it applied. Scenario investigators then reviewed the documents applicable to their scenarios to support their investigations.

3.2.2 Scenario Development

In March and April 2001, the Project conducted a process designed to use the information gathered to develop the universe of plausible scenarios to be investigated. With the assistance of the IRT, Project team members met to identify and discuss various ideas about possible dispositions of the fuel rods based upon their experience and the information contained in the initial document reviews. The Project Manager established a low threshold for scenario plausibility in light of the very early stage of the Project.

In Project meetings, observed by the IRT, team members suggested and discussed a wide range of ideas for possible scenarios. The ideas also included questions and suggestions about the potential disposition of the rods raised by members of the public at periodic Unit 1 decommissioning meetings. The ideas were collected and placed into different categories by location (e.g., Unit 1 SFP, Hanford, etc.), with each scenario assigned a unique identifying number. A complete list of the scenarios considered by the FRAP appears in Section 6 of the Appendix.

Once initial scenario ideas had been identified, the Project Manager assigned a pair of Project team members to more rigorously develop each scenario. Each of these pairs followed a standardized scenario description format designed to identify scenario "attributes" – those facts and assumptions supporting or refuting its plausibility. Upon completion of the detailed scenario descriptions, the pairs brought the scenarios again before the larger Project group and the IRT for discussion of those scenario attributes.

The assigned investigators developed an initial scenario assessment and considered whether the scenario should or should not be regarded as plausible. The team members, again following a standardized format, then identified all known information supporting the scenarios, what conditions needed to be true for the scenario to be plausible, and what assumptions were necessary. They also identified the information, conditions and assumptions that tended to disprove the scenario or make it unlikely to have occurred. After analyzing each scenario, the pairs assessed the plausibility of the scenario and articulated the basis for that assessment. They also recommended any additional actions (e.g., action plan, confirmatory inspections, etc.) that were warranted. The Project Manager and IRT reviewed the scenario descriptions and assessments.

Based upon these plausibility reviews, the FRAP assigned follow-up actions commensurate with the scenario's likelihood or potential significance. Of the seventy-five scenarios assessed by the FRAP, eight required fully developed action plans, ten required one or more confirmatory actions, twelve were determined to be implausible. The thirty-five scenarios that identified locations within the Unit 1 SFP were not subjected to the scenario assessment process. Rather, Project management determined that all in-pool scenarios deemed plausible by the group would be investigated by physical inspection. Six additional Millstone site locations were also investigated by physical inspection. Finally, although considered implausible, because of the significance of the potential consequences, the Project Manager decided to investigate four scenarios involving the possibility of theft or diversion of the fuel rods through an investigation.

The Project prepared detailed action plans and descriptions of confirmatory actions. The Project added additional scenarios as the investigation proceeded. During the course of the investigation, one scenario initially considered implausible (a shipment to Vallecitos in 1980) was upgraded to a full investigation and action plan. The table below presents a summary of the results of the scenario development and assessment process.

FRAP Scenarios by Disposition Method

Location	Action Plan	Confirmatory Actions	Implausible	Physical Inspection	TOTAL
Barnwell	4		1		5
Hanford	3		1		4
Millstone Site	1	3	7	6	17
Morris			1		1
Other			2		2
Unit 1 SFP		3		35	38
Theft/Diversion	3				3
Vallecitos	1	4			5
TOTAL	12	10	12	41	75

The investigation action plans identify possible measures to prove or disprove the attributes, information, conditions, and assumptions identified in the scenario assessments. Many of the actions in these action plans involved areas for discussion in the interviews conducted by the Project team and Root Cause Assessment team. In some cases, the action plans suggest sample questions designed to help probe the topic. All action plans were reviewed by the IRT and approved by the Project Manager.

Completion of every action in the investigation action plans was not necessary to fully investigate the scenario. Rather, the action plans served as guides to assist the investigators and to inform the interviewers of significant issues. Upon completion of the scenario investigations, the FRAP and IRT reviewed actions relative to each each action plan to ensure that necessary steps had been taken.

3.2.3 Implausible Scenario Analysis

As discussed above, the investigative process led the team to consider a wide variety of potential scenarios, many of which had no factual basis in the documents gathered. Nevertheless, to ensure consideration of even these most unlikely explanations, the team analyzed their plausibility. Although that effort did not directly aid in identifying the precise location of the fuel rods, it assisted the investigation by ensuring that the team did not overlook less obvious possibilities. In so doing, this process provided added assurance that the four locations identified as possible repositories of the rods are, indeed, the only four possible locations.

Given that these scenarios are implausible, there is no need to discuss in detail the scenarios or the basis for the determination of implausibility. For completeness of the report, however, some discussion of this work is warranted.

The team explored a number of scenarios associated with the movement of the fuel rods to another location on or near the Millstone site. For example, it considered whether the rods could have been transferred to another unit's spent fuel pool, or to a radwaste storage facility on-site. In looking at these possibilities, the team not only examined the barriers inherent in such a move, it also conducted a number of confirmatory inspections of the site locations, interviewed appropriate personnel, and reviewed documents associated with the operation and inventory of these facilities.

The team also examined whether the rods could have been removed from the site in something other than a shielded cask and shipped as low specific activity waste ("LSA") to some appropriate facility. Again, the team reviewed relevant processes, procedures, and practices, as well as the radiation levels of the rods and the other items shipped and confirmed that rods could not have been included in such a shipment without detection.

Additionally, the team considered whether the rods could have been shipped to the GE facility in Morris, IL. Knowing that Connecticut Yankee had properly shipped spent fuel to that facility in the past, team members and an IRT member conducted a review of the relevant documents and visited the GE facility to determine whether these rods had been included in any of those shipments. The visit and other analysis confirmed that the rods had not been shipped to GE Morris.

This brief discussion is, by no means, a comprehensive list of the implausible scenarios considered, but it provides some understanding of the scope, objectivity, and level of effort expended to assess even the most unlikely scenarios.

3.2.4 Global Search Plan

During the early weeks of the FRAP, the Project team followed NNECO's prior physical inspections with searches estimated to have a high-likelihood of success in finding the two fuel rods. These physical inspections focused on the gaps between spent fuel assemblies and their storage racks in unchanneled fuel assemblies. The space between an unchanneled fuel assembly and the spent fuel storage rack is sufficiently wide to permit storage of a spent fuel rod. An unchanneled fuel assembly in the spent fuel storage rack in shown in Section 1 of the Appendix. The physical inspection team inspected greater than 350 unchanneled fuel assembly locations by lifting the fuel assembly and inserting a light and a camera into the empty spent fuel rack position.

In addition to the unchanneled fuel assemblies, the FRAP examined a number of raised fuel assemblies – assemblies that did not appear fully seated in the bottom of the fuel racks. Using the same inspection method as used for the unchanneled assemblies, the investigators looked for evidence that the fuel assemblies might be resting on the missing fuel rods. Overall, more than 400 of the 2884 fuel assemblies in the Unit 1 SFP were pulled and inspected during this effort. Again, these inspections involved looking in and around the fuel racks. They did not involve the disassembly of the fuel assemblies or the inspection of the individual fuel rods.

During the course of this inspection of the unchanneled and raised fuel assemblies, the FRAP began developing a detailed and comprehensive inspection plan intended to inspect all likely and accessible areas in the Unit 1 SFP and reactor cavity where full-length rods or rods cut into several foot segments could be stored. With the assistance of personnel from Unit 1 Reactor Engineering, guidance from experts on the IRT, and suggestions and insights from GE, the Project established a comprehensive list of locations capable of physically accommodating the two rods.

This Global Search Plan listed the specific locations to be searched, unique characteristics of that location, and the planned inspection method. As with the non-pool scenarios, when additional information or insights suggested other locations not previously considered, the Project amended the Global Search Plan to incorporate those additional locations. The table below lists the thirty-eight scenarios addressed by inspection or other confirmatory action under the Global Search Plan.

Physical Inspection Scenario Descriptions

Scenario	Description
5.1.1	Inspection of MS-508 storage container.
5.1.2	Inspection of the gap between MS-508 storage container and the gun barrel (control rod rack storage cylinder).
5.1.3	Look for rods on the SFP floor in segments with or without pellets.
5.1.4	Look for fuel pellets separated from fuel rods.
5.1.5	Inspect the SRP-2D fuel bundle.
5.1.6	Examine water rod sites in the 8X8 fuel bundles. (A 7x7 fuel rod can fit into an 8x8 bundle water rod site.)
5.1.7	Inspect fuel assembly MS-557, the host assembly for the orphaned fuel rods.
5.1.8	Inspect unchanneled fuel bundles to see if the missing rods were placed in the gap between fuel bundle and storage rack.
5.1.9	Investigate whether or not a rod could be placed in the gap between a channeled fuel assembly and its storage rack.

Scenario	Description
5.1.10	Examine the area inside control rod blade guides.
5.1.11	Examine the rack cell area occupied by a control rod blade guide.
5.1.12	Inspect the contents, if any, of two square cans located in the SFP.
5.1.13	Inspect boxes of stored LPRMs and verify that no fuel rods are stored there.
5.1.14	Inspect the filter baskets hanging from the SFP wall and video tape.
5.1.15	Examine the Segmented Test Rod (STR) fuel assembly, MSB-125.
5.1.16	Inspect the empty storage racks.
5.1.17	Examine two cells containing debris.
5.1.18	Examine the channel storage racks containing fuel channels.
5.1.19	Inspect the control rod storage racks on the south end of the SFP for any evidence of fuel rods.
5.1.20	Inspect 1 ½" pipe on the north side of the SFP for fuel rods.
5.1.21	Inspect a cask liner used for instrument tubes.
5.1.22	Inspect the internal areas of the fuel preparation machine.
5.1.23	Inspect the fuel preparation machine external areas.
5.1.24	Inspect the two (2) dummy assemblies for possible rework and insertion of the orphan fuel rods.
5.1.25	Free space inspection of areas between fuel racks.
5.1.26	Examine areas between fuel racks and the SFP wall/liner.
5.1.27	Examine the two (2) boraflex coupon containers.
5.1.28	Examine the area between the fuel pool to Reactor cavity gates.
5.1.29	Examine scavenged fuel bundles.
5.1.30	Inspect the new fuel vault area.
5.1.31	Inspect the northwest wall area of the SFP for any objects which may have been placed there.
5.1.32	Examine areas on the top of the fuel racks.
5.1.33	Examine the raised fuel assemblies to determine why they will not seat and to look for the orphaned fuel rods.
5.1.34	Inspect the free space under the fuel racks.
5.1.35	Examine fuel assemblies for signs of disassembly and rework.
5.1.36	Examine miscellaneous items around and in pool. Stellite ball container, box of dry tubes, instrument tube, PVC filter, pump, control rod handle, cask liner.
5.1.37	Inspect the sump near the center of the spent fuel pool floor.
5.1.38	Examine free spaces between the cylinders of the control rod storage rack.

Execution of the searches and inspections identified in the Global Search Plan required coordination among the FRAP, Dominion Nuclear Connecticut, Inc. ("Dominion") personnel from Unit 1 Reactor Engineering, Operations, Site Health Physics, GE, and ROV Technologies, Inc. The vast majority of the inspections were performed using underwater cameras. Other visual inspections used underwater binoculars, fuel inspection equipment, or other devices. Areas beneath the spent fuel storage racks were inspected using a remotely operated, camera-mounted crawler, in conjunction with other cameras. The crawler used installed grippers to grasp and move items and to compare items to known references. These inspections also required expert use of various pieces of underwater lighting equipment to enhance visibility in the pool. Many inspections also involved use of radiation survey meters to measure the radiation levels of objects in the pool.

The Project Manager and IRT closely monitored the progress and results of physical inspections in the pool and reactor cavity. The FRAP provided regulators and Dominion weekly progress reports on the progress of the investigation in scheduled teleconferences with NRC headquarters, Region I, and state regulators in Washington, South Carolina, and Connecticut. The FRAP completed all planned inspections in the Unit 1 SFP and reactor cavity in August 2001, and dispositioned the results of the searches.

3.2.5 Interviews

Investigation of each action plan required interviews with knowledgeable individuals. The Project conducted over 200 interviews of current and former NNECO employees, NNECO retirees, current employees of Dominion, current and former contractor workers at Millstone, and personnel at GE, Hanford, and Barnwell. Members of the FRAP began the process by identifying key individuals responsible for, or directly involved with, various aspects of each of the scenarios. They also compiled a collection of documents relevant to the significant events and memory aids such as photographs of different shipping casks and the SFP at different times, sketches and diagrams of reactor hardware, and other relevant documents. Gathered as a group, members of the Project discussed potential interviewees and their expected areas of knowledge. They then prioritized the list for conducting the interviews.

The team identified over 100 individuals for formal, in-person interviews. These interviews were conducted by a limited number of FRAP and Root Cause Assessment team members to ensure consistency and continuity. The interviewers prepared formal written summaries of each interview. The formal summaries were then distributed to all members of the FRAP, Root Cause Assessment Team, and IRT, and discussed during weekly debriefing sessions.

In addition to the primary interviews, FRAP members conducted less formal telephone interviews of almost another 100 individuals, using a common questionnaire probing a wide range of topics. Based on their responses to these questions, the Project invited some of these individuals for more detailed interviews. As the investigation moved forward and more information surfaced, Project members also re-interviewed some individuals. A few key people were interviewed four or more times. FRAP members formally documented each interview.

On July 27, 2001, after a substantial majority of the available information had been collected and digested, and specific information holes had been identified, the FRAP conducted a one-day, facilitated panel discussion involving approximately two dozen of the most knowledgeable individuals.

Overall, the FRAP experienced good cooperation in the interview process. However, not everyone was available. Some individuals were deceased. Some could not be found. Others declined to cooperate, despite repeated attempts to persuade the individuals to assist the investigation.

3.2.6 GE Support

Supplementing NNECO's efforts, GE provided additional support to the investigation. In June 2000, a GE team, comprised of personnel from the GE facilities in Wilmington, NC and San Jose, CA met with the Project team. GE personnel provided suggestions for enhancements of the physical inspection plan and conducted interviews of GE personnel involved with Millstone Unit 1 and with the segmented test rod ("STR") program – a program run by GE at Millstone Unit 1 and elsewhere in the 1970s and 1980s to improve fuel quality. The GE team also reviewed available documents at GE facilities in Vallecitos and San Jose, CA, and in Wilmington, NC. Later in the investigation, GE invited individuals from the FRAP to visit GE locations to review additional documentation. Additionally, former GE workers participated in the July 27, 2001, panel discussion.

3.3 The Standard of Proof

To determine whether the evidence developed in the investigation established a fact or a conclusion, the team required that there be clear and convincing evidence of that fact or conclusion. As discussed in FRAP Guideline For Weighing Evidence, M10063-10, this means that the evidence must be sufficiently convincing that it leaves no substantial doubt in the mind of a reasonable person that the finding or conclusion is true. In other words, the finding must be far more than theoretically possible or even likely; it must be highly probable.

Using this standard, it is possible that the weight of the evidence available on a certain matter may suggest the existence or non-existence of a particular fact. But if the evidence available was based on documents that were unclear, on records that were incomplete, or on memories that were clouded, that evidence would not be sufficient to support the finding.

The investigation used this standard, rather than a lower "preponderance of the evidence" standard, because the purpose of the investigation was to render an objective determination about the actual location of the fuel rods – not simply to weigh the available evidence. Indeed, this investigation involved many matters that occurred over twenty years ago. Not surprisingly, the body of evidence is imperfect. In fact, four persons who may have had relevant information are deceased. Two others, including one person who was very active on the spent fuel pool floor in 1978 and 1979, refused to cooperate with the investigation. Twenty-nine others identified for interviews could not be located. And, many people interviewed had considerable difficulty recalling key events. So too, document collection efforts were not perfect. Among the documents that could not be located were a number of old spent fuel maps, GE field notes of fuel movements, Unit 1 Maintenance Department photographs and logs, and the personal files of many former employees, one of whom was the Reactor Engineer who first identified the rods in May 1979.

These circumstances make it clear that it would be unwise to simply take the available evidence, weigh it, and render a determination without considering whether the quality of the evidence is such that the finding or conclusion is highly probable. Accordingly, the findings and conclusions contained in this report are based upon the accumulation (or absence) of clear and convincing evidence.

4.0 RESULTS AND CONCLUSIONS

The investigation did not produce clear and convincing evidence of the specific location of the two fuel rods from MS-557. The investigation found no credible evidence to believe, however, that the fuel rods are in any location other than a facility licensed to possess, and protect the public from, radioactive material. Consequently, there is no undue threat to the health and safety of the public, the workers, or the environment.

4.1 Findings and Results of Key Scenario Investigations

4.1.1 Background

4.1.1.1 Early History of the Fuel Rods

Early fuel records show conclusively that fuel assembly MS-557 consisted of 49 fuel rods when Millstone received it on June 13, 1969.[13] Those records also show that the assembly included a center spacer capture rod with serial number BK 0136 and a tie rod with serial number BP 0406.[14] MS-557 was one of the 580 assemblies placed in the core when the Unit 1 reactor first achieved criticality in October 1970.[15]

On September 1, 1972, seawater entered the primary coolant system through the condenser on Unit 1.[16] Because of the intrusion of the seawater, management conducted an orderly shutdown of the unit, removed the assemblies from the core, and placed them in the Unit 1 pool.[17] On October 8, 1972, workers from GE disassembled MS-557 and placed the 49 individual rods in seven GE eight-rod containers.[18] During the disassembly, one tie rod dropped, breaking part of the upper end plug shank on that rod.[19] As a result, GE workers placed that tie rod and the center spacer capture rod in a single eight-rod container.[20] Available records do not disclose the location of the container in the SFP. GE then shipped various non-fuel structural components of MS-557 to its Vallecitos laboratory to study the potential effect of the seawater intrusion.[21] Shipping records do not suggest that the two separate fuel rods from MS-557 accompanied the non-fuel components. Contemporaneous notes indicate that all 49 rods were left in the Unit 1 SFP.

In May 1974, GE workers reassembled MS-557 with 47 of the 49 original fuel rods.[22] The handwritten notes of the Unit 1 Reactor Engineer reflect the re-assembly of MS-557, but they make no mention whatsoever of the original missing center spacer capture rod and the damaged tie rod.[23] Neither those notes, nor any other document, indicate whether the two rods were included in the reassembled bundle, left in the eight-rod container, or treated otherwise. The notes are simply silent.

The investigation found no SFP maps, fuel records, or SNM records that mention the two fuel rods between disassembly in October 1972, and March 1979. Moreover, no one interviewed recalled seeing the rods during this period.

4.1.1.2 Key Records of the Fuel Rods in 1979

On March 13, 1979, engineers prepared two SFP maps, both of which include a notation of an unspecified number of "fuel rods" from an unidentified assembly located in the southeast corner of the SFP.[24] No other records describe the circumstances surrounding this entry. The Reactor Engineer who initialed the maps does not recall how that entry came to be or what that entry represents.[25] Although not conclusive, the evidence suggests that this entry represents the two rods from MS-557.

On May 15, 1979, the same Reactor Engineer prepared a memorandum that indicates that on May 12, 1979, workers from GE read the serial numbers on two fuel rods and concluded that the rods were the center spacer capture rod and tie rod from MS-557.[26] Two weeks later, the Unit 1 Superintendent wrote to GE expressing his appreciation for their support in identifying these rods.[27]

The reliability of this May 15, 1979 memorandum is key to this investigation. If it is reliable, a host of pre-May 1979 activities that could have affected, or that could explain the disposition of, the rods become moot. If it is not accurate or reliable, almost seven years of SFP activities and a host of off-site shipments become possible explanations for the current status of the rods. Because of the existence of considerable circumstantial evidence corroborating various aspects of the May 15, 1979 memorandum, the investigation concluded that there is clear and convincing evidence that the memorandum is reliable and that workers actually saw the two rods from MS-557 on or about May 12, 1979.

Although the investigation has reached this conclusion based on the evidence available, the passage of time, the absence of confirmatory records, and the existence of some contradictory evidence counsel against placing absolute confidence in this conclusion. In other words, the investigation cannot conclude with absolute certainty that the rods were in the pool on May 12, 1979. But the evidence reviewed was sufficiently compelling to remove any substantial doubt about the reliability of the memorandum of May 15, 1979.

GE's identification of the two fuel rods enabled the Unit 1 Reactor Engineer to prepare a SNM Kardex file card on or about May 12, 1979, for the two rods identifying the location of the rods, the weight of uranium contained in the rods, and their condition.[28] Except for the entries made on May 12, 1979, however, the card file contains no other information about the fuel rods, their location, or disposition.

We cannot presume that the rods remained in the location where they were placed after their identification. In fact, in the May 15, 1979 memorandum, the Reactor Engineer expressed his intent to move the rods.[29] Specifically, he noted that the rods "will be stored in the fuel rod storage rack in the North-West corner of the spent fuel pool until they can be incorporated in a scavaged [sic] fuel assembly."[30] The investigation did not find any evidence, however, that he followed through and placed the rods in another bundle.

4.1.1.3 The Status of the Rods After the May 1979 Serial Number Reading

When GE read the serial numbers on the rods in May 1979, Unit 1 was in the midst of a refueling outage.[31] That outage ended on June 27, 1979.[32] At some point between the end of the outage and the beginning of an audit on November 8, 1979, audit documents indicate that unit personnel prepared a map of the spent fuel pool.[33] The investigation, however, has not discovered any SFP map prepared during that period. Thus, we cannot conclude – one way or the other – whether the fuel rods appeared on that map, and if they were on the map, where the map depicts the rods.

That map may be significant because in September and October, 1979, contract workers from Crouse Nuclear Services cut LPRMs that were stored in the Unit 1 SFP and placed them in liners in the pool.[34] If the missing SFP map includes a depiction of the rods, and if the engineers prepared the map after Crouse completed its work, the missing map would be evidence that the rods survived the cutting campaign and were not cut by mistake.

Although there is no direct evidence that Crouse workers inadvertently cut the rods, that possibility cannot be ignored. Because LPRM hot sections are similar in length and diameter to a fuel rod, a person who is unfamiliar with boiling water reactor components would have difficulty distinguishing between the two.[35] Adding to that difficulty, the Crouse workers did not have visual aids, such as borescopes or reverse periscopes, to help identify the underwater objects. Moreover, if the fuel rods were being stored in the corner of the spent fuel pool, as the memorandum of May 15, 1979 indicates, those workers would not have expected to find fuel being stored outside the fuel racks, with non-fuel items. Indeed, after the SFP re-racking in March 1979, the fuel racks containing the spent fuel were between 22 and 90 inches from the walls of the pool. [36] Encountering an item that looks like an LPRM, in a place where non-fuel items were stored, underwater and under conditions of limited visibility, could well explain how fuel rods could have been inadvertently cut. Nevertheless, the evidence is simply insufficient to determine to any reasonable degree of certainty that the Crouse workers actually cut the rods in the Fall of 1979.

4.1.1.4 The Removal of the Rods from SFP Maps in 1980

A SFP map prepared on February 26, 1980 – four months after Crouse finished the LPRM cutting operations – potentially resolves the question of the inadvertent cutting of the fuel rods.[37] That map depicts the two fuel rods in a square in the northwest corner of the SFP with the caption "2 Fuel Rods MS-557."[38] A later SFP map dated April 30, 1980, also contains the same entry and same notation about the fuel rods.[39] By all appearances, that April map is a copy of the February map, with one item about certain segmented test rods deleted. The April 1980 SFP map is the last known document that mentions the two fuel rods.

If accurate, these maps prove that the rods were in the SFP after the Fall 1979 LPRM cutting campaign. The practice used to prepare SFP maps during that period, however, does not necessarily assure their accuracy. Specifically, the engineers did not always draw new maps each time they issued a SFP map.[40] Nor did they always perform a visual inventory of each item in the pool before issuance of the map.[41] Often, they updated a prior map to reflect changes in the pool since the last map.[42] Based upon interviews, it is possible that engineers placed the rods on either the missing SFP map or the February 1980 map without the benefit of personal observation at the time of the map's preparation. In fact, the engineer who prepared much of the map said that the notation of the "2 Fuel Rods MS-557" on the February 1980 map is not in his handwriting as the remainder of the entries on that map.

If no personal observation of the rods occurred in February 1980, it is also possible that the engineer(s) responsible for the preparation of later SFP maps might not have known about an inadvertent cutting of the rods and, as a result, would not have changed earlier entries reflecting the rods. That practice could explain how cut rods could go undetected, but still appear on later SFP maps. The investigation did not uncover sufficient evidence to conclude, however, that the rods were, in fact, cut by mistake.

Of course, the converse is also true. In other words, the maps could well be accurate representations of the pool at the time of their preparation. Consistent with the Reactor Engineer's memorandum of May 15, 1979, the February and April 1980 SFP maps (and possibly on the earlier missing map) show the two fuel rods to be in the northwest corner of the SFP.[43] Other than the SFP map preparation methodology, i.e., preparation by exception, there is no reason to believe that the maps erroneously depict the fuel rods. That methodology and the ultimate inability to locate the fuel rods, however, raise too many questions about the accuracy of those maps to reach a definitive conclusion about the rods' condition or location after the Fall 1979 LPRM cutting campaign.

A September 1980 SFP map complicates the analysis further and, indeed, shows that engineers did not always prepare SFP maps by replicating, and then updating, earlier versions. In September 1980, reactor engineers prepared a SFP map that is not simply a copy of an earlier map.[44] Among other differences, this map contains no reference of any sort to the fuel rods. The existence of a freshly drafted SFP map at least suggests some additional increment of accuracy, and may support the notion that the rods were cut, placed in a "scavenged" bundle, or disposed of in some other unknown way. But the Reactor Engineer who identified the fuel rods in May 1979 believes that the omission of the fuel rods from that map was simply an inadvertent oversight in drafting.[45] If he is correct, the practice of generating maps based upon changes in SFP composition could explain how engineers could perpetuate the error in maps drafted after September 1980. And, in fact, not one SFP map prepared after September 1980 – or any other document of any sort – mentions the two fuel rods.

This inconsistent evidence precludes reaching a conclusion about the location of the rods in 1980, and thereafter. The loss of fuel rod accountability does not mean that the rods were not in the SFP, but the absence of any record of the fuel rods for the next 20 years makes the identification of their precise location or disposition challenging at best.

4.1.2 Results of Scenario Investigations

4.1.2.1 The 1980 Shipment To Vallecitos

As previously discussed, the absence of any reference to the individual fuel rods in any records after April 1980 could be attributable to: (a) the rods having been inadvertently cut during the Fall 1979 LPRM cutting campaign; (b) the placement of the rods in another assembly or their undocumented movement to some other unidentified location in the pool; or (c) a simple oversight in the creation of the September 1980 SFP and the perpetuation of that mistake in later maps. Another possibility arose in April 1980, when Unit 1 shipped a shielded cask to GE's Vallecitos facility.

On May 5, 1979, GE personnel removed a segmented test rod from fuel assembly MSB-125, unscrewed its four segments, and placed the segments in a GE–1600 shipping rack.[46] Ironically, on that same date, GE and NNECO workers also took MS-557 and MS-330 from their respective locations in the SFP and moved them to the fuel prep machine in the SFP. Both of these assemblies were in the core during the 1972 seawater intrusion and GE tested the fuel rods from both after that event. MS-557 and MS-330 remained in the fuel prep machine for about 24 hours, until they were returned to their storage locations. The documents do not indicate the reason for the movement of these assemblies to the fuel prep machine or what work, if any, occurred there. As discussed earlier, one week later, on or about May 12, 1979, workers from a GE channel measurement crew read the serial numbers on the two fuel rods and, based upon the similarity between the numbers read, and those in records, concluded that the rods were from fuel assembly MS-557.[47]

In July 1979, a GE fuel handling crew arrived at Millstone to reconstitute another assembly, GEB-20. On July 20, 1979, GE removed some non-fuel hardware from that assembly and placed it in the same shipping rack that housed the segmented test rods, which an earlier GE crew placed there in May 1979.[48] The shipping rack remained in the SFP.

On December 28, 1979, GE notified the NRC that it intended to ship the GE-1600 cask, with the previously loaded shipping rack, from Unit 1 to GE Vallecitos.[49] The individual in the NRC responsible for preparing NUREG-0725 also prepared a "Spent Fuel Shipment Data" form that contained information about the shipment.[50] Two entries may be important to the question of the content of the shipment. First, the NRC employee entered the number "4" next to the line asking for the "Number of fuel segments."[51] But beneath a typed entry for "Number of fuel rods," he wrote "8.8 kgs."[52] Both entries are handwritten.

The shipment left Millstone on April 30, 1980.[53] The DOE/NRC Form 741 for this shipment – the official record of the transfer of special nuclear material – indicates that the shipment contained 2.4 kg of uranium when it left Millstone.[54]

GE signed the Form 741 on May 7, 1980, acknowledging receipt of the shipment and "accepting shipper's weights."[55] The actual weight of the uranium contained in the four STR segments was only about 2.4 kg, which is consistent with the 2.4 kg entry on the Form 741. The 2.4 kg entry is also very close to the 2.5 kg amount reported by the NRC in the initial NUREG-0725 report, an NRC document that reports shipments of spent fuel and the amount of spent fuel shipped.[56] NRC officials informed the Project that the NRC employee who prepared the "Spent Fuel Shipment Data" form would have done so based upon letters and/or telephonic information provided by GE.[57] The NRC employee who actually prepared this form informed the NRC and Project Team members that he did not recall Millstone Station at all or the 8.8 kg entry, much less the basis for this entry.[58]

In 1990, a different NRC staff person changed the NUREG-0725 shipment amount from Millstone – for the first time since 1980 – to reflect a shipment that is generally consistent with the 1980 entry on the NRC "Spent Fuel Shipment Data," but inconsistent with the signed DOE/NRC Form 741.[59] The NRC employee responsible for the NUREG 0725 change is deceased.[60] The NNECO official who signed the DOE/NRC Form 741, which reflects 2.4 kg of uranium in the shipment, is also deceased.

The evidence cited above does <u>not</u> establish that the two fuel rods are at GE Vallecitos. In fact, the majority of the evidence indicates the rods are not at that facility. In particular, the official record of the shipment, the DOE/NRC Form 741, is consistent with the weight of the four segmented test rods and consistent with the inventory. The NUREG 0725 issued after the 1980 shipment reflects that amount as well. Additionally, a review of the GE Vallecitos "Material Balance Status" forms did not reveal an amount of SNM attributable to the SNM contained in the two fuel rods. Moreover, GE inspection processes at Vallecitos required that the container be opened and the contents inspected.[61] There is no indication that the receipt inspection led to the discovery of the two rods from MS-557. Had the rods been there, the receiving inspector almost certainly would have provided some indication of his discovery.

Although this evidence is quite strong, and may even be compelling, there are discrepancies that have not been resolved. For example, GE receipt records do not precisely match the GE shipping inventory for the irradiated hardware contained in the April 30, 1980 shipment. Specifically, a GE representative signed a GE Fuel Operations Procedure on April 10, 1980, which included a list of the items placed in the shipping rack.[62] The handwritten "Inventory of Rec'd Reactor Hardware" indicates that on May 8, 1980, GE received two additional lock tab washers and eight nuts that were not on the signed shipping inventory.[63] And, two expansion springs that were on the shipping inventory do not appear on the receipt inventory or in the receipt photograph.[64] These discrepancies certainly do not establish that two fuel rods were included in the shipment, but they preclude reliance on the inventory documents as categorical proof of the contents of the shipment.

Additionally, as noted earlier, two NRC records (the Spent Fuel Shipment Data and 1990 version of NUREG 0725) indicate that GE received 8.8 kg of SNM in the shipment of April 30, 1980. That amount of SNM exceeds the amount contained in the four, segmented rods by about 6.4 kg – an amount slightly less than the 7.5 kg of SNM contained in the two fuel rods from MS-557. The NRC has investigated this discrepancy but cannot identify the basis for this entry.[65] Likewise, GE has reviewed its records and it, too, cannot reconcile these documents. The two NRC employees who would be most likely able to resolve the issue are either deceased or unable to recall any relevant information.[66] Although the GE receipt records and processes described above seem to preclude the inclusion of the rods, the inability of anyone to explain the 8.8 kg entry compels the investigation to conclude that – although very unlikely – GE Vallecitos must be included as a possible repository.

Additionally, GE loaded the segmented test rods on May 5, 1979 – the same day that the parent assembly of the two unaccounted for rods (MS-557) suddenly appeared for unexplained reasons in the fuel prep machine.[67] That "scrap" assembly had not been worked on since GE reassembled it in 1974, and yet, on the day the shipping rack was loaded, MS-557 was moved to the fuel prep machine. Perhaps related, seven days later, GE identified the two stray rods from that assembly.[68] The convergence in time of this movement of MS-557, the identification of the two fuel rods, and the loading of the segmented rods in this shipping rack may be coincidental, but, at a minimum, the timing raises unanswered questions about a possible relationship between this shipment and the two fuel rods.

The shipping rack containing the segmented rods and the irradiated hardware could have easily accommodated two cut fuel rods. Moreover, the shipping rack remained in the Unit 1 SFP for almost <u>one year</u> before being shipped to Vallecitos. Indeed, after receiving the four segmented rods in May 1979, the rack remained in the pool. Again, in July 1979, it received the irradiated hardware from assembly GEB-020.[69] But even then, the rack remained in the pool until its shipment in late April 1980 – over 11 months after the segmented rods were loaded. Clearly, ample opportunity existed to load the rods in the rack.

Finally, the shipment of the rods on April 30, 1980, could well explain the inability of anyone to recall seeing the rods after GE's identification of the rods in May 1979. And, if the SFP map of April 30, 1980 was not the product of a visual confirmation, but was prepared to reflect only those known changes, the map could well have been prepared without reflecting the shipment on April 30, 1980.[70] The absence of the rods from the September 1980 SFP map – a map that is not merely an amended copy of a prior map – could, in fact, accurately reflect the shipment of the rods.[71]

Again, these considerations do not warrant a conclusion that the two fuel rods are at Vallecitos. To the contrary, the clear weight of the evidence favors a finding that the rods are not at Vallecitos. The record discrepancies and open questions, however, do not permit the investigation to exclude the possibility that the rods were shipped to Vallecitos.

4.1.2.2 The 1985 Shipments to Hanford

In late 1984 and early 1985, Millstone implemented a program to reduce the amount of irradiated waste in the Unit 1 SFP. NNECO hired GE to perform "consolidation and densification services" for control rod blades ("CRBs") and LPRMs, and to provide assistance in loading activities.[72] Initially, the contract envisioned only one shipment of an IF-300 cask to the commercial LLRW facility on the Hanford reservation in Richland, WA. GE and NNECO amended the contract, however, and three IF-300 shipments occurred.[73]

The investigation did not produce clear and convincing evidence that the two fuel rods from MS-557 were shipped to Hanford. In fact, there is no direct evidence that they were included in any of these three shipments. Nevertheless, the evidence is not sufficiently compelling to exclude the possibility that the fuel rods were inadvertently included.

The March 20, 1985 Shipment

As noted earlier, the evidence does not establish either the location or condition of the fuel rods after May 1979. This uncertainty creates at least the possibility that workers could have unintentionally loaded cut fuel rods into the liner before shipping the first IF-300 cask on March 20, 1985. The inventories and related documents, however, do not provide any evidence to support a conclusion that the rods were shipped. Rather, the only items reflected in the shipping documents that could have been confused with the fuel rods were 38 LPRMs that GE cut in early 1985.[74] But the detailed procedures that GE followed, the related documentary evidence of procedural compliance, and interviews clearly establish that those items were, in fact, LPRMs and not fuel rods.[75] Moreover, the evidence clearly establishes that GE loaded the 38 LPRMs that they cut, not other LPRMs that had been previously cut and were stored in the SFP – and not inadvertently cut fuel rods.[76]

Although that conclusion is sound, there was an opportunity for the loading of additional items that precludes the categorical exclusion of this shipment. Specifically, one of the GE workers recalled that the IF-300 liner lid was not closed when GE finished its cutting and loading work on February 9, 1985.[77] Reports in 1985 indicating that the Hanford and Barnwell LLRW repositories might be closing, provided a possible incentive for NNECO to want to load additional material in the shipment.[78] But having the motive and opportunity to load additional material does not make it so. Moreover, workers would have had no reason to violate procedures and regulatory requirements by loading additional material and not recording it on shipping records.

Additionally, the physical dimensions of the liner effectively precluded the shipment of full-length fuel rods. Simply stated, the liner was five inches too short to hold a full-length fuel rod or an eight-rod container loaded with a fuel rod.[79] The insertion of a full-length rod would have required a nearly empty liner and a pronounced bow in the fuel rod.[80] The documents establish that the liner was not empty when GE workers loaded the LPRMs and no one interviewed recalled any manipulation of the items being loaded.[81] There were, however, no significant physical restrictions on the loading of cut fuel rods. Indeed, the liner had more than enough space to accept two cut rods.[82] But the investigation found no evidence that cut rods were actually placed in the liner or shipped.

The May 29, 1985 Shipment

Similarly, there is no direct evidence that the fuel rods were included in the second shipment to Hanford. In this shipment, the only items on the inventory that bore any resemblance at all to fuel rods were 38 cold ends of LPRMs.[83] Unlike hot ends, however, an LPRM cold end is more than one inch in diameter, notably larger than that of a fuel rod.[84] And the radiation levels of the cold ends in this shipment were considerably less than that of an irradiated fuel rod.[85] Moreover, the evidence indicated that the cold ends shipped in this cask were the cold ends from the LPRMs cut by GE workers in early 1985.[86] As noted earlier, the procedures used by GE, and the documentation associated with that cutting operation, provide clear and convincing evidence that GE did not inadvertently cut the two fuel rods.

As in the case of the first shipment, however, there was also an opportunity for the loading of additional items into the liner of the second shipment. In particular, workers removed CRB handles from three old containers that were in the pool and loaded them into the IF-300 liner for shipment.[87] The containers that housed the CRB handles may have also contained other, unidentified irradiated items. Although there is virtually no possibility that a worker could mistake a fuel rod, or fuel rod segment, for a CRB handle, the investigation could not rule out the possibility that some other items in the three old containers were also transferred to the IF-300 liner. Again, however, there is no evidence that such a transfer occurred, much less that the fuel rods were transferred from an old container to the IF-300 for shipment.

Similarly, while workers were loading the IF-300 liner, old PB-1 and AP-101/ANEFCO liners were transferred to the cask laydown area for identification of the contents of those liners.[88] The workers were not instructed to load the contents of the old liners into the IF-300.[89] The IF-300 loading was a separate activity, but the presence of these old liners provided an opportunity to transfer items from those liners to the IF-300 liner. But again, there is no direct evidence that the fuel rods were in any of those liners and there is no evidence of any sort that they were transferred to the IF-300 liner.

The July 31, 1985 Shipment

NNECO conducted the third IF-300 shipment in essentially the same manner as it did the second shipment. Once again, there is no evidence that the shipment included the two fuel rods or segments of the rods. There were, however, two aspects of this shipment that created the opportunity for the inadvertent inclusion of the rods.

First, workers loaded 40 segments of LPRM hot ends, which the final inventory describes as coming from 8 LPRM hot ends.[90] As previously noted, LPRM hot ends are similar in appearance to fuel rods. The evidence indicates that the workers loaded all of the LPRM segments that were in a particular container on the west wall of the SFP.[91] The investigation was unable, however, to trace the specific history of these LPRM segments to determine whether they contained, or may have contained, cut fuel rods. Nevertheless, for this shipment, the Project Manager and Project Engineer required that workers confirm the identity, volume, mass, composition, number of cycles of core exposure, year discharged from the core, location in the core, and major dimensions of inventoried items before loading.[92] Those requirements also necessitated concurrence of Radiological Assessments personnel and Reactor Plant Systems before loading items into the liner.[93] Although the investigation did not find documentation specifically providing this data for the LPRM hot ends included in this shipment, the investigation did find that the Project Engineer submitted the required waste classification information and curie calculations - information that would have required that he have that data.[94]

The second opportunity to inadvertently place cut fuel rods in this shipment arose when workers unloaded items from an old PB-1 liner. As discussed in the second shipment, the old PB-1 liners contained unidentified irradiated material. In this shipment, the Project Manager specifically instructed the workers to unload one PB-1 liner that was in the cask laydown area, "in conjunction with" the loading of the IF-300 liner.[95] He limited the loading of items from the PB-1, however, to the types of items designated for shipment, i.e., velocity limiters and CRB handles.[96] The workers were not instructed to transfer all items in the PB-1 to the IF-300.[97] And there is no evidence that workers ignored these instructions. In fact, the notes of one worker indicate that when he unexpectedly encountered two LPRMs in a liner with poison curtain handles, he did not load the LPRMs or other items that he found, but instead called them to management's attention.[98]

As in the case of the two earlier shipments to Hanford, the evidence does not establish that the rods were shipped to Hanford in 1985.

4.1.2.3 The 1988 - 2000 Shipments to Barnwell

In the late-1980s, NNECO conducted a number of significant activities to improve operations in the Unit 1 SFP. Those activities included a substantial re-racking of the SFP in 1989 to increase the pool's storage capacity. The Unit also made multiple shielded shipments of waste between 1988 to 2000, to the LLRW facility in Barnwell, South Carolina. The evidence is not sufficient to establish that the fuel rods were included in any of the shipments to Barnwell.

The May 1988 Shipments

In anticipation of the 1989 re-rack, Northeast Utilities Service Company ("NUSCO") hired WasteChem in January 1988, to perform a major clean up of irradiated hardware, contaminated materials, and filters in the Unit 1 SFP.[99] Documents associated with this work reveal that WasteChem submitted its proposal and, in fact, began work without having been provided a precise list or characterization of the various irradiated hardware and contaminated items in the pool to be processed and shipped.[100] This clean up effort included three shipments of TN 8L shipping casks and one CNSI 3-55 cask. Each TN-8L cask included three rectangular liners, each one large enough to accommodate full length rods and the eight-rod container. The CNSI 3-55 liner was not large enough to hold full length rods or the eight-rod container.

The uncertainty about the non-fuel contents of the SFP – particularly the number and location of LPRMs – is potentially significant. WasteChem reported that it shipped 15 full-length LPRMs, consistent with the bid specification.[101] The report of 15 full-length LPRMs is, in fact, consistent with the Unit's operating history.[102] During the late-1985 refueling outage, workers removed eight LPRMs from the core and, during the 1987 outage, they removed seven more LPRMs.[103] The fact that these LPRMs still had their hot and cold ends joined when WasteChem arrived to process and ship them precludes any serious consideration that the two fuel rods from MS-557 could have been mistakenly included for shipment with these LPRMs.[104]

The accounting of the previously cut LPRMs, however, is a different matter. For example, NUSCO's 1987 bid specification indicates that the pool contained five containers of hot ends from 96 LPRMs.[105] WasteChem reported, however, that it shipped, in addition to the 15 full-length LPRMs, hot ends from 98 LPRMs, which it found in nine "baskets" and three "inserts."[106] Moreover, the identity and source of the cut LPRMs in these baskets and inserts could not be determined with certainty.[107] Given the limited number of LPRMs shipped in the 1985 shipments to Hanford (38 in the first shipment and 8 in the third shipment), and the fact that 38 of these were cut by GE in 1985,[108] the 98 (or 96) segmented

LPRMs shipped in 1988 were most likely cut during the 1979 or 1984 LPRM cutting operations. As discussed earlier, a relatively inexperienced contractor work force performed the September to October 1979 LPRM cutting operations. (The 1984 LPRM cuttings occurred on only two days in August 1984, and were performed by NNECO operators.)[109] Thus, if in 1979 or 1984, workers cut the fuel rods by mistake and placed them in any of the twelve baskets and inserts found by WasteChem, the rods could have been inadvertently shipped to Barnwell in 1988.

The loading procedures used by WasteChem would probably not have led to the identification of the fuel rods, if they were in the containers of cut LPRMs. WasteChem did not attempt to verify the identity of the LPRM segments or perform a radiological survey of each piece. Rather, they surveyed each of the twelve containers as a whole, and then placed the contents of each container into a shipping liner.[110] Specifically, WasteChem loaded the contents of six of the twelve baskets and inserts of LPRMs in the CNSI 3-55 liner, and the remaining six baskets and inserts into four of the six TN-8L liners.[111] Records show that approximately two-thirds of the old LPRM segments were placed in the CNSI 3-55 liner. The remaining one-third were dispersed in four of the TN-8L liners.[112]

WasteChem did, however, measure the total length of LPRM hot end material in each container before loading it into a liner. They performed this measurement to determine the number of fission chambers being shipped. The total number of feet of LPRM hot sections measured and shipped by WasteChem is the equivalent of 90 LPRMs.[113] Analysis Unit 1's LPRM history indicates, however, that there were <u>less than</u> 90 LPRMs actually available for shipment. Indeed, GE records indicate that between four and six LPRMs, or segments of LPRMs, had been previously shipped to GE Vallecitos in 1972 for testing, unbeknownst to NNECO reactor engineers in 1988.[114] NNECO records do not reflect this shipment. Additionally, after the 1988 shipments, NNECO found three additional LPRMs in the pool that it believed had been shipped in 1988.[115] Also, at some point after the 1988 shipment, WasteChem unexpectedly found an unidentified quantity of LPRMs sections in a container with fission chambers.[116] Thus, if WasteChem accurately measured an amount of material equal to the length of 90 LPRMs before the May 1988 shipments, or if it shipped 98 LPRMs as it indicated in its final report, a substantial portion of that material must have been something other than LPRMs.

The investigation revealed no direct evidence that the fuel rods account for the additional material shipped. But, the discrepancy at least suggests the possibility that the fuel rods could have been inadvertently included in the shipment. More important, the inclusion of the contents of the old baskets and inserts with somewhere between 90 and 98 LPRM's worth of segmented material identified as LPRMs created a substantial opportunity to have inadvertently shipped the fuel rods if they were cut previously. Again, however, the evidence is not sufficiently convincing to support a conclusion that the rods were included in this shipment.

The 1989 and 1990 Shipments

After the May 1988 shipments, NNECO conducted the planned re-racking of the Unit 1 SFP. Soon after the re-rack was completed, NNECO performed another clean-up of the pool beginning in the Fall of 1989. That clean-up effort culminated in Unit 1 shipping four shielded casks to Barnwell in late 1989 and 1990. The investigation did not produce clear and convincing evidence that any of these shipments included the two fuel rods. One principal discrepancy in the May 7, 1990 shipment (the third shipment), however, causes that shipment to be a potential explanation for the disposition of the fuel rods.

At the conclusion of the 1988 clean-up campaign, NNECO managers believed that all LPRMs had been shipped off-site, with the exception of the fission chambers cut from 46 LPRMs in 1985 (and possibly 1984).[117] However, what was believed to be an LPRM segment 8 to 12 feet long was noted during the 1988 re-rack project.[118] Accordingly, data provided to vendors bidding on the 1989 clean-up effort indicated that the contractor would be required to ship, among other things, 184 (4x46) fission chambers and one 12 foot LPRM segment.[119] As noted above, a November 1, 1988 radiation survey indicated that three LPRMs remained in the pool after the 1988 shipments. WasteChem's proposal reflected the intent to ship three LPRMs. Additionally, an unsigned, undated letter from WasteChem indicates that WasteChem experienced delays in its performance under the contract because "extra LPRM sections in the container with 184 fission chambers required processing, and additional handling."[120] The evidence indicates that WasteChem did not ship the three LPRM segments.[121] Nor does the evidence indicate whether the "extra LPRM sections" were, in fact, confirmed to be LPRMs, whether WasteChem assumed them to be LPRMs because they were in a container with fission chambers, or whether they were actually shipped. The absence of any other information clearly precludes reaching any conclusion about the identity of these items or a conclusion about the likelihood that the shipment contained the fuel rods.

Of course, the presence of LPRMs after the 1988 shipments is not necessarily suspicious. But, their presence in the pool after NNECO believed that it had shipped all LPRMs adds additional evidence that the objects shipped in 1988 were not LPRMs, as workers believed at the time. Regardless, the uncertainty of the true identity of these items contained in the box of fission chambers in the third shipment precludes a conclusion that there is clear and convincing evidence, one way or the other, about the contents of that shipment.

The 1992 Shipments

In 1992, Unit 1 again hired WasteChem to make three shielded shipments from the Unit 1 SFP to the LLRW facility at Barnwell. WasteChem used the TN-RAM cask for all three shipments.[122] Because of its limited size, this cask and, thus, these shipments could not include full-length fuel rods.[123]

Of the three shipments, only the shipment of December 8, 1992 (the second shipment) provided a reasonable opportunity for segments of the two fuel rods to have been included. And, even for that shipment, the possibility does not appear to be great, but it cannot be discounted completely.

The opportunity for workers to have inadvertently loaded the fuel rods in that shipment arises because that shipment included the contents of a 12"x12"x 42" stainless steel box, which according to the bid specification and a SFP Inventory Log, contained "miscellaneous trash [measuring] 150R/hr."[124] The Radiological Engineering Section Supervisor indicated in an interview, however, that the container actually included old LPRM pieces.[125] The waste characterization for this shipment, prepared by the Radiological Engineering Section Supervisor, indicates that LPRM pieces, the equivalent of three LPRMs, were included in this shipment.[126] He based this conclusion on the word of the then Reactor Engineer, who informed him that the items were cut-up LPRMs.[127] The actual identity of the items in the box is uncertain because individual pieces were not radiologically surveyed.[128] Rather, workers surveyed only the external surface of the box.[129] If the Reactor Engineer was correct, those LPRMs would have been older LPRMs that were not disposed of in earlier shipments.[130] This provides additional evidence that the segments shipped in 1988 may not have been all LPRMs.

Indeed, the evidence is clear that the box did not include LPRMs recently removed from the core during the immediately preceding outage. The six LPRMs that were removed from the core, during the 1991 outage, were processed in accordance with station procedure, and then tied to the side of the pool in approximately 26-foot long segments that still had the hot and cold sections joined.[131] The waste characterizations for the second and third TN-RAM shipments account for each of the six full-length LPRMs removed during the 1991 outage.[132]

But, because of the possibility that workers in the late 1970s may have inadvertently cut the fuel rods believing them to be LPRMs, and because the contents of the box of old LPRM pieces were not verified before shipment, the investigation could not exclude the possibility that segments of the fuel rods were included in the TN-RAM shipment of December 8, 1992.

The 2000 Shipments

In anticipation of decommissioning, Unit 1 hired NUKEM, the successor of WasteChem, to conduct a series of shipments to the LLRW facility at Barnwell in 2000.[133] Specifically, Unit 1 made six shielded shipments, five in a TN-RAM cask, and one in a CNSI 8-120B cask.[134]

The investigation concluded that the fuel rods were not included in the first three TN-RAM shipments or in the CNSI 8-120B shipment. Additionally, given the size of the TN-RAM[135] and CNSI 8-120B[136] casks, full-length rods, either alone or in an 8-rod container, could not be loaded.[137]

The final two TN-RAM shipments probably do not include the two fuel rods, either, but the evidence is not sufficiently clear and convincing to reach that conclusion. For example, the October 1999 bid specification soliciting proposals for these shipments identified a single 72-inch section of an instrument dry tube for shipment.[138] That same bid specification also indicated that there were two boxes containing cut-up segments of 12 instrument dry tubes in the pool to be surveyed and considered for shipment. (Ultimately, the radiation levels of these tubes precluded their shipment.) What is potentially significant, however, is the fact that, by 2000, Unit 1 had discharged only 12 dry tubes from the reactor vessel.[139] Thus, if the bid specification is accurate in saying that the two boxes in the SFP contain the segments of 12 instrument tubes, the 72-inch "instrument dry tube" also identified for shipment cannot be an instrument dry tube. This does not mean that the item was a fuel rod. It may have been one of the source holders removed in 1978.[140] Because dry tubes and source holders have similar diameters of about 0.7 inch,[141] which is also similar to the 0.57 inch diameter of a fuel rod, the possibility exists that the "dry tube" is one of the source holders. Other than the physical similarity between an instrument dry tube and a fuel rod, and the potentially erroneous identification of the 72-inch item, however, there is no evidence that suggests that this item was, in fact, part of one of the MS-557 fuel rods. Moreover, the shipping records do not clearly indicate that this 72-inch item, whatever it was, was actually shipped. In fact, none of the items listed in any inventory identify this 72-inch object as having been shipped.

The final TN-RAM shipment contained an additional anomaly. That shipment included an unidentified "bucket of debris."[142] Having no description of the contents of the bucket, the size of the bucket, or the length of time the bucket was in the SFP makes any pronouncement about its contents little more than speculation. Some evidence suggests that the bucket contains pieces of boron tubes, but this evidence is not conclusive. Additionally, a radiological survey of the bucket indicates that the contents were 125 R/hr,[143] which does nothing to either confirm or exclude the presence of cut fuel rods. Regardless, the survey results are suspect because the survey is dated one week <u>after</u> the shipment left Millstone.[144] This evidence is far too unreliable to support any conclusion about the presence of the fuel rods in this final shipment.

4.1.2.4 The Spent Fuel Pool

Concurrent with the investigation of the scenarios described above, the team conducted an inspection of the Unit 1 spent fuel pool and the control rod blade guides in the reactor vessel cavity to determine whether the fuel rods remained in some undocumented location. To conduct this inspection, qualified team members prepared and implemented a Global Search Plan.

The Global Search Plan established a comprehensive list of locations capable of physically accommodating the two rods. After identifying these areas, the team developed appropriate inspection plans and, using underwater cameras, a robot, and various other forms of equipment, the team examined the accessible locations of the spent fuel pool, including the free space in the pool.

Although that plan required the inspection of many areas in the spent fuel pool, it did not contemplate the physical inspection of every fuel assembly or item in the pool. Indeed, inspectors checked the vast majority of the assemblies by observing the upper tie plates to determine if there was any evidence that the assembly had been disassembled after it left the core for the last time. That inspection searched for, among other things, assemblies with new or missing lock tab washers or new nuts. If an assembly did not have such hardware, the team concluded that the two fuel rods could not have been inserted in that assembly because of the absence of evidence of disassembly. On the other hand, if an assembly exhibited signs of disassembly, the team conducted additional work to determine if the assembly contained the correct number of fuel rods.

In addition to searching for signs of disassembled fuel assemblies, the team identified certain locations in the pool as potentially having a greater likelihood of containing one or both of the two fuel rods. For example:

- GE conducted an inspection of the parent assembly, MS-557, and confirmed that the center spacer capture rod and a tie rod were actually missing from that assembly.

- The team considered SRP 2D, the assembly that GE used to house the spent segmented test rods, as a likely place to store two separate fuel rods. GE inspected that assembly and concluded that all of the rods present were part of the segmented test rod program, not the rods from MS-557.

- The team also considered it possible that the two fuel rods could be stored in MS-508, a damaged fuel assembly that rests in a container in a control rod storage rack in the spent fuel pool. The team used a camera to examine the assembly, its container, and the space around the container. That inspection showed all 49 fuel rods from that assembly to be in place.

- The team conducted a visual inspection of MSB-125, the fuel assembly that housed segmented test rods when in the core. The assembly contains the expected number of full-length fuel rods and dummy rods. The observation of the upper tie plate revealed that the assembly had not been disassembled since it was last in the core. Accordingly, it could not contain the two rods from MS-557.

- The team inspected those assemblies in the spent fuel pool that are "raised," i.e., they are not fully seated in the storage rack, to see if a fuel rod or fuel rod segment caused the assembly to be raised. The inspectors lifted the assemblies and inspected the vacated space in the storage rack, but did not find the rods.

- The team conducted an inspection of the free space in the pool, including the areas under and between the fuel storage racks.

The inspections of the specific locations, the fuel assemblies, and the free space in the spent fuel pool did not locate the two fuel rods.

Although comprehensive, the execution of the Global Search Plan does not permit a conclusion that the two fuel rods, or segments of the rods, are not in the reactor cavity or spent fuel pool. That final determination will not be possible until all 2884 fuel assemblies and obstructions are inspected and ultimately removed from the pool. As noted, the Global Search Plan addressed the areas that the team considered capable of accommodating full-length or large segments of fuel rods. It did not address every possible place that the rods, or smaller rod segments could be. Nor did it address some less likely places because of the perceived low likelihood of locating the rods and/or because the inspection could result in a significant radiation exposure for the inspectors. For example:

- The team did not take apart the eight-by-eight fuel assemblies to inspect the water rods in those assemblies to see whether a fuel rod had been inserted in that space. A fuel rod can physically fit in that space and one GE employee recalled storing single fuel rods in water rods at another site. The visual inspection of the assemblies looking for some sign of post-irradiation work on the assemblies, however, provides some assurance that the rods were not placed in a water rod.

- Likewise, the team did not physically disassemble and inspect the rods of each of the 2884 fuel assemblies in the pool. To disassemble each of these assemblies would require about five years to complete and would involve an exposure of about 2,200 man-rem. Moreover, a rod-by-rod inspection of over 167,000 fuel rods would have an associated risk of a fuel handling accident. To conduct such an inspection, each assembly would have to be lifted from its storage rack location, moved to a fuel prep machine, disassembled, inspected rod-by-rod, reassembled, and returned to its storage rack. Even if safely performed, the effectiveness of the inspection is questionable because it would require the underwater reading of small serial numbers etched around the circumference of the fuel rod's end plug. Difficult under the best of circumstances, years of corrosion product build-up on the fuel rods make accurate readings of the serial numbers even more challenging.

- The team did not inspect the entire length of the channeled fuel assemblies to see whether a segment of a rod was lodged between the channel and the assembly. In thirteen instances, the team raised the assembly somewhat, but not to a height that would permit an inspection of the entire channel. For the remainder of the channeled assemblies, the team used a camera to inspect to a depth of about five feet from the top of the assembly. This depth would have detected a full length rod.

In conclusion, the spent fuel pool inspection was both focused and comprehensive. Its focused inspections targeted MS-508, MSB-125, and SRP-2D, and other likely fuel rod storage locations. Its comprehensive inspections searched the free space in the pool, the floor beneath the fuel storage racks, and other potential storage locations. The results of these inspections establish that, subject to the limitations of each search, the fuel rods are not in locations searched. But given the limitations and conditions discussed earlier, the inspections cannot rule out the possibility that the fuel rods remain in the spent fuel pool. The final answer to that question will only be found when the pool is emptied and its contents transferred to another location or repository.

4.1.2.5 An Examination of the Possibility of Theft or Diversion

Because the investigation did not find clear and convincing evidence that identifies the current location of the fuel rods, some may ask whether the rods were stolen. Certainly, the terrorist attack of September 11, 2001, and the heightened awareness of security matters have the potential to color this discussion in ways that it would not have been had the attack not occurred. But neither the sudden recognition of the vulnerability of our country to terrorism nor the magnitude of the tragedy can be allowed to alter the truth. There is simply no evidence of any sort that suggests that the fuel rods were stolen or diverted.

Soon after the investigation began, the team recognized that regardless of the ultimate outcome of the other scenarios, it should look for any sign of theft. It based this decision solely on the need to safeguard the public. There was no evidence, no suggestion, and no implication of any sort that prompted the inquiry into this topic. Nevertheless, the team created a scenario to examine this issue. Consistent with the process, the team considered the scenario implausible, but, again, because of the importance of this issue from a public health and safety perspective, it began a confirmatory investigation. Unlike other scenario investigations, however, this investigation did not have a shipment, a transfer, a location, or a particular event to investigate. Rather, its task was to determine whether an unknown, unreported theft occurred at an unknown time over a twenty-year period.

Simply stated, the investigation did not reveal a single piece of evidence that even remotely supports an inference, much less a conclusion, that the rods were stolen or diverted. Not one document or interview contains any indication of theft. Indeed, no one interviewed even offered an opinion that the rods might have been stolen.

The investigation, however, did not simply accept the absence of any evidence as proof that theft or diversion did not occur. Rather, the team conducted an assessment of the circumstances and conditions that would affect the Unit's vulnerability, or lack of vulnerability, to a theft of the rods from the spent fuel pool.

A successful theft or diversion of the fuel rods would require the breakdown of multiple, interlocking barriers. An examination of those barriers from May 1979, when GE verified the presence of the rods in the pool, through November 2000, when the Company began its initial investigation, confirms that the barriers were effective. Indeed, there was no time when a failure or weakness existed in all of the barriers against theft or diversion.

To understand the nature of the barriers, and the difficulty inherent in overcoming them, consider how some of the barriers would mutually support each other in preventing the theft of the rods.

First, the nature of the rods themselves makes theft or any unshielded handling inherently risky. As discussed earlier, spent fuel rods are highly radioactive, which means that they cannot be handled without the person taking special precautions to guard against receiving a high (potentially lethal) dose of radiation. This means that if a person tried to remove the rods without placing the rods in a properly shielded cask, the person would receive a very substantial, and potentially lethal, dose of radiation.

Second, because the spent fuel rods are highly radioactive, if someone were to try to steal the rods without the necessary shielding, not only would that person jeopardize his health, multiple radiation alarms on the refuel floor and various other radiation alarms throughout the reactor building would sound, signaling the presence of radiation and triggering a response from the Control Room, Site Security, and Health Physics, and others. Activation of certain alarms on the refuel floor would also trigger other reactions in the operation of various plant systems, such as standby gas treatment and isolation of reactor building ventilation.

Third, if the person were to recognize the need for shielding and try to use a cask of some sort to hold the spent fuel rods, the person would have to obtain a cask of sufficient size, weight, and shielding – not an easy, innocuous, or inexpensive task. Even if such a cask could be somehow obtained without notice, the task of bringing the cask into the reactor building and loading the cask on the refuel floor would be both cumbersome and obvious. Among other things, this activity would require the use of heavy equipment and a crane, and the breach of multiple security barriers and Health Physics checkpoints, as well as the participation of multiple persons, making the clandestine taking all the more risky and all the more unlikely. Additionally, various security barriers and work procedures exist that restrict access only to persons authorized to be in the locations and trained to perform specific work in those locations.

Fourth, any unauthorized work around the spent fuel pool would be subject to discovery by workers, Health Physics technicians, supervisors, operators, and contractors in the area, all of whom are trained to report suspicious activity, particularly unusual activity associated with nuclear fuel. Health Physics personnel in particular, carefully monitored the placement in, and removal of any item from, the spent fuel pool. Moreover, the presence on the refuel floor of an unauthorized cask, the unauthorized removal of material from the spent fuel pool, and the unauthorized loading of the material in the cask would not go unnoticed or unreported. Indeed, the fuel movements and loading operations alone would almost certainly require the assistance of multiple workers. Additionally, Control Room operators have the ability to monitor a television camera that observes activity on the refuel floor. And, operators make periodic rounds of the refuel floor to check on operations, activities, and the equipment in the plant. Security personnel also patrol the area, looking specifically for activities or conditions that are out of the ordinary or that otherwise could affect the security of the plant.

Fifth, security barriers, security alarms, and other measures exist to ensure that unauthorized material does not leave the refuel floor, the reactor building, or the site. Again, the unauthorized removal of a cask or unshielded fuel rods from the refuel floor and the reactor building would require the avoidance of multiple alarms and inspections. Site exit points also contain security measures and radiation alarms.

In short, there are multiple barriers, built to create a defense-in-depth, that would prevent the theft or diversion of the fuel rods.

Two additional reasons support the conclusion that the rods were not stolen or diverted. First, wholly apart from the various radiation, security, and personal barriers that exist to prevent theft, there would be little or no reason for someone to incur the effort and the extraordinary consequences associated with taking two spent nuclear fuel rods. The uranium contained in those rods is far less than that needed to achieve criticality and far insufficient to create a nuclear device or weapon. The rods are simply insufficient in quality and quantity. Moreover, the loss of accountability of these fuel rods occurred over twenty years ago. If a person took the rods when the loss of accountability occurred, it is very likely that the person would have made the taking known in some way by now. Indeed, as mentioned earlier, the highly radioactive nature of spent nuclear fuel makes its retention and actual use extraordinarily difficult, and in fact dangerous, from a practical perspective.

Second, the two spent fuel rods have no economic value. In fact, the radioisotopes found in the fuel rods are largely available in numerous commercial applications around the world and exist in businesses and locations far less secure than a nuclear power plant.

Consistent with this conclusion, since the late 1960s, the NRC (or its predecessor) has collected information about nuclear events involving potential breaches of nuclear security. Of the 1,944 "safeguards" events identified between 1976 and 2000, only thirteen occurred at a U.S. commercial nuclear power facility. Not one of those events involved the theft or attempted theft of nuclear fuel.

Finally, persons in the plant would have no motive to divert or improperly dispose of the rods in some unauthorized manner or in some unauthorized location, even if they could overcome the barriers. The presence of two fuel rods in a spent fuel pool has essentially no impact on the unit, its operations, or the cost of conducting business, either in the short or long-term. Moreover, the barriers and difficulties associated with an unauthorized disposal do not differ in substance from the barriers that prevent theft.

In short, a person attempting the theft or diversion of these rods would be risking almost certain detection and life-threatening health effects for items of virtually no value. There is simply no evidence that the two fuel rods were stolen or diverted.

4.2 Conclusions of the Investigation

The investigation did not produce clear and convincing evidence of the specific location of the two fuel rods from MS-557. The investigation found no credible evidence to believe, however, that the fuel rods are in any place other than the four locations discussed above. Specifically, the two fuel rods are in the Unit 1 spent fuel pool, the GE Vallecitos facility, the U.S. Ecology LLRW facility at

Richland, Washington, or the Chem-Nuclear LLRW facility at Barnwell, South Carolina.

The imperfect nature of the body of evidence precludes any attempt to assign reasonable or meaningful probabilities to the four locations. Such an assignment would be highly subjective, and of questionable value. Nevertheless, some better understanding of the evidence is possible.

The likelihood that the fuel rods remain in the spent fuel pool is low. Indeed, the comprehensiveness and quality of the inspections strongly suggests that the fuel rods are not in the pool. The inspections addressed both the most likely places that the rods would be stored, as well as the places that full-length rods (or large segments of fuel rods) could be stored. But the best reasonable efforts of the inspection team were not able to examine all areas of the pool or all areas where smaller segments of cut rods might have been placed. Additionally, safety considerations, pragmatism, and prudence precluded a rod-by-rod inspection of all fuel rods in the pool.

So too, the fuel rods are probably not at the GE Vallecitos facility. Nevertheless, the lack of any confirmed sighting of the rods in 1980, the timing of the April 1980 shipment, and the appearance of many unanswered questions about the April 1980 shipment prevent a categorical finding that the rods were not shipped. To be sure, the consistency of DOE/NRC Form 741 with the known weights of the segmented test rods being shipped, the GE receipt inspection of the arriving cask, as well as the GE testing of the contents of the shipment, provide strong evidence that the rods are not at GE Vallecitos. The GE receipt records for the non-fuel hardware, however, are not fully consistent with the shipping records. The inconsistency does not establish that the rods were shipped, but the appearance of discrepancies in the record of the shipment's contents precludes unconditional reliance on the documents. Perhaps most important is the difference between the weight of the SNM shipped (2.4 kg) and the entries on two NRC documents that indicate that GE received a greater quantity of SNM.

These facts, standing alone, require that the Vallecitos facility remain as a possible – albeit unlikely – location of the rods. The loading of the segmented test rods in this shipment on May 5, 1979, and the unexplained movement of MS-557, the parent assembly of the two fuel rods, to the fuel prep machine on that same day, creates another potential link between this shipment and the two fuel rods. The disappearance of the two fuel rods from all known documents later that year, and the disappearance of the two rods from the memories of those who should have seen or remembered the rods, adds to the uncertainties associated with this shipment. Again, the compilation of these matters does not establish that the rods are at Vallecitos. The possibility that they are, however, cannot be dismissed.

There is no clear and convincing evidence, and in fact, no substantial credible evidence, proving that the fuel rods were shipped to the U.S. Ecology LLRW facility at Hanford. An opportunity for the inadvertent shipment of the rods, however, existed to some small degree in three 1985 shipments. The likelihood of an inadvertent loading of the rods in the first two shipments, however, is not significant. GE's loading of the first shipment and the relative certainty regarding the identity of items bearing any resemblance to fuel rods in the second shipment, reduce considerably the likelihood that either of these shipments contained the fuel rods. For the third shipment, only the inclusion of the hot sections of eight LPRMs of uncertain origin causes this shipment to rise modestly above the others in likelihood. The identity of those LPRM hot sections cannot be established with certainty because, as noted, the source of these items could not be determined. Given the relatively small quantity of LPRM sections included in this shipment, however, the likelihood of inclusion of the fuel rods is not substantial.

So too, there is no clear and convincing evidence that the fuel rods were shipped to the Chem-Nuclear LLRW facility at Barnwell. Of the many shielded shipments to Barnwell, and the three shipments to Hanford, however, the two TN-8L shipments and the one CNSI 3-55 shipment to Barnwell in May 1988 stand out as having a significant opportunity to contain the fuel rods.

In those shipments, WasteChem workers loaded the segments of somewhere between 90 and 98 items described as LPRM hot ends. A review of the total length of LPRM hot ends measured by WasteChem, however, reveals that the shipments included items that could not be LPRMs, given the total number of LPRMs that had been removed from the core and were available for shipment and the number of LPRMs that remained in the pool after the 1988 shipments. That disparity provides the greatest opportunity for the fuel rods to have been included inadvertently among the LPRM hot end sections.

The evidence is clear that, regardless of the precise number of LPRMs included in those shipments, the vast majority of these LPRMs were from the 1979 cutting campaign discussed previously. The records also show clearly that neither NNECO nor WasteChem knew precisely the identity or characteristics of the items being loaded as LPRMs, which they had retrieved from old containers that had been stored in the pool since at least 1979. If the contractors from 1979 mistakenly cut the fuel rods, believing them to be LPRMs, and placed them in containers with LPRMs, it is likely that those cut rods were included in one or all three of the May 1988 shipments.

When NNECO completed the 1988 shipments, engineers responsible for the spent fuel pool believed that they had shipped all LPRMs. The records from the shipments in late-1989 and 1990, however, indicate that LPRMs remained. In fact, WasteChem records show that they encountered "extra LPRMs" in performing work associated with the 1989 and 1990 shipments to Barnwell. The record of those shipments, however, does not disclose any significant opportunities to have mistakenly shipped the fuel rods, but the appearance of extra LPRMs could be an indication that the items previously shipped as LPRMs were not, in fact, LPRMs.

One of the three 1992 shipments to Barnwell provided another – but a significantly diminished – opportunity to ship the fuel rods. The December 8, 1992, shipment of a TN-RAM cask included the contents of a box that engineering personnel believed to be cut-up LPRMs. The actual identity of the contents, however, is uncertain. Again, there is no evidence that this box actually contained the fuel rods, but if they had been cut and were inadvertently placed in the box, they could have been mistakenly shipped. Compared to the 1988 shipments, this shipment is significantly less likely as a possible explanation for the disposition of the rods.

Two of the six shielded shipments to Barnwell in 2000 contain anomalies in the documentation or a lack of clarity in the identification of the items being shipped. For example, the final shipment included an unidentified "bucket of debris" in the inventory with a survey level that neither supports nor refutes the possibility that the bucket contained segments of the fuel rods. That sketchy evidence precludes the exclusion of this shipment from consideration, but the likelihood that this shipment inadvertently contained the fuel rods is slight.

As discussed at the outset, the identification of the 1988 shipments to Barnwell as a possible explanation for the disposition of the fuel rods does not mean that the rods are at Barnwell. Neither the documents nor the interviews provided any evidence actually placing the fuel rods in these – or any other – off-site shipments. The evidence is not sufficiently clear and convincing to establish that the fuel rods are at Barnwell and the conclusions of this report must be read in that context.

4.3 Health and Safety Considerations

Because the investigation was not able to exclude the LLRW waste facilities at Hanford and Barnwell as possible locations for the two fuel rods, it is necessary to consider the potential health and safety effects, if any, of the shipment and disposed of the rods.

Wastes shipped to LLRW facilities are stored in liners transported by specially designed and licensed shipping casks. These low-level waste shipments are surveyed at the shipper's location before departure to ensure that radiation levels meet federal Department of Transportation and NRC standards designed to ensure the protection of public health and safety during shipment. The radiation levels of the fuel rods, if shipped, would fall well below those safety thresholds. Indeed, if shipped, the radiation levels of the fuel rods would have been lower than the radiation level of some of the other irradiated material authorized to be included in the shipment.

Upon arrival at the low-level waste disposal facilities, the liners were removed from the shipping cask and quickly deposited in burial trenches and covered with earth to shield workers and the public from radiation.

The burial of the rods at either LLRW facility would not increase the risk to the health and safety of the public, site workers, or the environment. Both facilities are designed and licensed to safely dispose of all radionuclides contained in the fuel rods. Indeed, all of the radionuclides contained in the two fuel rods are already present in the inventories of those facilities. Moreover, the current inventories of these radionuclides at the facilities far exceed the amount of radionuclides contained in the fuel rods. Thus, even if shipped, the presence of the rods would add only a small amount to the present inventories at the facilities. Although not licensed to accept these materials in the form of spent nuclear fuel, the addition of the rods should not cause either facility to have radionuclides that would change the site's performance assessment for continued long-term disposal. For this reason, the facilities' environmental and safety programs, which assure the safety of the long-term disposal of these radioactive materials, are adequate to account for the relatively small amounts of radioactive material found in the two fuel rods. The sites' operations and programs are also subject to extensive state regulatory oversight, independent assessments, and periodic inspections, providing further assurance of ongoing environmental protection. Indeed, none of the numerous assessments and inspections at either facility have revealed any environmental or other problems that could be attributable to the possible burial of two spent fuel rods. The NRC also provides additional oversight by conducting independent program evaluations of the States' overall regulatory programs and the Low-Level Waste Programs for both South Carolina and Washington.

ENDNOTES

1 Letter, from J. Kufel (NU) to A. Giambusso (USAEC), Abnormal Occurrence No. AO-72-22, , September 11, 1972, (Reference 1).

2 Special Report - Chloride Intrusion Incident, December 11, 1972, (Reference 2); Kardex Card, Fuel Assembly MS-557 Scrap, (Reference 3); MBA Transfer Form, Fuel Bundle Move for Inspection MS-557, October 6, 1972, (Reference 4).

3 Memorandum (hand-written), from H.W. Tamai (GE) to M. Hills and S. Scace (NU), Status of Fuel Inspection Area, undated, (Reference 5).

4 *Id.*

5 Field Notes, 1974 Fuel Reconstitution, by T.G. Piascik, beginning April 18, 1974, (Reference 6).

6 Tamai Memorandum, (Reference 5).

7 Memorandum, Fuel Rods, from T.G. Piascik (NU) to File, May 15, 1979, (Reference 7); Letter, from R.J. Herbert (NU) to D.T. Weiss (GE), Isotopic Composition of Fuel Bundle MS-657 (sic) Fuel Rods, May 29, 1979, (Reference 8).

8 Piascik Memorandum, (Reference 7).

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10 *Id.*

11 *Id.*

12 *Id.*; Kardex Card, MS-557 Fuel Rods, (Reference 9).

13 Kardex Card, Fuel Assembly MS-557 Scrap, (Reference 3).

14 Bundle Loading Record, attachment to Piascik Memorandum, (Reference 7).

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16 Abnormal Occurrence No. AO-72-22, (Reference 1); Special Report – Chloride Intrusion, (Reference 2).

17 *Id.*

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25 Interview of T.G. Piascik, June 27, 2001, (Reference 13).

26 Piascik Memorandum, (Reference 7).

27 Herbert Letter, (Reference 8).

28 Kardex Card MS-557 Fuel Rods, (Reference 9).

29 Piascik Memorandum, (Reference 7).

30 *Id.* (emphasis added.)

31 Millstone Unit 1, GE Cycle 6 Summary Report, Doc. No. 22A6387, Sheet No. 36; GE Cycle 7 Summary Report, Doc. No. 22A6855, Sheet No. 30, (Reference 14).

32 *Id.*

33 Memorandum, from A.W. Cretella/C.D. Mandigo to R.J. Herbert, Audit of SNM Inventory and Control Procedure RE 1001, November 15, 1979, (Reference 15).

34 Index of Millstone Unit 1 Radiation Work Permits, September-October 1979; RWP 797621, September 11, 1979, (Reference 16).

35 Interview of B. Perkowski, May 31, 2001, (Reference 17); Interview of D. Sadowski, June 22, 2001, (Reference 18); Interview of B. Spath, June 22, 2001, (Reference 19).

36 Letter, from B.J. Reckman (NUS) to R.J. Factora (NUSCO), Final Draft of Millstone Point 1 Environmental Impact Statement, February 27, 1976 (Excerpt), (Reference 20).

37 Millstone Unit 1 Spent Fuel Pool Map, End of Cycle 6, February 26, 1980, (Reference 21).

38 *Id.*

39 Memorandum, from T.G. Piascik (NU) to Reactor Engineering SNM File, Spent Fuel Pool Inventory, May 9, 1980, (Reference 22).

40 Interviews of M. Bigiarelli, May 30, 2001, (Reference 23), June 28, and June 29, 2001, (Reference 24); Interview of G. Harran, June 18, 2001, (Reference 25); Interviews of G. Newburgh, June 13, 2001, (Reference 26) and June 29, 2001, (Reference 27); Interview of T. Piascik, June 27, 2001, (Reference 13).

41 *Id.*

42 *Id.*

43 Millstone Unit 1 SFP Map, February 26, 1980, (Reference 21); Memorandum, Unit 1 SFP Inventory, May 9, 1980, (Reference 22).

44 Memorandum, from T.G. Piascik (NU) to Reactor Engineering SNM File, Spent Fuel Pool Inventory, October 8, 1980, (Reference 28).

45 Interview of T.G. Piascik, June 27, 2001, (Reference 15).

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47 Piascik Memorandum, (Reference 7).

48 Memorandum (handwritten), Re: GEB 20, from D.M. Johnson to NNECO, July 20, 1979, (Reference 30).

49 Spent Fuel Shipment Data Sheet, December 28, 1979, (Reference 31).

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51 *Id.*

52 *Id.*

53 DOE/NRC Form 741, Nuclear Material Transaction Report, SRP Retrieval, 4th Shipment, April 30, 1980, (Reference 32).

54 *Id.*

55 *Id.*

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Reference 89	Memorandum, from J.W. Heard, FRAP-01-012, Fuel Design Configurations for MP-1, April 9, 2001.

Reference 90	Specification P-MI-ME-1004, MP-1 – Request for Services; Personnel, Equipment and Labor Services for Spent Fuel Pool Cleanup, Rev. 1, October 6, 1999.
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Reference 92	Memorandum, from E. Biemiller, FRAP-01-083, Millstone Unit 1 Start-up Sources, September 12, 2001.
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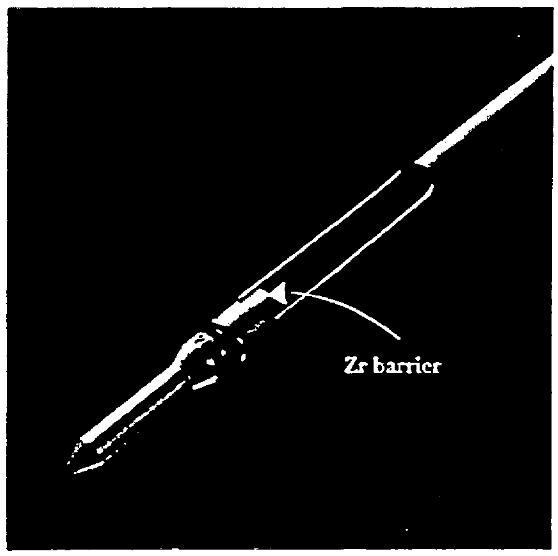
APPENDIX

APPENDIX INDEX

SECTION 1

FIGURES

Figure 1



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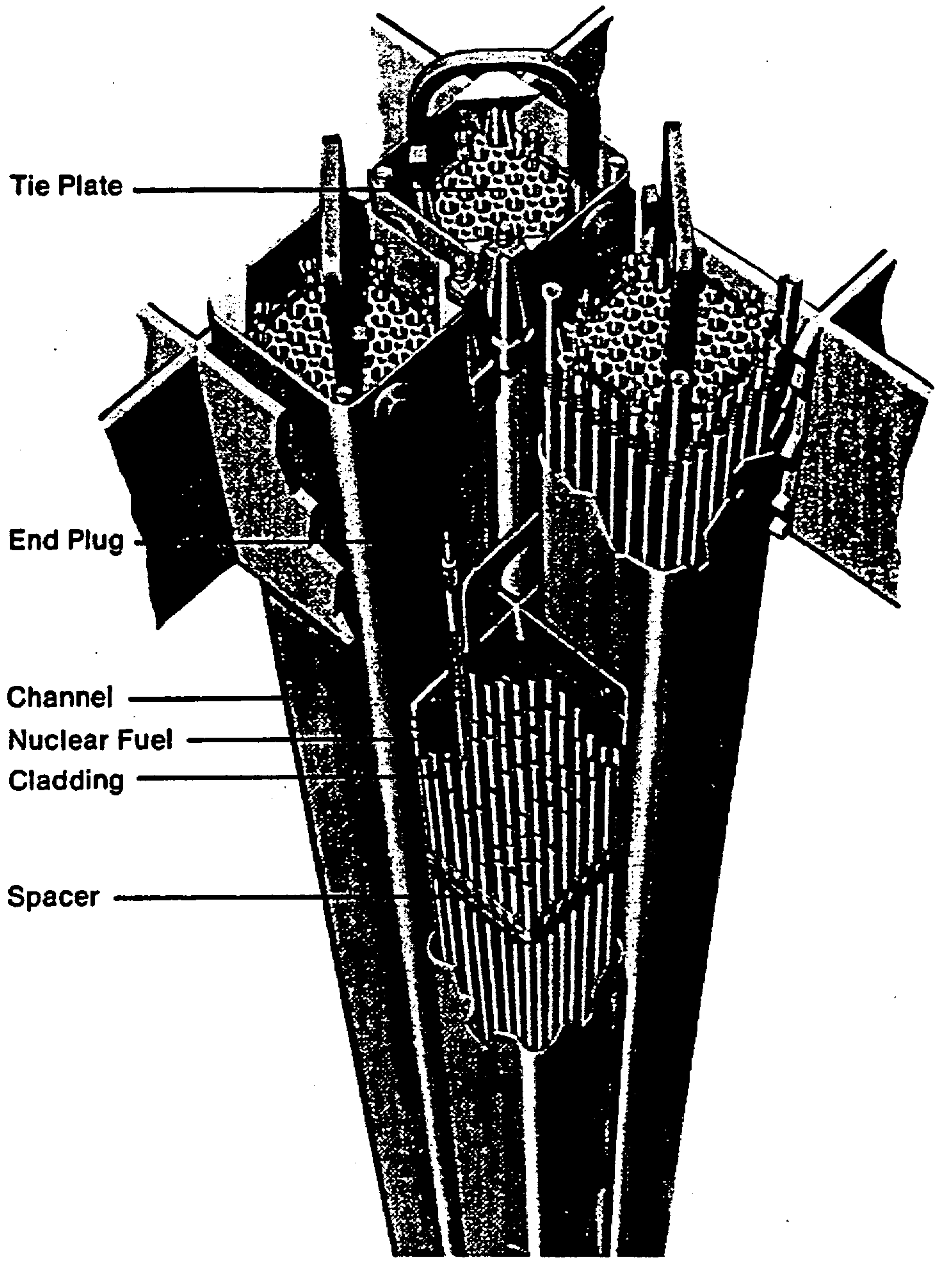

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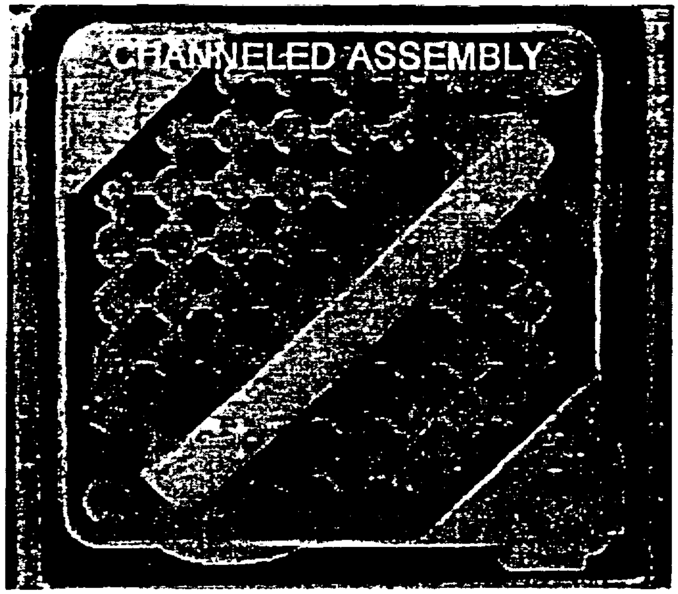

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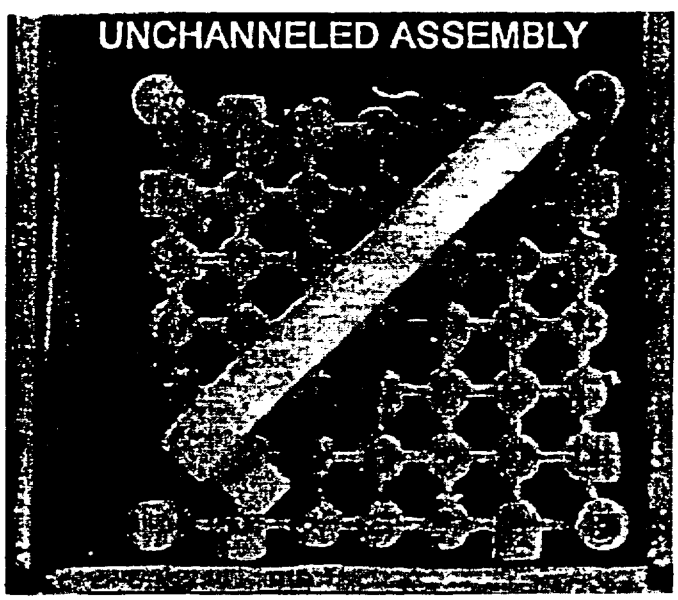

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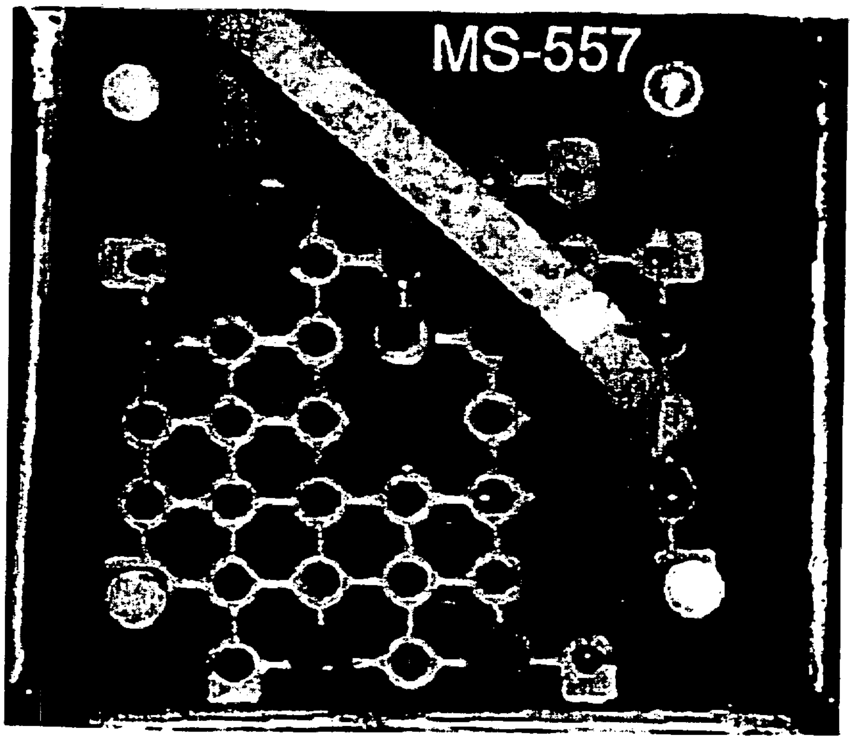


SECTION 2

PHYSICAL INSPECTIONS PERFORMED BEFORE FORMATION OF THE FRAP

Physical Inspections Performed Before Formation of the FRAP

The FRAP did not initiate this investigation. NNECO made substantial efforts and considerable progress in uncovering relevant information months before the formation of the Project.

Early NNECO Physical Inspections

NNECO's initial fuel assembly and spent fuel pool inspections focused on three areas. One area involved a broad search of the pool, including non-standard storage locations, such as behind and under spent fuel storage racks. To perform these spent fuel pool inspections, NNECO contracted ROV Technologies Inc., a group with significant experience in spent fuel pools and reactor video inspection. The second area involved inspections of fuel assemblies MS-557, MS-508 (a previously damaged fuel assembly), and storage assembly SRP-2D. GE performed the fuel assembly inspections under NNECO oversight. NNECO conducted the third set of inspections of other areas and miscellaneous locations.

MS-508

NNECO selected fuel assembly MS-508 for inspection as a potential location because it had been damaged when dropped during the refueling outage of 1974. The fuel assembly itself does not have sufficient extra space in its grid lattice to store a missing rod. However, it sits in a fuel canister designed to hold damaged fuel assemblies. The damaged fuel container is stored in an area of the pool away from the other spent fuel assemblies in a rack designed to hold control rod blades. The damaged fuel container in which MS-508 sits has space sufficient to store one or both of the missing fuel rods. On November 16, 2000, NNECO contractors visually inspected fuel assembly MS-508 with a color camera system without disturbing the damaged fuel assembly. However, the presence of rope and wire on the top of the damaged fuel assembly left over from rigging the damaged assembly into the secure storage location limited visibility.

MS-557

Assembly MS-557 is the original parent assembly of the two missing fuel rods. Prior to November 16, 2000, NNECO contractors visually inspected MS-557 with a color camera without disturbing the fuel assembly. The inspection showed that the fuel assembly's upper tie plate had been modified and that the center spacer capture rod protruded above the upper tie plate. The spacer capture rod appeared to be clean and free of the corrosion layer expected of an irradiated fuel rod. This suggested that it was not the original center spacer capture rod, but was a dummy rod. The inspection also revealed that the lattice location of the missing tie rod was empty. On December 5, 2000, a GE team began additional inspections of MS-557. The fuel assembly was moved to a fuel preparation machine where visual inspections confirmed that the missing tie rod was not located elsewhere in the assembly. To verify the identity of the center spacer capture rod, GE removed the assembly's upper tie plate and withdrew three fuel rods to allow visual inspection of the entire length of the center spacer capture rod. GE observed the rod over its full length; no indications of exposure to a reactor environment were observed. Additionally, the installed rod, which protruded above the upper tie plate, was observed to be measurably longer than the dimensions of the original, now missing, spacer capture rod. GE assembled MS-557 and it was returned to its storage location in the spent fuel storage racks.

SRP-2D

The Unit 1 SFP also contains a spent fuel storage assembly, similar to a spent fuel assembly, left behind as a result of GE's segmented test rod program. In the 1970s and 1980s, GE carried out a program of inserting segmented test rods ("STRs") in a specifically designated fuel assembly, MSB-125, subsequently removing the rods from that assembly, and shipping some of them to VNC for testing. GE placed those spent STRs not returned to VNC for testing in assembly SRP-2D for storage.

On December 5, 2000, assembly SRP-2D was also taken to the east fuel prep machine for inspection by GE. The inspections involved using a video system to observe the interior of the fuel assembly and to verify that the fuel rods present in the assembly matched those reflected in plant records. The fuel assembly was noted to have 15 segmented fuel rods and four full-length rods from the STR program. No other rods were observed in the fuel assembly.

SECTION 3

PERSONNEL INFORMATION AND ORGANIZATION STRUCTURE

Organization Structure and Personnel Information

Key Personnel

Frank C. Rothen
Mr. Rothen serves as the Executive Sponsor for the investigation on behalf of Northeast Utilities Service Company ("NUSCO"). As the Executive Sponsor, he is the senior manager on the project and primary point of contact to the Unit 1 licensee, Dominion Nuclear Connecticut ("DNC"). When named Executive Sponsor, Mr. Rothen was Vice President - Nuclear Work Services for Northeast Utilities Service Company.

Robert V. Fairbank
Mr. Fairbank is the Project Manager for the FRAP investigation. His responsibilities include management of the Investigation Team and its day-to-day operations. He possesses over 30 years of engineering and management experience in the nuclear power generation industry, with major experience in engineering, project management, and regulatory assurance.

Richard N. Swanson, P.E.
Mr. Swanson is the senior member of the Root Cause Assessment Team. He is a licensed Professional Engineer (mechanical) possessing 16 years experience with nuclear utilities (11 years in senior management positions) and 6 years as an independent consultant.

L. Joseph Callan
A member of the Independent Review Team ("IRT"), Mr. Callan has held several senior management positions within the U.S. Nuclear Regulatory Commission ("NRC") and has more than 30 years of nuclear experience. He has been a NRC Regional Administrator and the Executive Director of Operations. At present, he serves as a consultant to the nuclear industry and serves on several top-level oversight and advisory boards.

Bruce Hinkley
Mr. Hinkley is the lead member of the IRT. He has more than 25 years of nuclear industry experience and has held senior positions with nuclear utilities and engineering organizations. He is currently the Manager of Nuclear Projects with Stone and Webster.

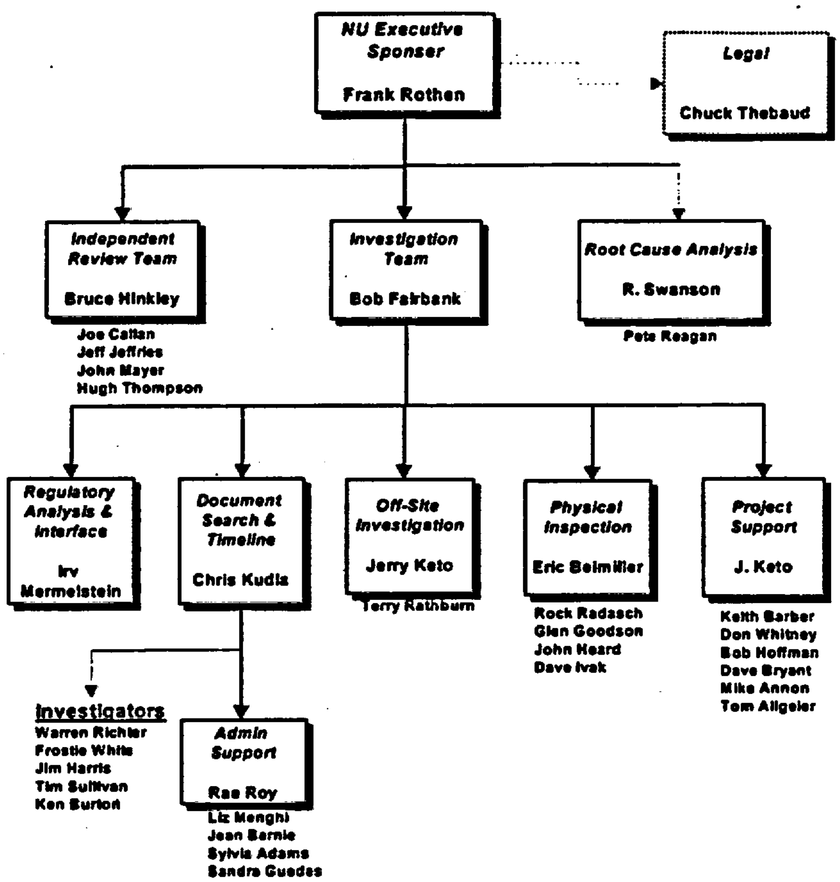
Jeffrey D. E. Jeffries, Ph.D., P.E.
A member of the IRT, Dr. Jeffries has 33 years of nuclear experience and is an internationally recognized expert in the areas of nuclear safety and applied risk assessment. He has been a senior manager with a nuclear utility, the Electric Power Research Institute, and a consulting firm. In addition, Dr. Jeffries has

taught nuclear engineering at two major universities. He has a Ph.D. in nuclear engineering and is a registered professional engineer.

John Mayer
A member of the IRT, Mr. Mayer has over 15 years expertise in the specialized field of nuclear fuels reliability and spent fuel characterization. He provides fuel and core component design review, fuel performance monitoring, failure prediction analysis, Special Nuclear Materials reports, and spent fuel inspection and characterization services. He also conducts fuel fabrication technical assessments at various vendor facilities, acting both as an Independent Technical Auditor and Technical Specialist during quality assurance audits.

Hugh L. Thompson, Jr.
A member of the IRT, Mr. Thompson has over 35 years of nuclear experience including several senior management positions with the U.S. Nuclear Regulatory Commission. He was Director of the Office of Nuclear Materials Safety and Safeguards and served as the Deputy Executive Director for Regulatory Programs. At present, he serves as an expert consultant to the nuclear industry in the areas of nuclear safety, nuclear waste management, and licensing.

FRAP Organization Chart



SECTION 4

FRAP GOVERNING DOCUMENTS

FRAP Governing Documents

M10063 Project Description

NNECO initiated the Fuel Rod Accountability Project ("FRAP"), project number M10063, in response to Condition Report M1-00-0548, dated November 16, 2000. The objective of the project was to determine the ultimate disposition of the two Unit 1 spent fuel rods. The Project Description includes broad guidance for project organization and staffing, process and methods for the investigation, internal and external communications, document control, quality assurance, training, and corrective actions.

M10063-0 FRAP Investigation Team Project Plan

The FRAP Investigation Team Project Plan provides a general overview of the investigation. It also sets forth a detailed description of the Investigation Team's responsibilities and tasks in determining the location of the two spent fuel rods. The document describes the Team's organization, roles, responsibilities, specific tasks, milestones, and success criteria.

FRAP Guidelines

There are ten Project Guidelines that apply to various aspects of the investigation. A brief description of each guideline follows.

M10063-1 Guideline for Development and Control of Project Guidelines, Correspondence, and Record Keeping

This guideline provides instructions and standards for adhering to other guidelines, correspondence controls, and record keeping. The guideline discusses the need and process for guideline development, formatting, approval, control, and review, along with the establishment of a centralized project file.

M10063-2 Guideline for Physical Inspections

This guideline addresses the physical inspection of the Unit 1 spent fuel pool. The document notes the scope of pool inspections, the need for inspection plans for each discrete inspection effort, and the completion of a written evaluation regarding the inspection results.

M10063-3 Guideline for Document Investigation

This guideline defines the process for the search and retrieval of documents, the subsequent document review, additional searches, and records retention. As an aid to the Investigation Team and the preparation of scenario dispositions, the guideline calls for the development and maintenance of a data base of collated document searches and the subsequent search results.

M10063-4 Guideline for Interviewing

The guideline provides instructions and guidance to FRAP Investigation Team interviewers in preparing for and conducting interviews. The document also sets forth the steps for evaluating and documenting the information obtained in the interviews.

M10063-5 Guideline for Scenario Development and Investigation

This guideline establishes the process for evaluating evidence leading to the identification of potential outcomes or scenarios for the missing fuel rods. The document describes the steps to identify, describe, screen, and prepare disposition documents for scenarios.

M10063-6 Guideline for Project Training

The guideline provides the training methods to be used and the requirements for documenting project-related training.

M10063-7 Guideline for Project Quality Assurance Plan

This guideline identifies potentially applicable procedures that may apply to the FRAP efforts. The document noted that it was likely no QA records would be produced by the project.

M10063-8 Guideline for Verifying the Inventory of Nuclear Fuel

This guideline was established to govern the creation of a detailed inventory of all the nuclear fuel at Millstone Unit 1. The document sets forth the process to create the inventory and verify fuel quantities on-site and those shipped to other locations.

M10063-9 Guideline for Condition Report Initiation

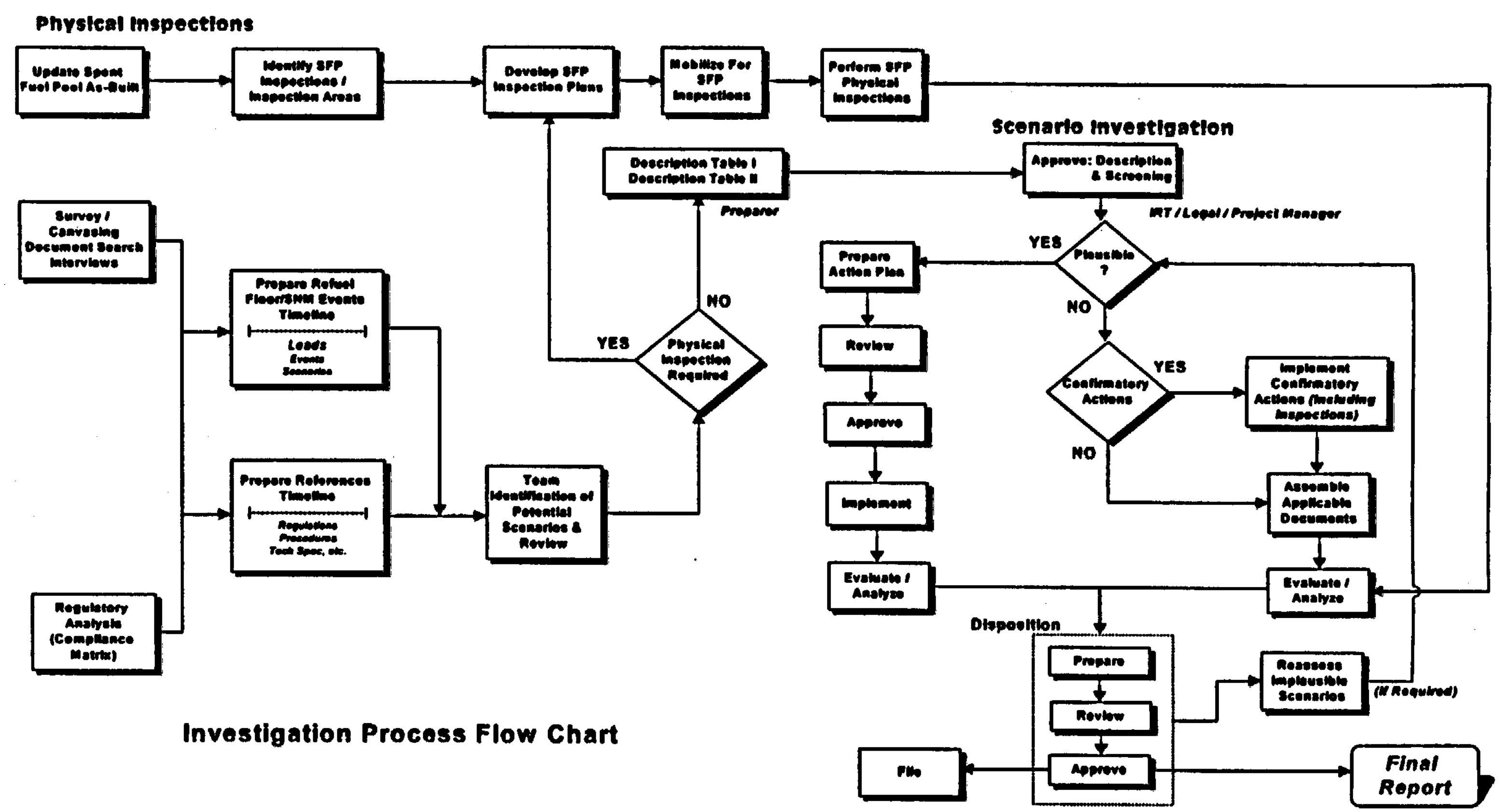
The guideline provides guidance for documenting deficiencies discovered while conducting the FRAP investigation. The guideline does not limit or prohibit any individual from writing a Condition Report.

M10063-10 Guideline for Weighing Evidence

This document provides general guidance to FRAP Team members on weighing and evaluating information obtained from documents, interviews, and other sources during the investigation. The document also establishes a "clear and convincing evidence" standard of proof.

SECTION 5

FRAP INVESTIGATORY PROCESS



Investigation Process Flow Chart

SECTION 6

LIST OF SCENARIOS

Unit 1 Spent Fuel Pool

5.1. 1 Inspection of MS-508
5.1. 2 Inspect gap btwn MS-508 and "gun barrel"
5.1. 3 Inspect SFP floor for rod segments
5.1. 4 Look for pellets separated from rods
5.1. 5 Inspect SRP 2D fuel bundle
5.1. 6 Inspect water rod sites (in 8x8 bundles)
5.1. 7 Inspect fuel assembly MS-557
5.1. 8 Inspect unchanneled fuel bundles
5.1. 9 Inspect channeled assemblies for gaps
5.1.10 Examine area inside CRB guides
5.1.11 Examine rack cell area holding CRB guides
5.1.12 Inspect square cans (2)
5.1.13 Inspect boxes of LPRMs
5.1.14 Inspect filter baskets
5.1.15 Examine STR fuel assembly MSB-125
5.1.16 Inspect empty fuel storage racks w/channels
5.1.17 Examine two cells containing debris
5.1.18 Examine channel storage racks w/channels
5.1.19 Inspect control rod storage racks
5.1.20 Inspect pipe(s) on north side of SFP
5.1.21 Inspect cask liner used for instrument tubes
5.1.22 Inspect internal area of fuel prep machine
5.1.23 Inspect external areas by fuel prep machine
5.1.24 Inspect two dummy assemblies
5.1.25 Inspect free space between racks
5.1.26 Examine area between racks and SFP wall
5.1.27 Examine two boraflex coupon containers
5.1.28 Examine area btwn SFP the reactor gates
5.1.29 Examine scavenged fuel bundles
5.1.30 Inspect new fuel vault area/racks
5.1.31 Inspect NW wall area
5.1.32 Inspect top of fuel racks
5.1.33 Examine raised fuel assemblies
5.1.34 Inspect free space under fuel racks
5.1.35 Examine bundles for signs of disassembly
5.1.36 Examine misc. SFP items
5.1.37 Inspect SFP sump
5.1.38 Examine space btwn cylinders of "gun barrel"

Millstone Unit 1, 2 & 3

5.2. 1a Fuel rods sent to "Bunker" for storage
5.2. 1b Fuel rods sent to "Bunker" for storage
5.2. 2 Unauthorized disposal (on-site)
5.2. 3 Fuel rods sent to Warehouse #9 for storage
5.2. 4 Fuel rods sent to MRRF for storage
5.2. 5 Drywell Sump
5.2. 6a Rods sent to MP2 (whole/recognized)
5.2. 6b Rods to MP2 (whole/unrecognized)
5.2. 6c Rods sent to MP2 (cut/unrecognized)
5.2. 7a Rods sent to MP3 (whole/recognized)
5.2. 7b Rods to MP3 (whole/unrecognized)
5.2. 7c Rods sent to MP3 (cut/unrecognized)
5.2. 8 MP1 RX
5.2. 9 MP1 Steam Separator Area
5.2.10 MP1 TIP Room
5.2.11 MP1 Storage Areas
5.2.12 Other

Hanford

5.3. 1 IF-300 Shipment - 3/21/85
5.3. 2 IF-300 Shipment - 5/29/85
5.3. 3 IF-300 Shipment - 7/31/85
5.3. 4 Other shielded shipments (e.g., resin / LSA)

Barnwell

5.4. 1 TN-8L - 1988 (1, 2)
5.4. 2 TN-RAM - 1989-90 (2)
5.4. 3 TN-RAM - 1992 (1,2,3)
5.4. 4 TN-RAM - 2000 (1,2,3,4,5)
5.4. 5 Other shielded shipments (e.g., resin / LSA)

Vallecitos

5.5. 1 GE-1600 shipment - 1980
5.5. 2 Shipment #2 - 1981
5.5. 3 Shipment - 1983
5.5. 4 Shipments - 1984 (1); 1985 (3)
5.5. 5 Other Shipment

Morris

5.6. 1 Shipment of LSA - 1985 (1,2)

Uncontrolled

5.7. 1 Unauthorized disposal (off-site)
5.7. 2 Unauthorized disposal (off-site)
5.7. 3 Theft from owner property

Other

5.8. 1a MP1 direct shipments
5.8. 1b MP1 direct shipments

SECTION 7

REGULATORY COMMUNICATIONS

List of Significant Regulatory Communications

NRC and Stakeholder Notification of Event

In accordance with the requirements of 10 CFR 50.72(b)(2)(vi), Northeast Nuclear Energy Company ("NNECO"), the then licensee of Millstone Unit 1, notified the U.S. Nuclear Regulatory Commission ("NRC") of its inability to determine the location of the two fuel rods on December 14, 2000 via NRC's Emergency Notification System. The notification provided a summary of the fuel rod event as understood at the time. NNECO also notified the NRC Region 1 and the State of Connecticut of the event on December 14, 2000.

Licensee Event Report

On January 11, 2001, NNECO submitted Licensee Event Report ("LER") 2000-02-00 to the NRC pursuant to the requirements of 10 CFR 20.2201(b). The LER provided a description of the event, a chronology, a description of the investigative effort, information regarding any impact upon health and safety, current investigative action, and future actions. On March 30, 2001, NNECO supplemented the LER by providing an update of the progress made in the ongoing investigation.

Weekly Telephone Calls

Open communications have existed between the NRC, NNECO, Dominion Nuclear Connecticut, Inc. ("DNC"), the States of Connecticut, South Carolina, and Washington to ensure that all parties are informed and kept abreast of current issues, schedules, and the status of ongoing activities. The primary communication vehicle was a weekly conference call with stakeholders. These conference calls began in December 2000, and have continued throughout the investigation.

Public Meeting at King of Prussia

On April 23, 2001, DNC and Project leaders met with officials from NRC Region I at their office in King of Prussia, PA. The purpose of the presentation was to provide the NRC with an understanding of the status and progress of the investigation.

NRC Inspections

The NRC completed an inspection, No. 2000-18, of Millstone Unit 1 on April 27, 2001. This inspection focused on the Conduct of Operations and Radiation Protection and Chemistry ("RP&C"). As part of the RP&C inspection, the NRC reviewed the licensee's effort to locate the two spent fuel rods.

The inspection results were documented in the NRC Inspection Report No. 05000245/2000018, dated June 4, 2001. In this Report, the NRC Inspector noted that dedicated staffing for the investigation had expanded through the end of the inspection period, with 21 professional/technical staff working on the project as of April 23, 2001. Also, the Inspector noted that an independent oversight review team had been formed to review investigation activities as they were being developed. The Report concluded that the investigation effort was progressing in a thorough and systematic manner and the investigation results would be reviewed as they became available.

SECTION 8

INDUSTRY COMMUNICATIONS

Industry Communications

Northeast Nuclear Energy Company submitted information to the Institute of Nuclear Power Operations ("INPO") describing the missing fuel rod event. In turn, INPO issued OE11903, "Location of Two Full - Length Irradiated Fuel Rods Can Not be Determined" to INPO members on February 9, 2001. The INPO report summarized the Millstone Unit 1 missing fuel rod event.

SECTION 9

COMMUNITY COMMUNICATIONS

Community Communications

As part of the effort to maintain an open dialogue with the public, the Fuel Rod Accountability Project ("FRAP") leadership met with community groups to discuss the status of the investigation. Project management met with the Millstone Unit 1 Decommissioning Advisory Committee ("M1DAC") on a near monthly basis from January to May 2001. These public meetings took place on:

- January 4, 2001
- February 1, 2001
- March 1, 2001
- May 3, 2001

Also, project management met with the Nuclear Energy Advisory Committee ("NEAC"). The meeting with the NEAC occurred on May 17, 2001.

In these meetings, the Executive Sponsor, the Project Manager, and, on some occasions, a representative from the Independent Review Team, discussed the ongoing investigative activities, searches of the Unit 1 spent fuel pool, and upcoming activities. Members of the Project also responded to questions from the committees and the public.

SECTION 10

INTERNAL COMMUNICATIONS

Internal Communications

The Millstone Nuclear Power Station internal publication "*To the Point*" carried articles summarizing events associated with the missing fuel rods. These articles, dated January 29, 2001 and April 29, 2001, solicited assistance from anyone in the Millstone site community with information related to the two missing fuel rods.

In addition, on March 2, 2001, Frank C. Rothen, the Executive Sponsor for the Fuel Rod Accountability Project, sent an email communication on the Millstone network requesting assistance from anyone with knowledge that would assist the investigation.

SECTION 11

OVERSIGHT AND ASSESSMENT

Oversight and Assessment

The Fuel Rod Accountability Project ("FRAP") team included over 20 full-time professionals and various administrative support personnel. These professionals averaged over 28 years of experience in the industry. The team members included former managers in engineering, operations, and regulatory assurance. Other team members served as former first-line supervisors, project managers, and engineers.

FRAP work practices were standardized and governed by written guidelines and, where applicable, procedures. Project personnel were trained on the requisite guidelines and procedures to ensure a high degree of quality and consistency. Furthermore, FRAP deliverables were reviewed by the Independent Review Team ("IRT"), legal advisor, and Project Manager for accuracy, quality, consistency, and auditability. Additionally, third-parties performed nine assessments to ensure the effectiveness of complying with FRAP Guidelines and processes.

The Project anticipated that the results of the FRAP investigation would not produce any Quality Assurance ("QA") records. However, the Project's efforts have been guided by QA principles. That is to say, reviews conducted in accordance with FRAP Guidelines have been conducted by technically competent personnel to assure completeness of the activity performed. All Project documents, such as correspondence (internal/external), interviews, and records reviewed and deemed pertinent, have been retained to assure completeness.

Training

The Project trained personnel to assure that those assigned to this project had the appropriate level of understanding to perform their assigned tasks. FRAP guidelines assured a consistent approach to training. The guidelines also provided for the methods of training to be used and for documenting an individual's qualification for a specified task, with the justification for that qualification.

The training methods used were drawn, in large measure, from the requirements stated in Unit 1 Decommissioning Document U1-TQ-1, Rev.1, "Personnel Qualification and Training." (The requirements of 10 CFR Part 50, Appendix B; 10 CFR 50.120; and ANSI 18.1 -1971 were not applicable to the project, even though U1-TQ-1 was designed to meet these criteria.)

The FRAP team conducted two "self-assessments" to evaluate whether project personnel were acting in compliance with project guidelines. In June 2001, the first assessment determined that personnel were following the procedures set forth in the Document Investigation Guideline, M10063-3. The second assessment, completed in July 2001, reviewed the documentation of project training in accordance with Guideline M10063-6 and document review procedures in M10063-3. The second self-assessment concluded that the FRAP Team was conducting training in conformance with the applicable guidelines.

Independent Review Team

The IRT was comprised of five independent (non-NU or DNC) personnel with significant, relevant industry experience. They reported directly to the FRAP Executive Sponsor. As noted, the IRT was independent of the line functions with the FRAP Investigation Team structure so that it could provide the Executive Sponsor with an unbiased perspective on matters pertaining to the project. The IRT provided oversight and ongoing review of key decisions, conclusions, plans, procedures, guidelines, methods, scenarios, schedules, external communications, selected internal communications, root cause investigation, and other areas necessary to provide added assurance of the respective accuracy, quality, consistency, and auditability of project activities.

Third-Party Assessments

A total of nine third-party assessments were performed. The assessment team was comprised of highly-qualified individuals from Duke Engineering and Services. The purpose of these third-party assessments was to evaluate the effectiveness of complying with FRAP Guidelines and processes established to disposition the location of the two missing fuel rods. The scope of the independent assessments included, but were not limited to, physical inspections, document searches, personnel interviews, scenario dispositions, adequacy and responsiveness of corrective actions, and administrative controls.

The third-party assessments identified 33 issues that were individually tracked to closure by the Project. Many of these issues were process improvements that the Project adopted and promulgated in guideline revisions. In some instances, the issues related to recommended improvements of project deliverables, such as the physical inspection report. One of the more significant recommendations concerned the addition of a second applicability and relevance review of documents after the scenarios were developed. The Project implemented these recommended improvements.

In two instances, the Project wrote corrective action reports (or condition reports) due to an identified deficiency in the implementation of an existing guideline. The Project corrected these two deficiencies.

EXHIBIT 5

Root Cause Investigation

LOSS OF ACCOUNTABILITY OF TWO FUEL RODS AT MILLSTONE UNIT 1
(CR #M1-00-0548)

Prepared By:
Team Members

10/24/01
Peter L. Reagan, PE
(Qualified per TQR CA00002)

10/24/01
Richard N. Swanson, PE, Team Lead
(Qualified per TQR CA00002)

Approved By:

CR Owner Date 10/25/01

EXECUTIVE SUMMARY

While evaluating fuel assemblies for dry cask storage in the fall of 2000, the Millstone Unit 1 Decommissioning project identified an inability to account for two fuel rods from a fuel assembly that was part of the initial core load. Those fuel rods were removed from fuel assembly MS-557 when the fuel vendor took it apart to support material analysis following a 1972 chloride intrusion event. They were last credibly verified as present in the Millstone Unit 1 spent fuel pool in May 1979.

Northeast Utilities Service Company initiated a project to locate the missing fuel rods in early 2001, including a comprehensive investigation to determine fuel rod location by the Fuel Rod Accountability Project (FRAP) and the chartered Root Cause Assessment Team (RCAT) that produced this report. The RCAT members were qualified to, and functioned in accordance with, the requirements of Millstone Station root cause assessment procedures.

This assessment was based, in part, on FRAP investigation findings. This report documents the RCAT's answers to two key questions:

- Why did Millstone Unit 1 lose accountability of the two fuel rods?
- Why didn't Millstone Unit 1 recognize the accountability loss sooner?

As stated in the Millstone root cause analysis procedure, "A root cause analysis provides an effective means of determining the fundamental cause(s) that, if corrected, will prevent recurrence of an adverse condition." Root cause analysis involves the focused use of a set of analytical tools to solve problems. Using these tools, the RCAT developed recommendations that focused on the circumstances that led to this event and how the resulting consequences could be eliminated or better controlled in the future.

CAUSATION

The RCAT concluded that the root cause of this event was an unrecognized over-reliance on Millstone Unit 1 Reactor Engineers to compensate for organizational and process weaknesses in implementing the special nuclear material inventory and control procedures. As summarized below, that unrecognized over-reliance masked certain behaviors and conditions that led to this event (the elements of the root cause):

- Process weaknesses associated with special nuclear material inventory and control and radwaste characterization;
- Weaknesses in coordination of spent fuel pool activities and procedural adherence; and
- Inconsistent supervision and inconsistently applied oversight of spent fuel pool activities by knowledgeable individuals.

The RCAT did not establish the deeper reasons why there was an unrecognized over-reliance upon the REs in the past. It would be extremely difficult, if not impossible, to establish why people made the choices they did 20 or 30 years ago due to the departure of individuals through retirement, resignation, transfer, or death. In the considered opinion of the RCAT, it was not necessary to do so to resolve current concerns or to prevent their recurrence. The RCAT found no specific evidence of currently unrecognized over-reliance on the Reactor Engineers.

More robust processes and procedures by definition reduce organizational reliance upon individual performance. Recommendations for actions in response to this event were targeted to address procedure and process weaknesses. Pending full implementation of those recommendations, the RCAT recommended interim compensatory measures.

REASONS FOR LOST ACCOUNTABILITY

MP1 lost physical accountability of the two MS-557 fuel rods because organizational and process weaknesses in implementing the SNM inventory and control procedures placed the MP1 REs in a position that required personal performance to compensate for the way Unit 1 controlled and coordinated spent fuel pool work and accounted for special nuclear material. When personal performance slipped during a critical turnover between Reactor Engineers in late 1980, the vulnerable process did not function in a way sufficient to prevent the loss of physical accountability of the two MS-557 fuel rods. The special nuclear material inventory and control process itself lacked many of the administrative and physical barriers needed for robust rod-level accountability. RCAT recommendations included actions to address these weaknesses.

The vulnerabilities associated with physical accountability of individual fuel rods did *not* extend to physical accountability of fuel assemblies or radiological controls. Fuel assembly physical accountability was effective and Millstone Unit 1 maintained physical control of the two individual MS-557 fuel rods as radioactive material.

REASONS LOST ACCOUNTABILITY WAS NOT RECOGNIZED SOONER

MP1 did not recognize the loss of physical accountability of the two MS-557 fuel rods sooner because it did not effectively maintain and periodically compare a single, integrated, readily retrievable "inventory of record" with the physical SNM inventory. The RCAT recommended remedial corrective action to reconcile current fuel inventories at Units 1, 2, and 3 with "inventories of record." Those activities were completed prior to the conclusion of this investigation. Other recommendations included reconciliation of non-fuel SNM inventory and establishment of procedural requirements for future SNM inventory reconciliation.

SIGNIFICANCE

The RCAT drew the following conclusions with respect to event significance:

- *Physical Control of Fuel Rods:* Minor; loss for Millstone Station was limited to two fuel rods from Unit 1. Millstone Station effectively accounted for all other Unit 1 fuel, and all fuel at Units 2 and 3.
- *Health and Safety, and Radiological:* Negligible; public and worker health and safety (including criticality safety) are protected by past and current processes and practices.
- *Environmental:* Negligible; offsite locations with credible potential to have received the rods are licensed for isotopic limits far in excess of the content of the two rods.
- *Schedule:* No impact on Unit 1 decommissioning or other Millstone Station activities.
- *Financial:* Moderate; Fuel Rod Accountability Project cost about $9 million.
- *Implications for Units 1, 2, and 3:* Minor: Neither Unit 2 nor Unit 3 was similarly vulnerable to physical loss of fuel rods. Both stored individual fuel rods in fuel racks with other fuel, unlike Unit 1. Fuel inventories were reconciled at Units 1, 2, and 3, confirming there were no other instances of lost fuel rods. Identified opportunities for improvement of Millstone's special nuclear material control and accountability program should be easily resolved.
- *Regulatory:* Unknown, but did not measurably impact NRC "Performance Indicators" or "Regulatory Cornerstones" as currently defined. The possibility that fuel rods may have been buried in Agreement State low level radwaste facilities raises regulatory issues that should be discussed among appropriate regulatory agencies and affected licensees.

RECOMMENDATIONS

The RCAT provided several recommendations in response to this event, and noted that many of them were either in progress or already completed prior to completion of the investigation. The RCAT focused its recommendations on the prevention and detection of future events. Recommended corrective and preventive actions included remedial corrective actions, interim compensatory measures, corrective actions to prevent recurrence, enhancement corrective actions, and effectiveness review. Section 5.2, "Corrective and Preventive Actions," provides recommendations in the following areas:

- Procedure and process improvements;
- Coordination of spent fuel pool activities;
- Oversight and supervision of spent fuel pool and special nuclear material inventory activities; and
- Post-implementation verification of corrective action effectiveness.

TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of this root cause analysis was to determine why Millstone Unit 1 (MP1) experienced a sustained loss of physical accountability of two irradiated fuel rods from fuel assembly MS-557. Condition report (CR) M1-00-0548 documented this adverse condition on November 15, 2000.[1] The charter for this root cause analysis was to answer two questions:

- Why did MP1 lose accountability of the two fuel rods? And,
- Why didn't MP1 recognize the accountability loss sooner?

As stated in the Millstone root cause analysis procedure, "A root cause analysis provides an effective means of determining the fundamental cause(s) that, if corrected, will prevent recurrence of an adverse condition." Root cause analysis is a tool used to solve problems. Solutions developed using this tool focus on the circumstances that created the problem and how the resulting consequences of the event could be eliminated or better controlled in the future. The balance of this report presents a description of the event, event causes, analytical results, extent of condition evaluation, and recommended actions to prevent similar events in the future.

1.1 CLARIFICATION OF PURPOSE

This report is intended to be a self-critical use of hindsight to identify problems and the sources of those problems. The conclusions and root causes identified in this report were discovered and analyzed using all of the information and results available at the time it was written. All such information was, of course, not available during the time frame in which people took action and made decisions. To the extent this report discusses "effectiveness," it does so knowing the ultimate outcome.

The purpose of using this self-critical approach is to provide the most comprehensive analysis possible for identifying "lessons to be learned" as a basis for improving future performance. The use of an open, documented self-critical analysis program is imperative in the nuclear power industry and cannot be compromised or confused with regulatory compliance evaluations or management prudence assessments. Indeed, unless otherwise stated, assessments of adequacy or effectiveness are not assessments of compliance with regulatory standards. Rather, in keeping with the purpose of fostering improved performance, such assessments measure performance against the industry goal of excellence.

Additionally, this report does not attempt to make a balanced judgment of the prudence or reasonableness of any of the actions or decisions that were taken by vendors, utility management, or individual personnel based on the information that was known or available to them at the time.

[1] Operations screened 11/16/00

1.2 PROBLEM STATEMENT

Spent fuel characterization performed by Northeast Nuclear Energy Company (NNECo) in 2000 as part of MP1 decommissioning identified that two fuel rods documented in inventory records as present in the Spent Fuel Pool (SFP) in 1979 could not be physically located.[2] Control and inventory of special nuclear material[3] (SNM) including the two fuel rods is a requirement of Federal regulation.[4]

The Root Cause Analysis Team (RCAT) developed the following working definition of "accountability" for SNM[5], based upon the requirements of 10CFR Part 70 ("Domestic Licensing of Special Nuclear Material") and industry experience:

"Accountability" means having the ability, within a reasonable period of time:

- To provide documentation of number and locations of SNM unit inventory; and
- To physically verify that SNM unit locations and amounts correspond with inventory documents.

Federal regulations, specifically 10CFR70.4, defined categories of SNM in terms of strategic significance as low, moderate, or high. SNM of low strategic significance requires significant technical capability to convert to a form compatible with weapons use. The two fuel rods were of low strategic significance.

1.3 INVESTIGATION SCOPE

NUSCo initiated this investigation to determine "how and why Millstone 1 failed to maintain fuel rod accountability," including why the deficiency was not discovered sooner. RCAT members were qualified in accordance with Millstone Station requirement TQR CA00002 prior to beginning work, and performed this root cause assessment in compliance with Millstone Station procedures.

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[2] Condition Report CR M1-00-0548, "Historical Unaccountability of Fuel Rods"

[3] The NRC's regulatory definition of special nuclear material is contained in 10CFR70.4. In general terms applicable to nuclear fuel, SNM is plutonium, uranium-233, or uranium enriched in the isotopes 233 or 235.

[4] See Section 2.2, "Background", below.

[5] The RCAT used this definition of physical accountability because it was consistent with regulatory guidance and focused on requirements applicable to commercial nuclear power plants.

The RCAT was directed to consider[6]:

- The factors that affected the consequences of the event, including:
  1) The pre-existing causal factors that made the plant vulnerable to the event,
  2) The triggering events or conditions that turned the vulnerability into a consequential event,
  3) The factors that made the consequences worse, and
  4) The mitigating factors that kept the event from having more severe consequences;
- Generic Implications;
- Quality and safety impact, including separate and distinct discussions of consequences and significance; and
- Proposed corrective actions.

1.4 INVESTIGATION APPROACH

The RCAT used the Phoenix[7] root cause assessment method and applicable Millstone Station procedures to evaluate this event. Accordingly, this assessment answered the following eight questions:

- What were the event consequences? (Quality and Safety Impact)
- What was the event significance? (Quality and Safety Impact)
- What made MP1 vulnerable to this event? (Vulnerability)
- What turned the vulnerability into a consequential event? (Trigger)
- What made this event as bad as it was? (Exacerbation)
- What kept this event from being worse than it was? (Mitigation)
- What should Millstone Station learn from this event? (Lessons to be Learned)
- What should Millstone Station do in response to this event? (Corrective and Preventive Actions)

[6] Appendix A.1 [NUSCo memo "Charter for Root Cause Investigation Revision 1", March 29, 2001 (Revised April 20, 2001)]

[7] As described in the "Phoenix Handbook" © 2000, by William R. Corcoran, Ph.D., P.E., NSRC Corp.

2.0 EVENT DESCRIPTION

2.1 EVENT DISCOVERY

In July 1998, NNECo decided to cease operating Millstone Unit 1 (MP1) after approximately 27 years of operation. Having made that decision, NNECo explored the possibility of using dry cask storage of MP1 irradiated fuel in an independent spent fuel storage installation (ISFSI) until (and unless) an acceptable federal repository for spent fuel became available. This, in turn, required characterization of the spent fuel to be stored in terms of its design, operational history, and isotopic weights (among other attributes). The necessary information had to be retrieved from a variety of station and corporate sources.

In the course of this evaluation, personnel identified historical discrepancies in fuel-related information during spring and early summer of 2000. The first indication of a Special Nuclear Material (SNM) accountability issue involving two irradiated fuel rods was the discovery of a May 15, 1979 memo to file. This memo (from the MP1 Reactor Engineer) was attached to a Kardex file card[8] and identified two individual rods from bundle MS-557 that were intended to be incorporated into an unspecified "scavenged" bundle. The memorandum and card file noted the rods' location in May 1979 as in the northwest corner of the SFP. By mid-Fall 2000, personnel had resolved fuel-related discrepancies except for location of the two fuel rods.[9]

Following initial fuel pool searches that did not locate the two rods, NNECo initiated condition report (CR) CR M1-00-0548 (*"Historical Unaccountability of Fuel Rods"*) on November 15, 2000[10] to enter the problem into the Station's corrective action program (CAP).

Following additional attempts to locate the fuel rods, Northeast Utility Service Company (NUSCo) initiated the Fuel Rod Accountability Project (FRAP) in early 2001. This team was responsible to accomplish:

- A systematic physical search for the fuel rods;
- A systematic documentation search for relevant information;
- Interviews of those individuals with potentially relevant information;
- An integrated assessment of all information obtained; and
- A final report of conclusions with respect to fuel rod location.

[8] MP1 used a Kardex brand card filing system as part of its SNM accountability documentation.

[9] Interview 14

[10] The CR was initiated on 11/15/00, and operations screened on 11/16/00.

The ensuing investigation involved more than two dozen team members, lasted about ten months, required about fifty thousand person-hours, and cost about $9 million.

NUSCo also chartered the RCAT to evaluate why MP1 lost accountability of two individual fuel rods, and why the problem was not discovered sooner. (See Section 1.3, "Investigation Scope".)

2.2 BACKGROUND

MP1 was a 660 mega-watt (electric) boiling water reactor (BWR) designed by General Electric and located in Waterford, Connecticut at Millstone Station. It began commercial operation in 1971 and operated until 1995.

NUCLEAR FUEL

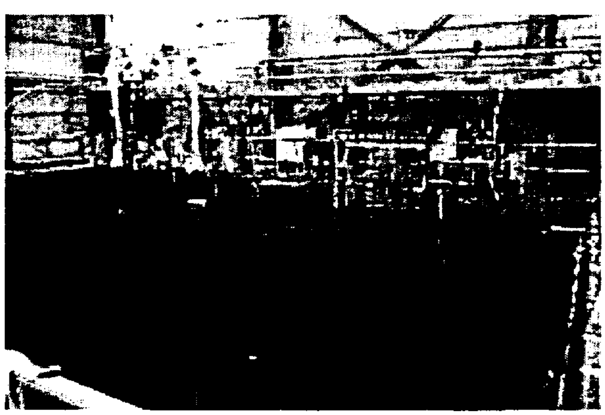
A full MP1 core consisted of 580 nuclear fuel assemblies, each of which was composed of either 49 fuel rods (for the "7x7" fuel used early in plant life) or between 60 and 63 rods (for "8x8" fuel used more recently). MP1 7x7 fuel rods were 13'2" long by 0.57" diameter.

Although fuel assemblies were not typically disassembled at nuclear power stations and generally remained intact for their entire existence, exceptions occurred when it was desirable to examine or replace individual rods. Bundle disassembly was typically performed by fuel vendors.

SPENT FUEL POOLS

Once used to produce power, nuclear fuel is highly radioactive and continues to produce heat for an extended period of time following removal from the reactor core. Acceptable storage of spent nuclear fuel requires, among other things:

- Removal of latent heat; and
- Radiation shielding.



Generating facilities meet these needs by using spent fuel pools to store irradiated fuel. The MP1 SFP is typical of light water reactors world-wide. It measures approximately 30.5 feet x 40 feet x 37.75 feet deep and contains about 340,000 gallons of water. This picture shows the MP1 SFP (circa 1972) looking in a northwesterly direction.

SPECIAL NUCLEAR MATERIAL

Special Nuclear Material is broadly defined by 10CFR70.4 as "... plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission ... determines to be special nuclear material... ." 10CFR70.4 also contains more specific definitions of certain categories of SNM.

At commercial nuclear generating stations, nuclear fuel (uranium enriched in the isotope 235) comprises by far the largest amount of SNM onsite. Other components with SNM at a BWR such as MP1 include startup sources, Source Range Monitors (SRMs), Local Power Range Monitors (LPRMs), Intermediate Range Monitors (IRMs), Traversing In-core Probes (TIPs), and various calibration sources.

10CFR70.4 defines categories of SNM in terms of strategic significance as low, moderate, or high. SNM of low strategic significance requires significant technical capability to convert to a form compatible with weapons use. The two fuel rods were of low strategic significance. In addition, the two rods provided less than one quarter of one percent of a "strategic quantity" as defined by the International Atomic Energy Agency.[11] Thus, the amount of fissile material contained in those rods is far less than that needed to achieve criticality or to create a nuclear device or weapon.

Facilities licensed by the NRC to possess SNM are required by regulation to account for SNM, on both a piece-count and aggregate isotopic-weight basis:

> "Each licensee shall keep records showing the receipt, inventory (including location), disposal, acquisition, and transfer of all special nuclear material in his possession..."[12]
>
> "... each licensee ... shall conduct a physical inventory of all special nuclear material in his possession under license at intervals not to exceed twelve months."[13]
>
> "*Physical inventory* means determination on a measured basis of the quantity of special nuclear material on hand at a given time. The methods of physical inventory and associated measurements will vary depending on the material to be inventoried and the process involved."[14]

EARLY EXPECTATIONS REGARDING NUCLEAR FUEL

The nuclear industry and the Atomic Energy Commission (AEC) (predecessor to the Nuclear Regulatory Commission (NRC)), anticipated an operational environment with relatively small amounts of spent nuclear fuel retained at generating sites. The irradiated fuel was to have been transported to fuel processing facilities for extraction and reuse of fissile material, and land burial of irradiated fuel constituents not suitable for further use. When MP1 began commercial service in the early 1970s, neither the AEC nor the utilities anticipated the need to store large amounts of spent fuel at operating reactor sites.

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[11] "Strategic quantity" is the amount of nuclear material required to manufacture an explosive device. These rods together contained about 180 grams of U^{235}. The "strategic quantity" of this isotope is defined by the IAEA as 75,000 grams.

[12] 10CFR70.51(b)(1)

[13] 10CFR70.51(d)

[14] 10CFR70.51(a)(8)

Large scale commercial reprocessing never materialized in the United States. As a result, operating nuclear sites were required to cope with ever-increasing amounts of irradiated fuel, for which their storage facilities (spent fuel pools) and SNM tracking systems (typically "Kardex" files or equivalent) were not initially designed. This became a fact of life for commercial nuclear power stations, including Millstone.

The SNM control and accountability systems of the late 1960s and early 1970s were designed to deal with a limited amount of fuel and with inventory tracking and control based on fuel assemblies. Although the capability to take apart irradiated fuel assemblies existed, the SNM control and accountability programs of that era were not always designed to accommodate the disassembly and subsequent storage of individual fuel rods. Fuel repair was performed only on a limited basis and generally conducted by highly skilled fuel vendor personnel. AEC and later NRC inspection guidance[15] similarly focused fuel-related SNM inspections on full fuel assemblies.

SNM AND RADIOACTIVE MATERIAL REGULATIONS

The principal regulations governing control of radioactive material and SNM control and accountability were:

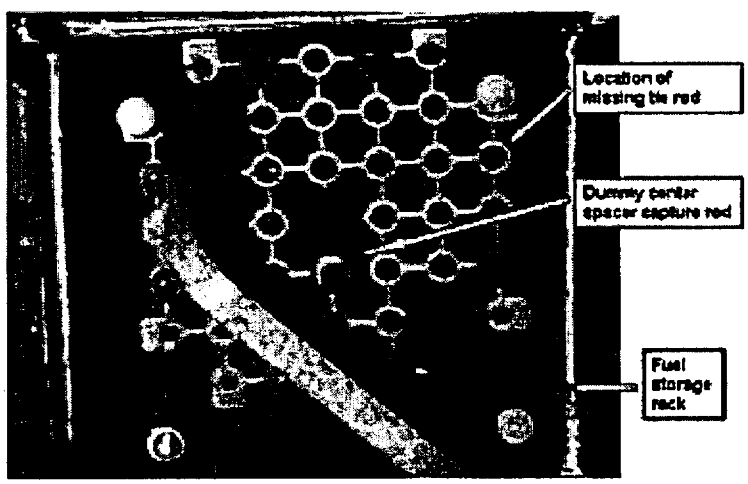
- 10CFR20 - Standards for Protection Against Radiation
- 10CFR61 - Licensing Requirements for Land Disposal of Radioactive Waste
- 10CFR70 - Domestic Licensing Of Special Nuclear Material
- 10CFR71 - Packaging and Transportation of Radioactive Material
- 10CFR72 - Licensing Requirements For The Independent Storage of Spent Nuclear Fuel And High-Level Radioactive Waste
- 10CFR73 – Physical Protection of Plants and Materials; Material Control and Accounting of Special Nuclear Material
- 10CFR74 - Material Status Reports, Nuclear Transfer Reports and SNM Physical Inventory Reports
- 49CFR172 - DOT Hazardous Waste Manifests and Transportation of Fissile Materials

[15] NRC Inspection Procedures 85102, "Material Control and Accounting – Power Reactor", 02/21/84; 85102, "Material Control and Accounting – Reactors", 03/29/85

2.3 EVENT NARRATIVE

EVENT TRIGGER[16]—CHLORIDE INTRUSION EVENT (1972)

On September 1, 1972, MP1 experienced a chloride intrusion event. Station management requested General Electric (GE) to assist in the evaluation of how chloride introduction impacted the reactor coolant system (RCS) (e.g., nuclear vessel and fuel components).[17] In October 1972, GE personnel disassembled fuel assembly MS-557 in the MP1 SFP, stored the associated 49 fuel rods in seven GE 8-rod storage containers, and shipped some of the non-fuel irradiated hardware to GE's Vallecitos Nuclear Center (VNC) in Pleasanton, California for evaluation. That work was done underwater in the MP1 SFP for both cooling and shielding purposes. GE personnel recorded placement of the MS-557 fuel rods into seven 8-rod storage containers and noted that one of the fuel rods had been damaged in handling.[18] Neither the FRAP nor the RCAT were able to find evidence that Millstone personnel documented the presence of individual fuel rods or the SFP location of the eight-rod containers when GE turned over associated documents and left the site in late 1972.[19]



"SCRAP" MS-557 FUEL ASSEMBLY

In April 1974, GE returned to MP1 and performed a number of fuel-related inspections and assembly reconstitutions,[20] including the reassembly of fuel bundle MS-557.[21] They did not, however, incorporate the damaged tie rod or the center spacer capture rod into the reconstituted assembly. The center spacer capture rod could not be reinstalled at MP1 because of its physical configuration. The damaged tie rod was not reinstalled

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[16] A "trigger" is the consummating factor for the event. Event triggers may also be called "triggering factors" or "initiating factors". Even when an organization is vulnerable to an event, the event does not happen unless that vulnerability is consummated.

[17] "Special Report, Chloride Intrusion Incident," 12/11/72

[18] GE memo, "Millstone Chloride Intrusion Fuel Inspection Task" dated 10/11/72, with attachments: single rod storage cans for MS-557, and handwritten note concerning "Status of Fuel Inspection Area" (date illegible)

[19] Based upon extensive document searches and interviews: interviews 6, 31; FRAP Group Interview PLR-RVF-07-27-01

[20] GE Report NEDM-20809, "Millstone Fuel Inspection and Repair, April 1974", July 1975

[21] Reactor Engineer's field notes, "1974 Fuel Reconstitution"; Material Transfer Form 74-32; Kardex card MS-557

either. GE personnel used a dummy center spacer rod to support the "scrap" assembly, and left a vacancy where the damaged tie rod would have gone.[22] See the photo above.

Those GE records of this work that were available in 2001 did not indicate what became of the two MS-557 fuel rods that had been stored separately in an 8-rod storage container in the SFP since 1972. The MP1 Reactor Engineer (RE) prepared a record of the reconstitution of assembly MS-557 as a "scrap" bundle, but did not mention that the assembly contained only 47 of 49 associated fuel rods, or that two rods were stored separately in the SFP.[23]

VERIFICATION, DOCUMENTATION OF TWO MS-557 FUEL RODS

In May 1979, the MP1 RE requested on-site GE personnel to read the serial numbers inscribed on the end plug of two rods in an 8-rod container to determine their origin.[24] Using the partially legible serial numbers, the RE and GE personnel concluded that the rods were the two fuel rods removed from the MS-557 bundle seven years earlier.[25] In an interview,[26] the RE said the two MS-557 fuel rods were then left in a container in the northwest corner of the SFP, and tied with a line or cable to the SFP railing. He thought that the line or cable was labeled, but the RCAT and FRAP found no confirmatory evidence that anyone else saw such a label.[27]

The RE documented the presence of the two fuel rods in a memo to file[28] and created a data card in the Kardex file[29] to record the location of the two rods in an 8-rod container, the location of the container in the northwest corner of the SFP, and the intention to ultimately incorporate these rods into a scavenged bundle. The SNM Accountant was aware that these rods had been discovered, and decided to continue reporting isotopic gram accountability based upon a complete assembly.[30] Although the RE believed he might have initiated a Material Transfer Form (MTF) to move the two MS-557 fuel rods to the fuel prep machine for serial number reading, neither the FRAP nor the RCAT was able to discover corroborating evidence.[31]

SFP maps from February and April 1980 documented the location of the two individual MS-557 fuel rods as the northwest corner of the SFP. The FRAP team found no

[22] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 1)

[23] Based upon review of MTF files; interview 31; Reactor Engineer field notes of 1974 Fuel Reconstitution, 04/18/74-05/31/74.

[24] Interview 29

[25] MP1 RE memo to file, "Fuel Rods", 05/15/79

[26] Interview 31

[27] FRAP group interview 07/27/01

[28] MP1 RE memo to file, "Fuel Rods", 05/15/79

[29] Kardex file card "MS557 Fuel Rods"

[30] Interview 9

[31] Based on extensive FRAP MTF review and interview 31

documentation of any kind that mentioned these two fuel rods after April 1980. The September 1980 SFP map omitted the two rods.[32] As discussed later in this narrative, the RCAT and FRAP concluded that SFP maps, by themselves, did not provide sufficiently reliable evidence one way or the other to establish the length of time that the two MS-557 fuel rods remained in the MP1 SFP following the May 1979 serial number verification.

THE EVENT AT THREE MILE ISLAND

The accident at the Three Mile Island Unit 2 (TMI-2) nuclear power plant near Middletown, Pennsylvania, on March 28, 1979, brought about sweeping changes involving emergency response planning, reactor operator training, human factors engineering, radiation protection, and many other areas of nuclear power plant operations. Shortly thereafter, the nuclear power industry formed the Institute for Nuclear Power Operations (INPO) with the mission to pursue "excellence" in the industry and to bring about an industry culture more focused on nuclear plant safety. It also caused the NRC to tighten and heighten its regulatory oversight.[33] SFP activities and design, however, were not specifically included in this significant effort.

US nuclear plants (including MP1) began to feel the impact of this event almost immediately. For at least the next decade, TMI-related changes required a great deal of utility and plant management attention, with non-TMI-related issues generally assigned lower priority by both utilities and the NRC.

REACTOR ENGINEER TURNOVER

In late 1980, the MP1 RE accepted employment with another utility and turned over his responsibilities to an engineer from the RE group.[34] The relieving RE was the lead engineer for an intense, critical-path project and had little time for turnover, which took place during a plant outage. During interviews in 2001, both individuals involved agreed that information exchange during turnover was minimal.[35] The relieving RE was certain that he had *no* knowledge of two individual fuel rods in the MP1 SFP at any time prior to 2000, and that they were not mentioned during the turnover with the outgoing RE.[36] The outgoing RE was uncertain as to whether he discussed the two individual rods.[37]

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[32] The historical record of MP1 SFP maps was incomplete as of the FRAP/RCAT investigation. After extensive document searches, interviews, and physical inspections of document files, neither the FRAP nor the RCAT was able to locate all MP1 maps believed to have been generated.

[33] NRC Web Page, "Three Mile Island 2 Accident" (URL: http://www.nrc.gov/OPA/gmo/tip/tmi.htm)

[34] Interview 31

[35] FRAP Group Interview PLR-RVF-07-27-01

[36] Interview 6

[37] Interview 31

APRIL 1980 SHIPMENT OF SEGMENTED TEST RODS TO VNC[38]

MP1 participated in a fuel test program with the fuel vendor beginning in the mid-1970s. As part of this program, segmented fuel rods were placed in MP1, used as nuclear fuel, and removed and shipped to the VNC for further tests and analyses. One such shipment was made in April 1980.

The FRAP identified two VNC record discrepancies associated with the April 1980 shipment. The first was an unexplained difference of 6.4 kg between the relevant NRC Form 741 and entries on two other NRC records.[39] This difference was slightly less than the weight of the SNM contained in the two fuel rods. The second inconsistency involved differences in shipping and receipt records for certain non-fuel items in that shipment.

The FRAP Final Report concluded that these conflicting facts were sufficient to maintain VNC as a possible location of the rods. The loading of the segmented test rods for this shipment on May 5, 1979, and the unexplained movement of MS-557 on May 5, 1979, created another potential link between this shipment and the two fuel rods. The shipping cask remained in the SFP until April 1980. The disappearance of the two fuel rods from all known documents immediately after the April 1980 shipment, and the disappearance of the two rods from the memories of those who should have seen or remembered the rods, added to the uncertainty about this shipment.

The FRAP concluded that the likelihood that the fuel rods are at GE's Vallecitos nuclear fuel handling facility is low, but it could not be dismissed.

FALL 1979 LPRM PROCESSING[40]

One of the activities required to support cleanup of the SFP was the cutting of LPRMs into segments that would fit into shielded casks for shipment to licensed low level radioactive waste (LLRW) facilities. In September and October 1979, contractor workers with limited experience in identifying reactor components were hired to cut numerous LPRMs that were stored in the MP1 SFP. Although the FRAP review found no direct evidence that the contract workers inadvertently cut the rods, that possibility cannot be ignored. Because LPRM hot sections are similar in length and diameter to a fuel rod, a person who is unfamiliar with BWR components would have difficulty distinguishing between the two.

Adding to that difficulty, the workers did not have visual aids, such as borescopes or reverse periscopes, to help identify the underwater objects. Moreover, if the fuel rods were being stored in the corner of the spent fuel pool (as the memorandum of May 15, 1979 indicates), those workers would not have expected to find fuel stored outside the fuel racks with non-fuel items. Indeed, after the SFP re-racking in March 1979, the fuel racks containing the spent fuel were between 22 and 90 inches from the walls of the

[38] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (pages 27-30)

[39] NUREG 0725 ("Public Information Circular for Shipments of Irradiated Reactor Fuel") and a related data sheet

[40] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 25)

pool. Encountering an item that looks like an LPRM, in a place where non-fuel items were stored, underwater and under conditions of limited visibility, could well explain how fuel rods could have been inadvertently cut.

Other LPRM cuttings were done to support SFP pool cleanup activities in 1984 and 1985. The 1984 LPRM cutting activities were conducted by trained NNECo operators, reducing the likelihood of mistaking LPRMs for fuel rods. The 1985 cuttings were done by experienced GE workers. The detailed cutting procedures they used virtually assured that they did not cut a fuel rod by mistake.

SFP CLEANUP/RADWASTE SHIPMENTS 1979-85

MP1 conducted a number of SFP clean-up activities between 1979 and 1985 to remove irradiated material and ship it to disposal sites for burial.[41] Individual fuel rods may have been confused with some of the material to be shipped. The potential for such a mistake was certainly present. The individual fuel rods were stored in an "8-rod container" and tied to the SFP railing when last observed in 1979, rather than placed in the fuel racks.[42] Interviews of individuals involved in SFP cleanup indicated that they were well aware of the need to stay away from the fuel racks while working in the SFP and did so, but considered items hanging off the SFP railings to be intended for disposal.[43]

MP1 made 798 off-site shipments of radioactive material between May 12, 1979, and the end of 1985. The FRAP investigation concluded that only three of these shipments could have inadvertently included the missing fuel rods due to the nature of respective shipping containers and their material content.[44]

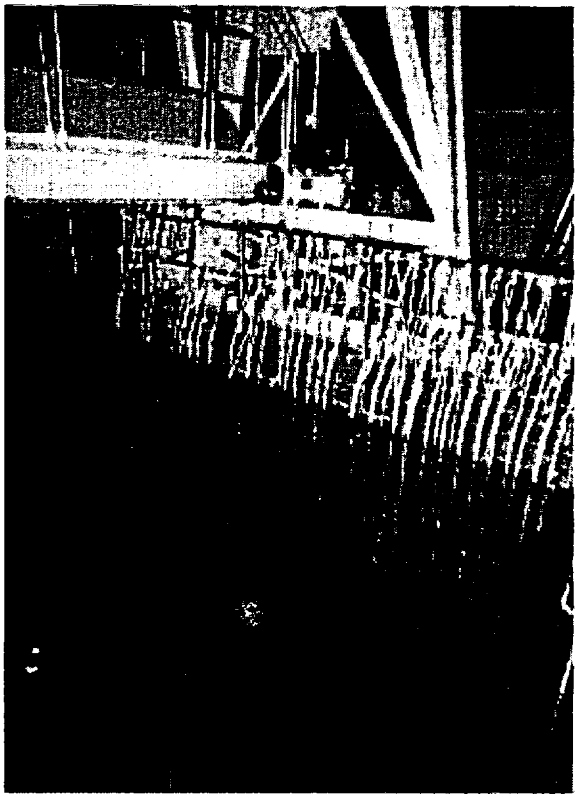
The picture below shows conditions of the MP1 SFP (circa 1985). Note the many ropes tied to the railing, attached to objects submerged below the water surface:

[41] These clean-up activities and associated radwaste shipments were discussed in detail in the FRAP Final Report and supporting documents. Discussion in this root cause assessment report was limited to only that necessary to establish a broad context of SFP history between discovery of the individual fuel rods in 1979 and discovery of their apparent loss in 2001.

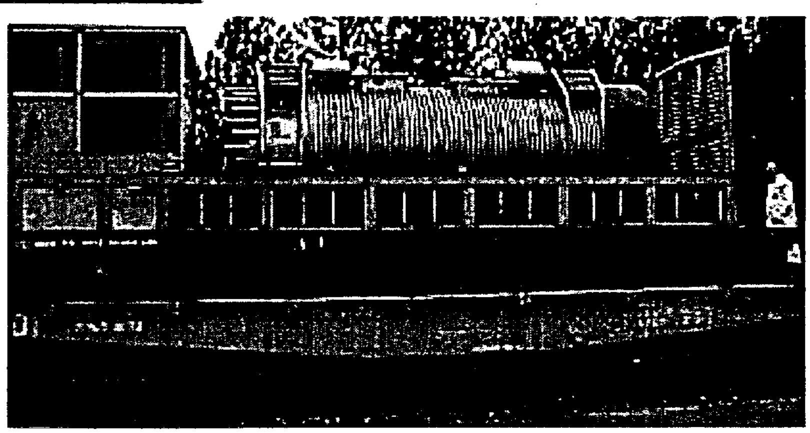
[42] Interview 31

[43] Interviews 2, 3, 7, 10, 22, 30, 36, 38, FRAP Group Interview PLR-RVF-07-27-01

[44] The other shipments contained materials with substantially lower radiological dose rates or that could not credibly be physically confused with fuel rods or rod segments. Materials in these categories included chemistry samples, solidified or dewatered condensate resin, solidified oil, solidified filter media, and/or dry active waste (DAW).



MP1 SFP, circa 1985



IF-300 Shipping Cask
(mounted on a rail car)

The three shipments during this period with potential to have inadvertently included cut up fuel rods in IF-300 shipping casks, occurred on March 20, May 29, and July 31, 1985, and were sent to the U.S. Ecology LLRW Facility, Richland, Washington.[45] The FRAP Final Report concluded that:[46]

[45] The FRAP concluded that shipment of full-length fuel rods in IF-300 casks was not credible, given a liner length 5 inches shorter than fuel rod length. See "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 31).

[46] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 30)

"The investigation did not produce clear and convincing evidence that the two fuel rods from MS-557 were shipped to Hanford. In fact, there is no direct evidence that they were included in any of these three shipments. Nevertheless, the evidence is not sufficiently compelling to exclude the possibility that the fuel rods were inadvertently included."

Factors creating the vulnerability to inadvertent shipment of fuel rods (specifically in the third shipment) included:[47]

- The similarity in the physical appearance of individual fuel rods and LPRMs;
- The 1979 cutting of LPRMs by contractor personnel who were unaware of the potential presence of two individual fuel rods in the pool and who lacked experience in the identification of boiling water reactor components;
- The inclusion of sections of 8 LPRMs whose operational history could not be recreated to prove that the items were LPRMs, as listed in the inventory of items shipped;
- The retrieval of specific items (velocity limiters and control rod blade (CRB) handles) from an old liner which also contained other unknown irradiated hardware and the placement of the velocity limiters and CRB handles into the IF-300 liner for shipment.

1988 SFP CLEANUP[48]

In anticipation of a SFP re-rack project, NUSCo initiated a separate project to clean up the MP1 SFP. Working with people at the site, NUSCo prepared a bid specification and hired WasteChem in January 1988, to perform a major clean up of irradiated hardware, contaminated materials, and filters in the MP1 SFP. This clean up effort included three shipments of TN 8L shipping casks and one CNSI 3-55 cask.

The FRAP concluded that, because of uncertainty about the contents of the some of the containers of irradiated hardware in the SFP that were processed during this cleanup campaign, shipments of irradiated hardware in 1988 could possibly have contained the two fuel rods.

A May 31, 1988 memorandum from the NUSCo project manager in Berlin, to MP1 Engineering at Millstone, describes the lessons learned after completion of the 1988 SFP clean up activity and makes recommendations for the upcoming 1989 re-rack project:[49]

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[47] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report"

[48] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (pages 33-35)

[49] Memo, RAD3-88-49 ("Millstone Unit No. 1 Spent Fuel Pool Cleanup", 05/31/88

"At the project onset in September 1987, the plant was unable to provide the data required to generate a complete and accurate list of radwaste in the pool. Level of activity and waste classification of the material known to be processed was also unavailable. A request to obtain this information was denied by the plant due to dose limitations of the Maintenance department and the impact on the plant's ALARA[50] goals. The original work specification, therefore, listed material to be processed based on old memos, notes and recollection of plant personnel. The vendors were essentially asked to bid on a 'black or Pandora's box' concept."

The uncertainty about the non-fuel contents of the SFP – particularly the number and location of LPRMs – is potentially significant. Millstone and WasteChem records indicated that this clean up project involved about 151 LPRMs:

- 15 full length LPRMs removed during the previous two refueling outages;
- A container of 184 fission chambers removed from the 46 LPRMs shipped in 1985; and
- Twelve baskets and inserts containing segments of about 90 LPRMs that had previously been cut.

As discussed earlier, a relatively inexperienced contractor work force performed the September to October 1979 LPRM cutting operations.

Thus, if in 1979, workers cut the fuel rods by mistake and placed them in any of the twelve baskets and inserts, the rods could have been inadvertently shipped to Barnwell in 1988.

Indeed, GE records indicate that LPRMs, or segments of LPRMs, had been previously shipped to GE Vallecitos in 1972 for testing, unbeknownst to NNECo reactor engineers in 1988. Segments of an additional LPRM were sent to another lab for testing. And, in a later shipment, three LPRMs appear that were previously thought to have been among those in this 1988 shipment. Thus, if WasteChem accurately measured an amount of material equal to the length of 90 LPRMs before the May 1988 shipments, or if it shipped 98 LPRMs as it indicated in its final report, some portion of that material must have been something other than LPRMs.

The loading procedures used by WasteChem would probably not have led to the identification of the fuel rods, if they were in the containers of cut LPRMs. WasteChem did not attempt to verify the identity of the LPRM segments or perform a radiological survey of each piece. Rather, they surveyed each of the twelve containers as a whole, and then placed the contents of each container into a shipping liner. Specifically, WasteChem loaded the contents of six of the twelve baskets and inserts of LPRMs in the CNSI 3-55 liner, and the remaining six baskets and inserts into four of the six TN-8L liners, two in each cask.

[50] ALARA stands for "As Low As Reasonably Achievable" and refers to a program to reduce and control personnel radiation exposure.

The FRAP concluded:[51]

> "There is no clear and convincing evidence that the fuel rods were shipped to the Chem-Nuclear facility at Barnwell, but the evidence available indicates that the opportunities for the inadvertent shipment of the rods to Barnwell are higher at this facility than any of the other three possible locations. Of 16 shielded shipments to Barnwell that were investigated by the Project, two TN-8L cask shipments and the one CNSI 3-55 cask shipment to Barnwell in May 1988 stand out as having the most significant opportunity to contain the fuel rods."

1989 RE-RACK AND SHIPMENTS IN 1989 AND 1990[52]

After the May 1988 shipments, NNECo conducted the planned re-racking of the MP1 SFP. Soon after completing the re-rack, NNECo performed another clean-up of the pool beginning in the Fall of 1989. That clean-up effort culminated in MP1 shipping one shielded cask to Barnwell in late 1989 and three in 1990.

At the conclusion of the 1988 clean-up campaign, Reactor Engineering believed that all LPRMs had been shipped off-site, with the exception of the fission chambers cut from 46 LPRMs in 1985 (and possibly earlier).

However, what was believed to be an LPRM segment 8 to 12 feet long was noted during the 1988 re-rack project. Additionally, a November 1, 1988 radiation survey indicated that three LPRMs remained in the pool after the 1988 shipments.

The presence of LPRMs after the 1988 shipments is not necessarily suspicious. But, their presence in the pool after NNECo believed that it had shipped all LPRMs provides additional evidence suggesting that the objects shipped in 1988 were not LPRMs, as workers believed at the time.

1992 AND 2000 SHIPMENTS[53]

In 1992, MP1 again hired WasteChem to make three shielded shipments from the MP1 SFP to the LLRW facility at Barnwell. WasteChem used the TN-RAM cask for all three shipments.

The opportunity for workers to have inadvertently loaded the fuel rods in the second shipment arises because that shipment included the contents of a 12"x12"x 42" stainless steel box, which according to the bid specification and a SFP Inventory Log, contained "miscellaneous trash [measuring] 150R/hr." The Radiological Engineering Section Supervisor indicated in an interview, however, that the container actually included old LPRM pieces. The waste characterization for this shipment, prepared by the Radiological Engineering Section Supervisor, indicates that LPRM pieces equivalent

[51] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 6)

[52] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (pages 35, 36)

[53] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (pages 36-38)

to three LPRMs were included in this shipment. He based this conclusion on the word of the then RE, who informed him that the items were cut-up LPRMs. The actual identity of the items in the box is uncertain because individual pieces were not radiologically surveyed. Rather, workers surveyed only the external surface of the box. If the RE was correct, those LPRMs would have been older LPRMs that were not disposed of in earlier shipments. This provides additional evidence that the segments shipped in 1988 may not have been all LPRMs. But, because of the possibility that workers in the late 1970s may have inadvertently cut the fuel rods believing them to be LPRMs, and because the contents of the box of old LPRM pieces were not verified before shipment, the FRAP could not exclude the possibility that segments of the fuel rods were included in the TN-RAM shipment of December 8, 1992.

In anticipation of decommissioning, MP1 hired NUKEM, the successor of WasteChem, to conduct a series of shipments to the LLRW facility at Barnwell in 2000. Specifically, MP1 made six shielded shipments, five in a TN-RAM cask, and one in a CNSI 8-120B cask.

The final shipment in 2000 included an unidentified "bucket of debris." Having no description of the contents of the bucket, the size of the bucket, or the length of time the bucket was in the SFP precluded the FRAP from making any pronouncement about its contents. Some evidence suggests that the bucket contained pieces of boron tubes, but this evidence is not conclusive.

EVENT DISCOVERY

NNECo's decision to evaluate the possible use of an ISFSI for interim post-shutdown storage of MP1 spent fuel required characterization of the fuel, including its design, operational history, and isotopic weights. The necessary information had to be retrieved from a variety of station and corporate sources. In the course of this evaluation, personnel identified a number of discrepancies in fuel-related information during spring and summer of 2000.

The first indication of a spent fuel inventory issue involving these two fuel rods was the discovery of the May 15, 1979 memo to file discussed earlier in this narrative. By mid-Fall of 2000 the personnel involved had resolved fuel-related discrepancies except for location of the two fuel rods.[54] Following initial SFP searches that were unable to locate the two rods, NNECo initiated condition report CR M1-00-0548 in November 2000.[55]

NUSCo initiated the FRAP in early 2001 to resolve this discrepancy.

SALE OF PLANT TO DOMINION; IMPACT ON INVESTIGATION

Dominion Nuclear Connecticut, Inc. (DNC) bought Millstone Station, effective March 31, 2001. The FRAP continued under the direction of NUSCo, with no substantial impact

[54] Interview 14

[55] CR M1-00-0548, "Historical Unaccountability of Fuel Rods", 11/15/00

on the investigation itself. Station requirements for Root Cause Assessments remained substantially unchanged.

FUEL ROD ACCOUNTABILITY PROJECT INVESTIGATION

The FRAP investigation was completed at the end of September 2001 and concluded:[56]

> "...the investigation has determined that the rods are: (a) in an undetermined location in the Unit 1 spent fuel pool; (b) at GE's Vallecitos nuclear fuel facility; or (c) at one or both of the low-level radioactive waste ("LLRW") disposal facilities in Barnwell, South Carolina ("Barnwell") or the Hanford reservation in Richland, Washington ("Hanford"). Even if inadvertently shipped to a LLRW facility, the presence of the rods does not pose a danger to the health and safety of workers, the public, or the environment."
>
> * * *
>
> "Of the four possible locations, the LLRW facility at Barnwell, SC had the most significant opportunity to receive the rods. In particular, three shipments in 1988 contained the segments of about 90 Local Power Range Monitors ("LPRMs") that had been cut into pieces many years earlier and stored in containers in the spent fuel pool. These items, which are very similar in appearance to the fuel rods, were most likely cut in late 1979, shortly before the fuel rods disappeared from later spent fuel pool maps. Because the workers cutting the LPRMs lacked experience with reactor components, the workers may have mistakenly cut the fuel rods believing them to be LPRMs, and placed them in a container with the LPRMs. Many, if not all, of the LPRMs in that container were shipped to Barnwell in 1988.
>
> "Having concluded that the LLRW facility at Barnwell had a significant opportunity to receive the fuel rods does not mean that there is clear and convincing evidence that the rods are there. The evidence simply does not support that conclusion. In fact, there is <u>no</u> evidence, either in the form of documents or from interviews, that actually places the fuel rods in any of the off-site shipments to Barnwell or any other facility. The identification of the 1988 shipments to Barnwell as a potential explanation for the disposition of the fuel rods must be read in that context and not regarded as an established fact."

[56] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M10063, Final Report" (pages 2, 3)

3.0. CAUSATION

By definition, a root cause is a cause that cannot be attributed to a deeper underlying cause. A "root cause" inherently involves the motivations for and limits upon human behavior—the deepest "*whys*" behind the choices individuals made and the ways in which they behaved.

3.1 ROOT CAUSE

The RCAT determined that the "Root Cause" of this event was an unrecognized over-reliance on MP1 REs to compensate for organizational and process weaknesses in implementing the SNM inventory and control procedures. That unrecognized over-reliance masked certain behaviors and conditions that led to this event (the elements of the root cause):

- Process weaknesses associated with SNM inventory and control and radwaste characterization (Section 3.1.1);
- Weaknesses in coordination of SFP activities and procedural adherence (Section 3.1.2); and
- Inconsistent supervision and inconsistently applied oversight of SFP activities by knowledgeable individuals (Section 3.1.3).

Each of these three "elements" of the root cause of this event are discussed below. Refer to Section 5.2, "Corrective and Preventive Actions" of this report for the recommended actions to address the causes of this event.

3.1.1 PROCESSES

Although SNM inventory and control procedures in effect in the 1970s and 1980s impacted the ability to effectively account for individual fuel rods, the RCAT found no evidence that they interfered with the ability of REs to adequately control and account for fuel assemblies. After thorough review of the MP1 SNM control and accountability process in effect throughout the history of MP1, the RCAT noted the following weaknesses with respect to control and accountability of individual fuel rods:

MP1 SNM inventory and control procedures

- MP1 SNM inventory and control procedures applicable to MP1 did not specifically require individual fuel rods to be designated as SNM until September 11, 1990.[57] Although the procedures in effect at MP1 prior to that time did not prohibit fuel rod designation as SNM, inventory practices in place prior to September 11, 1990 did not readily accommodate such designation.[58]

[57] Procedure ACP-QA-4.10, Rev. 0, "Special Nuclear Material, Inventory and Control" (Section 4, "Definitions"), 09/11/90

[58] NNECo memo MP-1-1993, "Response to NUSCo Audit of Millstone 1 SNM Inventory and Control Procedure, RE 1001," 02/09/82

- Procedures did not clearly define the basis against which physical inventories were to be compared. This, in effect, left it to the REs to decide which documents to use as an "inventory of record."
- Although procedures required the Kardex file to be updated, they did not require the Kardex file to be used as a basis for physical inventory.
- Procedures required physical inventories of SNM location changes since last inventory, rather than complete physical inventory, and relied upon MTFs initiated since the last inventory to establish the basis of comparison. This amounted to a tacit assumption that the last inventory was complete and accurate, and that all SNM moves were captured on history of movement documents.
- Procedures did not address the need to document the "as-left" condition in MP1 records after a fuel vendor performed fuel-related work.

Based upon interviews, document reviews, and procedure analysis, the RCAT concluded that MP1 effectively controlled fuel assemblies, but not individual fuel rods. The behaviors and conditions from which the RCAT drew this conclusion included:

- MP1 lacked a single, integrated, readily retrievable "inventory of record" against which to compare SNM physically present.
- The fuel-related SNM inventory was based on a fuel assembly as the "unit of property" (typical of industry practice at the time) and was not managed in a way that easily accommodated tracking of individual fuel rods.
- MP1 became aware of weaknesses in individual fuel rod accountability (at least in the early 1980s), but neither corrected those weaknesses nor took steps to mitigate their impact.
- Location of individual fuel rods was not documented in a way that assured their inclusion in the basis for comparison used in future inventories. MS-557 fuel rod location was documented in the Kardex file in 1979; however, movement records—not the Kardex file—were the basis for physical inventory. Neither the FRAP nor the RCAT found documentation of individual MS-557 fuel rod movements.

Historical practices in the radiological characterization of radwaste shipments were likely to have influenced the consequences of this event, given the FRAP conclusion that the two rods might have been inadvertently shipped to a LLRW facility.[59] Regulatory requirements and industry practices for shipment characterization varied over time, with substantially fewer requirements in effect in the late 1970s and early 1980s.

Regulatory requirements changed significantly in late 1982, when more stringent requirements governing land disposal of radioactive waste were established.[60] New

[59] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 2)

[60] 10CFR61, "Licensing Requirements for Land Disposal of Radioactive Waste", 47 FR 57463, 12/27/82

requirements for characterization of radwaste shipments impacted nuclear generating plants as well as LLRW facilities.[61] Like most of the rest of the industry, Millstone responded in the mid-1980s with an enhanced program for characterizing radwaste shipment content, including more rigorous procedures, additional resources (and a group dedicated to managing radwaste shipments), and increased management attention.

Legacy waste[62] characterizations were often limited. In some cases, irradiated hardware processed for shipping (but not shipped) pre-dated the new requirements by several years, and was not always well identified.[63] Fuel rods (if previously cut up) would not have differed visibly from LPRM segments or other rod-like material to be shipped.[64] However, a few interviewees indicated that either they or GE personnel could probably tell the difference between LPRM hot ends and fuel rods.[65]

3.1.2 COORDINATION OF SFP-RELATED WORK AND PROCEDURAL ADHERENCE

"Ownership" of the SFP and associated evolutions was historically divided among several MP1 organizations. That was not an uncommon industry practice; however the MP1 SFP-related work was sometimes ineffectively coordinated.[66] The REs were responsible for fuel analysis, inspection, and accountability; Maintenance was often responsible for support of cleanup activities; Operations was responsible for movement of fuel and other core components (e.g., LPRMs). Several groups processed LPRMs for disposal at various times in MP1 history. SFP re-rack projects were managed from the corporate office. Site engineering had some involvement in SFP-related projects (e.g., support for cleanup and special tooling).

The RCAT believed that effective coordination and communication, and clear ownership and accountability were necessary for adequate SFP-related work control, housekeeping, and material condition. Ineffective coordination between the owner of fuel (including MS-557 fuel rods) and the owner(s) of LPRM disposal (including cutting, storage, liner loading, and shipping) may have been a contributor to the loss of physical accountability of the two fuel rods, particularly if the rods were shipped to a LLRW facility.

The RCAT identified examples of less than strict adherence to MP1 SNM inventory and control procedures. Those that impacted individual fuel rod accountability were:

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[61] 10CFR61.55, "Waste Classification"; 10CFR61.56, "Waste Characteristics"

[62] "Legacy waste" is radwaste that was at least partially processed for shipment (but not shipped) prior to major changes in Station or regulatory waste characterization requirements.

[63] Examples can be found in "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (pages 33, 34, 35, 37)

[64] Interviews 12, 20

[65] Interviews 3, 7, 10, 26, 33

[66] Interviews 5, 9, 16, 17, 18, 24, 28, 31

- MP1 REs did not always generate MTFs for SNM movement within an item control area (ICA) as required by procedure.[67] Both REs during the 1970s and 1980s were of the belief that movement records were not always required for SNM movement within an ICA.[68] Other interviewees indicated, however, they would not move fuel within an ICA without an MTF.[69]
- MTFs apparently were not written for movement of individual fuel rods following discovery in 1979. Although the cognizant MP1 RE believed he might have initiated an MTF for the May 1979 movement of the MS-557 fuel rods to the fuel prep machine for serial number reading, neither the FRAP nor the RCAT found documented evidence that MTFs were used at any time to document individual MS-557 fuel rod movement subsequent to their removal from their parent fuel assembly.

3.1.3 SUPERVISION AND OVERSIGHT

On the basis of numerous interviews and detailed RWP review, the FRAP and the RCAT identified periods of time where MP1 supervision and oversight of SFP evolutions was inconsistent. For example, in the late 1970s through the mid 1980s direct control of SFP cleanup assignments was often delegated to personnel who might not have had the requisite knowledge.[70] Several individuals interviewed noted that they rarely saw knowledgeable Millstone or vendor personnel involved in direct supervision of SFP cleanup activities[71] and commented to the effect that "if it was hanging off the railing, it was waste material and we got rid of it."[72]

Most individuals interviewed volunteered the information to the effect that "we understood to stay away from the fuel racks—and fuel wouldn't have been put any place else."[73]

3.2 CONCLUSIONS

It is true that the RCAT did not establish the deeper reasons why there was an inadvertent over-reliance upon the REs. This was an exceptionally cold trail to investigate, with choices and behaviors that shaped the event dating back as far as the late 1960s. It would be extremely difficult, if not impossible, to establish *why* people made the choices they did 20 or 30 years ago due to the departure of individuals through retirement, resignation, transfer, or death. In the considered opinion of the

[67] This requirement began with procedure RE 1001/21001, "SNM Inventory and Control" (Section 6.3.1.1), 11/15/73

[68] Interviews 6, 31, FRAP Group Interview PLR-RVF-07-27-01

[69] Interviews 4, 23, 26, 27, 28, 33

[70] Interviews 1, 5, 8, 15, 19, 21, 22, 24, 26, 28, 32, 35, 37

[71] Interviews 1, 5, 8, 15, 19, 21, 22, 24, 26, 28, 32, 35, 37

[72] Interviews 2, 10, 11, 36; FRAP Group Interview PLR-RVF-07-27-01

[73] Interviews 6, 25, 27, 28; FRAP Group Interview PLR-RVF-07-27-01

RCAT, it certainly was not necessary to do so to resolve current concerns or to prevent their recurrence.

The RCAT concluded that unrecognized organizational over-reliance put the REs in a position in which personal performance was forced to compensate for a number of weaknesses associated with the way MP1 controlled and coordinated SFP work and accounted for SNM. The RCAT found no specific evidence of currently unrecognized over-reliance on the Reactor Engineers.

More robust processes and procedures by definition reduce organizational reliance upon individual performance. Recommendations for actions in response to this event were targeted to address procedure and process weaknesses. Pending full implementation of those recommendations, the RCAT recommended interim compensatory measures.

Finally, the RCAT answered the questions asked in the investigation charter as follows:

LOSS OF FUEL ROD ACCOUNTABILITY

MP1 did not accurately account for the missing fuel rods because it did not effectively initiate, validate, and maintain those records that were necessary to ensure physical accountability of the fuel rods after they were removed from their parent assembly. Examples of such records or lack thereof included a single, integrated, readily retrievable "inventory of record"[74], MTFs, and SFP maps.

Additionally, MP1 experienced weaknesses in SNM control and inventory procedures and/or procedural adherence, a control process that did not readily accommodate consideration of individual fuel rods, and a failure to effectively apply basic inventory principles. When the RE who identified the two rods left Millstone in early 1980, he did not ensure that his successor knew of the existence and location of the two rods.[75] Because the processes and procedures were weak, the loss of this knowledge ultimately also led to the loss of accountability of the two rods.

Based on document reviews, interviews, and research performed by the FRAP team,[76] the RCAT concluded MP1 lost physical accountability of the two fuel rods because:

- Although not certain, the MS-557 fuel rods were likely stored near irradiated hardware intended for disposal, rather than in a location widely understood by MP1 SFP workers to be "off limits" (i.e., SFP fuel racks);

[74] SNM "inventory of record" means a single, integrated, readily retrievable listing of SNM entities ("pieces") that reflects SNM entities that should be on-hand and is updated in a timely manner to reflect additions and removals. SNM entities "that should be on-hand" are entities received less entities properly removed.

[75] Interviews 5, 6, and 31

[76] The FRAP concluded that the missing MS-557 rods were in one of four locations, but was unable to conclusively identify which one ("Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report", page 3).

- MP1 conducted a number of extensive SFP cleanup projects that included shipments of highly irradiated nuclear components, some of which had physical and radiological similarities to fuel rods;
- Weaknesses existed in SFP activity coordination and ownership; and
- SFP-related activities were inconsistently supervised, and oversight by knowledgeable individuals was inconsistently applied.

The vulnerabilities of the SNM control and inventory process did not extend to radiological controls. Physical control of the rods as radiological material was maintained, and was an important factor in protecting public and worker health and safety.[77]

UNTIMELY RECOGNITION OF ACCOUNTABILITY LOSS

MP1 did not recognize the loss of fuel rod accountability sooner primarily because SNM inventory practices did not effectively compare all SNM entities physically present with an "inventory of record." MS-557 fuel rods were not specifically part of the basis against which physical inventory was compared. The inventory practices were ineffective because:

- They confirmed the presence of expected SNM entities, rather than identified all SNM present; and
- Were typically limited to sighting those entities that had been moved since the last inventory, rather than complete inventories of SFP SNM content.

Underlying these practices were weaknesses in SNM control and inventory procedures, a control process that did not readily accommodate consideration of individual fuel rods, and a failure to effectively apply basic inventory principles.

The RCAT believed that other factors also played a role in the delayed recognition of the loss of physical accountability for the two MS-557 fuel rods. Those factors included CAP implementation, self-assessment of key SNM control and accountability program activities, and supervisory observations of work. Each of those factors offered the potential, but not the certainty, that this event might have been detected sooner. Because the CAP was beyond the scope of this investigation and an existing focus area for Millstone in 2001, the RCAT made no recommendations in that regard. The RCAT did include recommendations related to self-assessment and supervisory observations.

[77] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 2)

4.0 ANALYSIS

4.1 SNM INVENTORY AND CONTROL PROCESS

The SNM control and inventory process played an important role in this event. This process is discussed below, followed by a description of the "state of the industry" that was developed through discussions with other nuclear stations.

4.1.1 MP1 SNM INVENTORY AND CONTROL PRACTICES

Overall requirements for SNM accountability were defined in 10CFR70, "Domestic Licensing of Special Nuclear Material" (10CFR70).[78] Regulations require nuclear generating plants to:[79]

> "... establish, maintain, and follow written material control and accounting procedures that are sufficient to enable the licensee to account for the special nuclear material in the licensee's possession..."

"Special nuclear material" was first defined in regulation in 1956[80], with the definition unchanged as of 2001.[81] The definition of "special nuclear material of low strategic significance"[82] was added in 1985, and has not changed since.[83] Each of the two fuel rods from MS-557 met the definition of SNM of low strategic significance because they contained approximately 90 to 95 grams of U^{235} plus small amounts of other fissile material.[84]

MILLSTONE SNM INVENTORY AND CONTROL PROCEDURES

SNM inventory and control activities at Millstone were defined in procedures. Those procedures were in place at MP1 before commercial operation and have evolved through the present. SNM procedures were initially issued at MP2 in 1973 and in 1984 for MP3.

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[78] Although "SNM Accountability" itself was not

[79] 10CFR70.51

[80] 10CFR70.4(m); Federal Register, 02/03/56

[81] Based upon historical search of 10CFR70.4

[82] 10CFR70.4(aa)

[83] Based on historical search of 10CFR70.4

[84] Each of the two fuel rods met the 10 CFR Part 70.4 definition of SNM of low strategic significance because they contained more than "15 grams of plutonium or the combination of 15 grams when computed by the equation, grams = (grams contained U-235) + (grams plutonium) + (grams U-233)." According to the MP1 Kardex file, rod BP0406 and rod BK0136 initially contained 3,892 grams and 3,656 grams of uranium respectively. Those two fuel rods had a U-235 enrichment of 2.44%. Therefore, each of the two missing MS-557 fuel rods contained on the order of 90-95 grams of U-235 and met the definition of SNM of low strategic significance.

The inventory and control procedures established MP1 requirements for administrative receipt of SNM, tracking and documentation of SNM movements, reporting of SNM information to the corporate SNM accountant, periodic physical inventories, and SNM audits.

Throughout MP1 operations, SNM control and "entity" inventory activities centered around two positions: the RE and the RE Bookkeeper. By contrast, the corporate SNM Accountant was responsible for maintaining and reporting isotopic weight inventories for all three Millstone units, and was not directly involved in physical inventory of SNM entities. Additional positions involved with SNM control and "entity" inventory included the cognizant licensee Officer (generally the Unit Superintendent), individuals who received and handled SNM, the SNM "Executor", and the SNM "Checker".

MP1 INVENTORY AND CONTROL PROCEDURE, CIRCA 1979

The procedure for SNM inventory and control in effect in 1979 did not specifically mandate its applicability to individual fuel rods. Rather, like the previous version it stated:[85]

> "NOTE: For the purpose of this procedure, the following shall be considered to be SNM:
>
> Fuel Assemblies
>
> Fission Chambers
>
> Any other material designated by the Reactor Engineer."

MTFs were key documents in the SNM accountability process upon which subsequent physical inventory and record keeping depended. MTF initiation for SNM entity moves was critical to maintaining accurate SNM records. Concerning the use of MTFs, the RCAT noted a possible point of confusion in the "SNM Inventory and Control" procedure in effect at the time.[86]

> The ICA definition (section 1.2.2) stated, "Item Control Areas (ICA's) may be any physical areas designated by the Unit Reactor Engineer which are clearly separable from all other areas and are within the protected area of the plant site. ... All material subject to this procedure must be stored within designated ICA's and *no material may be transported across the boundaries of any ICA without completion of a Materials Transfer Form* except as provided in 6.3.1." [Emphasis added]
>
> However, Step 1.3.2.1 stated that the RE was responsible for "Initiating requests for movement of SNM across ***or within*** the boundaries of any ICA (see 1.2.2)." [Emphasis added]

[85] Procedure RE 1001, Rev. 1, "SNM Inventory and Control," 01/17/79, section 1.2.1; also Rev. 2, 05/11/79

[86] Procedure RE 1001, "SNM Inventory and Control," Rev. 2, 05/11/79

Step 6.3.1, Initiation stated that "A Materials Transfer Form may be initiated by the Unit Reactor Engineer or his designee and is required under the following conditions as specified:

> "6.3.1.1 Any movement of SNM ***within*** or across the boundaries of any ICA requires the previous preparation and approval of a Materials Transfer Form, except as exempted in Paragraphs 2 and 3 to follow." [Emphasis added]

The two paragraphs that followed (6.3.1.2 and 6.3.1.3) allowed MTFs to be created "as soon as practical" after completion of SNM moves in narrowly defined situations.

The RCAT concluded that, although somewhat internally inconsistent, the procedure required MTF initiation for *all* SNM movement, whether within or across ICA boundaries. However the MP1 REs in the 1970s and 1980s believed MTFs were not always required for movements within an ICA during this time period.[87]

MP1 SFP Maps and Mapping Practices

To better understand the role of the maps and how they were produced, maintained, and updated, the RCAT reviewed available SFP maps and associated documents with members of the RE group from the 1970s and 1980s during a number of interviews.[88] The RCAT developed the following composite description of SFP map/SNM inventory practices:

SFP maps were used to compare actual fuel location within the SFP with expected location during fuel inventories of the SFP.

Draft versions of "new" SFP maps were usually prepared from the previous map and movement history records. This was a laborious, tedious effort requiring numerous hand entries. A number of REs involved in MP1 SFP SNM verifications in the '70s and '80s described the process as "cut and paste," with new maps being completely redrafted only when the existing map had deteriorated beyond reasonable use.

None of the MP1 REs interviewed recalled performing SFP inventory with a blank map. "Verification" of SFP maps did not generally involve the entire SFP; typically, only items moved since the previous map (as documented on MTFs or equivalent) were verified. If movement records were not generated (MTF or equivalent), the associated item(s) would probably not have been visually verified. The continued presence of fuel assemblies would have been confirmed by counting the number of assemblies in the SFP.

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[87] Interviews 6, 31

[88] Interviews 5, 6, 13, 14, and 27

Physical SFP map "verification" amounted to visual confirmation that expected fuel assemblies were in expected locations, and did not include inspecting for the presence of fuel (or other SNM) where it was not expected.

Non-fuel SNM entities (e.g., dunking chambers, SRMs, and LPRMs) were not documented on SFP maps.

SFP maps were maintained within RE Department records. At the time of this investigation, all of the SFP maps that were believed to exist could not be retrieved from either the RE Department or nuclear records.

Given the SFP mapping practices described above and the use of these maps as the basis against which physical items were compared during SNM entity inventories ("piece counts"), the RCAT concluded that uncorroborated documentation of the presence or absence of individual fuel rod location on SFP maps was not necessarily a reliable indicator of physical presence or absence of individual fuel rods in the SFP.

Inventory Process Weaknesses

After thorough review of SNM inventory and control procedures in effect throughout the history of MP1, the RCAT noted a number of weaknesses associated with their application to individual fuel rods. These weaknesses, however, did not adversely impact control and accountability of intact fuel assemblies.

- MP1 SNM procedures were confusing with respect to content, logic and format; construction of flowcharts diagramming programmatic actions revealed a number of instances in which informed assumptions by procedure users were necessary to carry out procedural intent. In spite of this, MP1 maintained control of fuel assemblies. MP1 procedures improved somewhat in the late 1980s, and again throughout the 1990s.
- SNM inventory and control procedures applicable to MP1 did not specifically require individual fuel rods to be designated as SNM until September 11, 1990.[89] Although the procedures in effect prior to that time at MP1 did not prohibit fuel rod designation as SNM, inventory practices did not readily accommodate such designation.[90]
- Procedures did not clearly define the basis against which physical inventories were to be compared ("inventory of record"), or describe the requirements inventories were to meet. This, in effect, left these decisions to the REs and the extent to which they applied the inventory process.
- While procedures required the Kardex file to be updated, they did not require the Kardex file to be used as the basis for physical inventory.

[89] ACP-QA-4.10, "Special Nuclear Material, Inventory and Control" (Section 4, "Definitions"), 09/11/90

[90] NNECo memo MP-1-1993, "Response to NUSCo Audit of Millstone 1 SNM Inventory and Control Procedure, RE 1001," 02/09/82

- Procedures required physical inventories of SNM location changes since last inventory, rather than complete physical inventory, and relied upon MTFs initiated since the last inventory to establish the basis of comparison. This method relied heavily on the last inventory and presumed that all SNM moves were captured on movement documents.
- Procedures were silent with respect to interface with fuel vendor evolutions, and did not address the need to capture the "as-left" condition (i.e., after fuel-related work was performed by a fuel vendor) in the MP1 SNM control and inventory system.
- MP1 REs did not always generate MTFs for SNM movement within ICA as specified in the procedure.[91] REs during the 1970s and 1980s were of the erroneous belief that movement records were not required for SNM movement within an ICA.[92] Other interviewees, however, indicated that they would not move fuel within an ICA without an MTF.[93]
- MTFs apparently were not written for movement of individual fuel rods following discovery in 1979. The RCAT was unable to locate evidence that MTFs were used to document individual MS-557 fuel rod movement at <u>any</u> time.

The RCAT concluded that as the SNM procedures matured, the process for controlling SNM entities became more robust. For example, MP2 specifically addressed SNM status of individual fuel rods in 1987.[94] About three years later in 1990, Millstone Station issued a site procedure, applicable to all three units that specifically required individual fuel rods to be classified as SNM.[95] Later program documents further defined SNM control requirements and provided a "road map" of implementing documents.[96]

CURRENT SNM CONTROL AND ACCOUNTABILITY PROGRAM

As of the completion of this investigation, current responsibilities and requirements for the SNM Control and Accountability Program are intended to be defined by Master Manual 13 and subordinate implementing procedures. Master Manual 13 exists; however, the implementing procedures are in various stages of development with full implementation scheduled for December 2002.[97]

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[91] Procedure RE 1001, Rev. 2, "SNM Inventory and Control", 05/11/79, step 6.3.1 and subordinate steps

[92] Interviews 6, 31

[93] Interviews 4, 23, 26, 27, 28, 33

[94] Procedure EN 21001, Rev. 9, "Special Nuclear Material Inventory and Control" (Section 1.2.1), 08/26/87

[95] Procedure ACP-QA-4.10, Rev. 0, "Special Nuclear Material Inventory and Control" (Section 4, "Definitions"), 09/11/90

[96] Procedure MP-13-SNM-PRG, "Millstone Special Nuclear Material Control and Accountability Program", Rev. 0, 09/27/99

[97] Based upon review of existing procedures and discussion with Process Owner, Nuclear Fuels and Safety Analysis

Based on review of the current SNM program (MP-13-SNM-PRG) and implementing procedures, and interviews with cognizant personnel, the RCAT concluded that Millstone had effective administrative control of SNM as of investigation completion, albeit with room for improvement.

4.1.2 CONTEMPORANEOUS INDUSTRY SNM INVENTORY AND CONTROL PRACTICES

The RCAT contacted about a dozen nuclear licensees to establish a general picture of past and present inventory and control practices within the nuclear industry. The sample included both BWRs and pressurized water reactors. This effort was qualitative in nature, and not intended to be a scientific survey.

The RCAT developed the following description of SNM inventory and control practices at US nuclear generating plants:

- SNM inventory and control programs were much less formal in the 1970s than in 2001.
- There was no consistent industry practice for documenting and defining the official physical inventory ("inventory of record"), either in the past or as of the date of the survey. Some stations utilized a computer program; others used manual systems.
- Some stations indicated they currently used an electronic data base developed and maintained from SNM movement records as the "inventory of record." (The RCAT noted that this practice relied heavily on consistent use of movement records for documenting movement of *all* SNM, including individual fuel rods.)
- Most of the stations contacted reported that they had always used some type of "history of movement" form when moving individual rods.
- NRC guidance was available prior to 1975, until approximately 1997 in the form of a Regulatory Guide.[98] This document addressed control and accountability of individual fuel rods.
- Some stations currently had individual fuel rods or fuel fragments stored in special containers in the SFP fuel racks. None of the stations contacted had individual fuel rods stored outside of fuel racks at the time of the survey. Evidence was inconclusive as to whether all of the stations contacted always stored individual rods in fuel racks in the past.
- Several stations stated that they had always designated individual fuel rods as SNM entities when not installed in fuel assemblies. For a number of other stations, the evidence was inconclusive with respect to if they had done so

[98] Regulatory Guide RG-5.29, Rev. 1, 06/75, which endorsed ANSI N15.8 guidelines for nuclear material control systems at nuclear power plants.

throughout their entire operating history. One station's current written procedures did not explicitly require individual rods to be designated as SNM.

- A number of stations reconciled[99] their fuel inventory upon learning of the MP1 event. In some cases stations found this to be more difficult than they had initially anticipated.
- RE at most stations exercised inventory controls for all items in the SFP (fuel and non-fuel).
- None of the stations contacted believed they had current problems with their ability to account for individual fuel rods.

The RCAT concluded that past MP1 practices were generally similar to industry practices at that time, with the possible exceptions of always designating and tracking individual fuel rods as SNM entities, and consistent initiation of history of movement records for SNM movement within an ICA. Evidence was inconclusive as to whether historical storage practices for individual fuel rods at MP1 differed substantially from contemporaneous practices at other "older BWRs." Current practices for fuel rod control and accountability at Millstone Station appeared to be consistent with industry norms.

[99] To "reconcile," as used in this report, means:

a. To compare physical SNM entities to an SNM "inventory of record" (a single, integrated, readily retrievable listing of entities that is the difference between entities received, less entities appropriately removed);

b. Identify differences, if any, between SNM entities physically present and the "inventory of record";

c. Determine reason(s) for mismatches, if any, between documentation and physical entities; and

d. Take appropriate action to address mismatches, including appropriate documentation and reports.

4.2 MISSED OPPORTUNITIES

The RCAT identified a number of "missed opportunities" to have recognized event precursors or causes that might have changed the course of the event had they not been missed. It was unrealistic to expect that every opportunity could have been contemporaneously recognized and promptly acted upon. The important collective "message" was the cumulative opportunity available to MP1 to have identified an event in the making and to have taken action to prevent the event or mitigate its consequences.

The RCAT considered missed opportunities in terms of how they might have been identified. Opportunities presented themselves through self-identification, in the conduct of or response to internal audits, when responding to NRC inspections, and through review of industry operating experience. Each of these areas is discussed below.

4.2.1 SELF IDENTIFICATION

Opportunities for workers and line management to have self-identified precursors or causes that might have changed the course of the event included:

- SFP cleanup campaigns
- SFP mapping
- Comparison of practices and procedures between station units
- Definition, use and maintenance of an SNM "inventory of record"
- Recognition of individual rods in SFP: 1972; 1974; 3/9/77 memo to GE requesting SRP rods be incorporated into a scrap fuel bundle [MP-1-360]
- "Extent of condition" in response to 1981 GE notification of wrong STR rods put in core[100]
- Extent of condition in response to self-identification of the loss of two IRMs (1994)[101]
- Formal self-assessments (weaknesses noted in 1997 audit[102])

[100] GE Memo Fuel Operations and Testing Units to Fuel Project Manager, "Millstone-1 STR Bundle Loading Analysis," SYO-120, 05/12/81

[101] NRC Inspection Report No. 50-245/94-19, 07/21/94 [reported inability to locate two IRMs in LER 94-016-00 "Loss of Special Nuclear Material Accountability", 05/23/94]

[102] Nuclear Oversight Audit Package MP-97-A04-07, "Special Nuclear and Byproduct Materials", AE-97-4089, 05/16/97

The RCAT found limited evidence of formal self-assessment performance in the area of SNM control and inventory. The evidence found was limited to assessments performed within sixteen months of investigation completion.

The RCAT concluded that if self-assessments were performed prior to 1994, they were of limited effectiveness. Additionally, the RCAT found no specific procedural requirement for Reactor Engineering to self-assess the SNM control and accountability program prior to February 1998. Procedure MC 5, Special Nuclear Material Inventory and Control (starting with Rev. 0, 02/23/98, and continuing through the date of this report), included a requirement for Reactor Engineering to evaluate on a yearly basis the need to perform a Nuclear Oversight audit or a self-assessment of the SNM inventory control program.[103]

The RCAT found documents reporting that self assessments had not been performed between 1994 and 1999. The 1997 audit concluded:[104]

> "MP1 RE appears not to have had an effective self-assessment program since 1994. [The limit of the period examined by the audit.] The issues identified by NRC in NOV [Notice of Violation] 50-245/94-19, based on inspection of M1, remain open. NNECo's response to this NOV included commitments to corrective action (procedure changes) to be completed by 9/30/94 which has [sic] not been implemented. NSAB[105] Audit 24047 [reported 9/27/94] identified many of the same issues which remain open."

The 1999 audit observed:[106]

> "MC-5 requires that each of the Unit Reactor Engineering Departments evaluate the need to perform a self assessment of the SNM Inventory and Control Program on a yearly basis. The MP1, MP2, and MP3 Reactor Engineering Departments performed this evaluation in 1998 and determined that they would not perform these self assessments. They justified this, in part, based on the completion of the 1997 SNM audit. This was a missed opportunity to identify and correct the Deficiencies identified during the current Audit."

The 2001 audit noted that a self-assessment of SNM inventory and control had been satisfactorily completed since the 1999 audit.

The RCAT reviewed self-assessments performed in 2000[107] and concluded that the assessments adequately evaluated compliance to SNM control and inventory

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[103] As described in section 1.8 of MC 5, there was no specific regulatory requirement for annual SNM audits at commercial nuclear power stations. However, each Unit was required by procedure to "periodically perform an audit or self assessment of the SNM records."

[104] NUSCo memo AE-97-4150, 06/23/97, "Nuclear Oversight Audit Package MP-97-A04-07, 'Special Nuclear and Byproduct Material Control and Accountability'"/audit report MP-97-A04-07 (undated) (page 31)

[105] NSAB is the "Nuclear Safety Assessment Board".

[106] NUSCo memo SES-NO-99-006, 06/18/99 "Northeast Utilities Quality Assurance Audit MP-99-A08, 'Special Nuclear/Licensed Materials' Millstone Station"/audit report MP-99-A08 (undated) (Executive Summary, page 2 of 5)

procedures. However, neither self-assessment identified inventory process vulnerabilities, or the lack of a definitively established "inventory of record."

The RCAT also reviewed a self-assessment finished shortly before the completion of this investigation that was targeted to examine the adequacy of "inventories of record" for the three Millstone units.[108, 109] The assessment purpose was to establish the "inventory of record" for each unit, and to evaluate the adequacy thereof. The assessment concluded that the "inventory of record" consisted of the semi-annual SNM inventory maps of cores, spent fuel pools, and new fuel vaults, and recommended a number of changes to procedure MC-5 ("Special Nuclear Material Inventory and Control") to clarify requirements associated with SNM inventories.[110]

In a separate but related effort, Millstone reconciled fuel on-hand at MP2 and MP3 with the newly-determined "inventories of record".[111] MP1 fuel had been previously reconciled with inventory records by the FRAP project.

4.2.2 *INTERNAL OVERSIGHT ASSESSMENTS*

The responses to internal audits might also have recognized precursors or causes, for example:

- SNM audit (memo NE-82-F-004 of 01/05/82) noting GE STR shipping mix-up and problems with SNM card file system.
- The Unit 1 Superintendent's response to this audit (MP-1-1993 of 02/09/82) stating "accountability of SRP[112] rods will continue to be performed using reconstitution documents provided by the General Electric Company."
- Opportunities to ask about accuracy of inventory during each audit
- "Extent of Condition" assessment for audit-identified deficiencies

[107] Self-assessment MP-SA-00-112 of 12/00, "Special Nuclear Material Inventory and Control" [for MP2, MP3]; Self-assessment Decomm-00-205 of 06/06/00, "Self Assessment of Special Nuclear Material Control at MP1 (MC-5)"

[108] Self Assessment MP-SA-01-046, "Self Assessment Report, Special Nuclear Material", September, 2001

[109] Additional description of scope and relationship to other activities was documented in Dominion memo NE-01-F-280, "Millstone 2 and 3 Special Nuclear Material Reconciliation (CR-01-08963)", 10/05/01.

[110] Prior to this self-assessment, "inventories of record" were not specifically defined for all three Millstone units. The "evaluation of adequacy" amounted to a verification that "inventories of record" were accurate. Although not emphasized by the report, this verification was a non-trivial exercise that required review and comparison of all Form 741s, US government TJ-23 reports, "shuffleworks" program output (SNM maps), and Kardex file entries, as well as verification of records retrievability.

[111] DNC memo NE-01-F-280, "Millstone 2 and 3 Special Nuclear Material Reconciliation (CR-01-08963)", 10/05/01

[112] SRP was the "segmented test rod program"

The RCAT reviewed 32 audits of MP1 SNM inventory and control conducted between September 1971 and June 2001[113]. The SNM audit program may be categorized into three distinct groupings in terms of chronology and audit quality:

- Audits conducted by the SNM Accountant, Nuclear Fuels, and/or Licensing personnel between 1971 and 1986;
- Audits performed by the Millstone/NUSCo quality organization between 1987 and 1994; and,
- Audits performed by the Millstone/NUSCo quality organization after 1994.

Audits by SNM Accountant & Non-QA Personnel (1971 – 1986)

The SNM Accountant and/or other non-QA organization personnel performed SNM audits for the first 16 years of MP1 operation. The RCAT observed that this group of audits, as documented by associated reports and audit plans, exhibited a number of weaknesses.

Station response to audit findings was typically limited to correcting the specifically identified deficiencies, with no evidence that "extent of condition" evaluations were performed. Neither the audit reports nor the responses appeared to consider the potential significance of reported deficiencies.[114]

An historic audit weakness (missed opportunity) was a failure to identify an obvious loss of component accountability of STR program individual fuel rods in 1981, or to note that the issue had been previously reported by the NRC.[115] The associated audit report "discussed" this event as follows:[116]

> "During this discussion, [the Reactor Engineer] indicated that two (2) partial length fuel rods from MSB 125, the STR bundle, were mixed up during the reconstitution at the end of Cycle 7. Two rods that were shipped to GE were found to have different serial numbers than those scheduled for shipment, and the rods scheduled for shipment were actually still contained in the STR bundle which was reinserted in the reactor at the beginning of Cycle 8."
>
> * * *
>
> "[The Reactor Engineer] also indicated that a problem exists in the tracking of the segmented fuel from the STR bundle—MSB-125. Some of the fuel pins were grouped together by date received as a single SNM card file entry, then part of the initial receipt was shipped off site or part removed from the bundle and placed in SFP as assembly MSB-125 was reinserted into the core. This item was not resolved."

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[113] As best the Root Cause Team could determine, these 32 audits were all the internal audits conducted of Unit 1 SNM control and accountability throughout plant life.

[114] For example, the RCAT found no evidence that the physical inventory process vulnerability to untimely, incomplete, or inaccurate MTF initiation was considered by either auditors or MP1, although numerous examples of MTF-associated errors were reported in a number of audit reports.

[115] NRC Inspection Report 50-245/81-06 & 50-336/81-05, 07/14/81

[116] Audit Report, "Audit of SNM Inventory and Control Procedure RE 1001," (memo NE-82-F-004), 01/05/82

Approximately one month following publication of the Audit Report, the Unit 1 Superintendent responded to the SNM Accountant concerning the failure to enter MTF data for the STR Bundle (MS 125) into the SNM card file[117]:

> "... As was discussed at the time of the audit, entry of this data is not compatible with the present SNM card file system. The tracking method being developed by Connecticut Yankee and an alternate method being developed by NNECo Reactor Engineering personnel will be considered for implementation upon completion. Until that time, accountability of SRP rods will continue to be performed using reconstitution documents provided by the General Electric Company."[118]

This mistaken accounting of the two segmented rods is significant because it provided MP1 with the knowledge that its SNM tracking and control processing were not effective in preventing the loss of accountability of individual fuel rods. In other words, the event provided an opportunity for MP1 to have either prevented the loss of physical accountability of the two MS-557 rods, or to have discovered the loss sooner. Additionally, the SNM Accountant, who participated in the audit, was aware that two individual fuel rods from MS-557 also existed outside of an assembly. Nevertheless, he did not draw a correlation between the STR shipment and the potential vulnerability of the rods from MS-557.

Audits by Millstone/NUSCo Quality Organization (1987—1994)

The quality organization took over responsibility for SNM audits beginning in 1987. Review of the 11 audits performed between 1987 and 1994 indicated that audit quality improved. They were now performed by personnel trained in audit techniques and requirements; audit durations were greater, procedural requirements against which performance was compared were more clearly specified, and audit reports became more detailed. Audit reports began using clearer language to describe findings and non-compliance with procedural requirements was labeled as such.

That said, these audits continued to exhibit some of the weaknesses present in the earlier group of audits, including:

- A focus on compliance to procedures without evaluation of procedural adequacy to meet regulatory intent;

[117] NNECo memo MP-1-1993, "Response to NUSCo Audit of Millstone 1 SNM Inventory and Control Procedure, RE 1001," 02/09/82

[118] Apparently, the SNM Accountant accepted this response. The Root Cause Team noted that GE reconstitution documents:

- Provided documentation of "as left" conditions at the time GE personnel left Millstone Station;
- Were not discussed or otherwise authorized for use by the SNM Inventory and Control procedure in effect at the time;
- Had not prevented the 1981 loss of control of SRP test rod segments;
- Did not interface with Millstone SNM inventory and accountability documentation (i.e., Kardex file, MTFs)

- Little or no evaluation of the effectiveness of past corrective actions;
- Little evidence that NRC inspection observations were considered;
- Little evidence that line ability to find and fix its own problems was evaluated.

While Station responses improved in terms of the detail reported, corrective actions generally continued to be limited to correction of specific deficiencies identified, with no evidence of "extent of condition" evaluation performance. Neither the audit reports nor the responses questioned the significance or potential impact of the cumulative deficiencies reported over the years.

Audits by Millstone/NUSCo Quality Organization (after 1994)

Beginning in 1997, Millstone SNM audits improved dramatically in terms of depth, preparation, and thoroughness. Major improvements included:

- Consideration of NRC observations;
- Evaluation of effectiveness of past corrective action;
- Comparison of Millstone Station to industry practices;
- Consideration of "Operating Experience";
- Evaluation of self-assessments;
- Adequacy of procedures to carry out regulatory intent.

Audits in this most recent grouping were conducted in 1997, 1999, and 2001. In the course of its investigation, the RCAT discovered essentially no additional information relevant to current station performance beyond that considered by the most recent audit.

The RCAT concurred with conclusions of the 2001 audit that procedural compliance and program implementation has significantly improved in recent years, based upon its own in-depth review and analysis.

4.2.3 NRC INSPECTIONS

The AEC and later the NRC concentrated (and continues to focus) SNM inspection resources on fuel fabricators and facilities that used high enrichment fuel. Inspection and oversight of generating plants in the area of SNM was a lesser priority, as reflected by less in-depth and less frequent inspections.[119] The fuel used by generating plants licensed under 10CFR50 is of low enrichment, with individual fuel rods falling in the category of "SNM of low strategic significance."[120]

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[119] Interview 34

[120] Refer to Section 2.2, "Background" for a discussion of SNM and SNM of low strategic significance.

The RCAT reviewed the NRC Inspection Procedures dating from 1984 and 1985 applicable to SNM inventory and control inspections.[121] Where the procedure discussed fuel-related SNM, it did so in the context of fuel assemblies and did not address the potential for fuel rods to be present outside of fuel assemblies.

The RCAT reviewed over 40 inspection reports covering the entire period of MP1 commercial operation in the course of this investigation, of which 23 examined SNM inventory and accountability, fuel handling, or SFP conditions. Of these inspection reports, four presented opportunities to have mitigated the event to one extent or another:

- In April 1976, the NRC issued a NOV to MP1 for failure to keep current the "SNM Inventory Account" and "Summary of Fuel", failure to conduct periodic piece count inventories, and failure to perform other SNM control activities in a timely manner.[122] Failure to identify two individual rods in the SFP until 1979 suggests that corrective actions in response to this violation did not include establishing an accurate inventory of on-hand SNM. This was a missed opportunity to have: (1) performed a complete inventory of SNM (and SFP content) and documented the two individual rods earlier; and, (2) identified and corrected the deficiency that caused the then-current inventory and tracking process to have missed the two rods.
- In March 1978, the NRC noted that MP1 did not adequately oversee vendor activities associated with the MP1 STR program (No quality assurance (QA) hold points designated or surveillances scheduled).[123] Interfaces between MP1 and the STR program did not change beyond the addition of QA hold points and MP1-performed surveillances. The opportunity to establish practical methods for tracking and controlling individual fuel rods was (apparently) not taken.
- As discussed earlier, in April 1981, the NRC noted that the wrong STR segments had been installed in the MP1 core.[124] To the best of the RCAT's ability to determine, the response was limited to increased MP1 oversight of vendor STR activities and vendor procedural enhancements. MP1 SNM control practices and the process interface between vendor STR program and MP1 SNM inventory practices remained unchanged. The SNM Accountant at the time knew that two individual fuel rods from MS-557 were in the SFP as of May 1979, but did not associate weaknesses in controlling individual SRP rods with the potential for similar problems in controlling the two MS-557 rods. This was a missed

[121] NRC Inspection Procedure 85102, "Material Control and Accounting—Power Reactors", 02/21/84, and it's replacement Inspection Procedure 85102, "Material Control and Accounting—Reactors", 03/29/85

[122] NRC Inspection Report 50-245/76-08, 05/25/76

[123] NRC Inspection Report 50-245/78-07, 04/03/78

[124] NRC Inspection Report 50-245/81-06 and 50-336/81-05, 07/14/81

opportunity to identify this potential problem, and correct the process weakness.

- In July 1994, the NRC issued a NOV to MP1 for inability to locate two IRMs (self-identified) and several other non-fuel SNM issues (identified by the NRC).[125] The MP1 response attributed the violations to "management's failure to establish and monitor adequate standards and expectations with regard to the appropriate handling and control of non-fuel SNM."[126] The RCAT was unable to locate evidence that fuel-related SNM practices changed in any way, or that robustness of fuel-related SNM control was evaluated for potential vulnerability. This was a missed opportunity to have examined whether the "management failure" extended to fuel-related SNM, to have performed a complete SNM reconciliation, and to have identified the event several years sooner.[127]

Based on a review of inspection reports, inspection procedures, relevant regulations, and conversations with and interviews of NRC personnel,[128] the RCAT concluded:

- Some of the NRC inspections (historical) identified issues regarding radwaste shipments and SNM control and accountability that should have been previously identified by line organizations, NNECo management, or internal oversight.
- For some (historical) NRC inspections findings, the RCAT could not always determine exactly what (if anything) was done to resolve the condition and prevent recurrence.
- NRC inspections were not the limiting factor in the area of SNM control and accountability performance at MP1; MP1 responses to inspection observations corrected the specifically identified discrepancies, but did not adequately address "extent of condition".

[125] NRC Inspection Report 50-245/94-19, 07/21/94

[126] NUSCo letter B14940, "Millstone Nuclear Power Station Unit No. 1, Reply to Notice of Violation and Notice of Deviation, Inspection Report No. 50-245/94-19," 08/26/94 (page 3)

[127] The RCAT noted that had the event been identified in 1994, a number of documents destroyed during decommissioning activities would have been available, the "investigation trail" would have been "less cold", and then-current location of fuel rods may have been possible to establish with more precision than the FRAP was able to do.

[128] Interviews 61, 34

The responses to NRC inspections might also have recognized precursors or causes. Examples include:

- 04/76 NOV for failure to keep current SNM Inventory Account and Summary of Fuel; failure to conduct periodic piece count inventories, other SNM control activities not performed in timely manner
- 03/78 weaknesses in MP1 oversight of STR rod program
- 04/81 NRC noted wrong rods in core re: STR program
- 07/94, NOV re: inability to locate two IRMs (self-identified); response limited to non-fuel SNM

The RCAT observed that in 2001, station management expected the SNM control and accountability program "owner" to implement timely and effective corrective action to resolve concerns and prevent recurrence, and to use trending to identify issues before they became self-revealing events. The RCAT found evidence that personnel involved with SNM control and accountability currently used the CAP.

4.2.4 INDUSTRY OPERATING EXPERIENCE

The RCAT concluded that available industry operating experience did not provide a sufficient basis for concern that fuel-related SNM accountability weaknesses might be present at MP1. The "internal operating experience" (in the form of internal audits and site-specific NRC inspections) was of greater significance.

As noted elsewhere, the inability to account for two individual fuel rods at MP1 was the first event of its kind in the US nuclear industry. The opportunity to have learned from a similar event elsewhere was therefore not available.

The RCAT conducted a comprehensive search of common nuclear industry "operating experience" sources, and identified numerous examples of incidents at other nuclear plants involving SNM issues. However, none of these individual incidents presented sufficient reason to question whether a similar problem might exist at MP1.

In a 1988 Information Notice, the NRC identified the industry's SNM performance weaknesses.[129] The weaknesses identified, however, were not such that MP1 should have realized that its accountability of individual fuel rods was lacking.

[129] NRC Information Notice 88-34, "Nuclear Material Control and Accountability of Non-Fuel Special Nuclear Material at Power Reactors," 05/31/88

4.2.5 *CORRECTIVE ACTION PROGRAM (CAP)*

The function of the CAP is to identify and resolve potentially adverse behaviors and conditions, and improve performance. It accomplishes this by providing a process through which the organization can report problems to be evaluated, prioritized, and acted upon in a manner commensurate with issue significance and organizational importance.

Although a full assessment of the CAP was beyond the scope of this investigation, the investigation included limited examination of how this program was utilized by personnel involved with SNM control and accountability.[130] Based upon this examination, the RCAT concluded that the CAP, had it been properly utilized, might have prevented or mitigated the event. That could have happened by identifying opportunities for improvement at a low level, before they became more significant self-revealing events. In support of this conclusion, the RCAT found indications that workers did not use the CAP as liberally as the CAP envisioned, that conditions once identified, were not always entered into the CAP, and that responses to conditions entered into the CAP were not always complete or timely. As a result, the company missed opportunities for action that might have prevented this event or its precursors.

The age of the event and availability of documentation limited the ability to determine the extent of historical CAP utilization in the area of SNM control and accountability, and there was no practical way to determine what potentially adverse behaviors or conditions might have existed in the 1970s that were not identified and documented in the CAP. However, the RCAT noted examples of both untimely response and under-utilization of the CAP to document and resolve issues identified by internal or external oversight. These examples included the following:

- A 1977 audit[131] identified weaknesses related to physical and gram accountability of segmented test rods, but did not conclude that the process was ineffective in accounting for individual STR rods. An extent of condition review could have evaluated the potential for other SNM entities (e.g., MS-557 fuel rods) to be similarly affected. Had such an evaluation been performed in response to the 1977 audit, procedures might have specifically required rod-level accountability sooner, or when the MS-557 fuel rods were identified in 1979, and the eventual loss of physical accountability of the MS-557 fuel rods might have been prevented.
- An April 1981 error in SRP program tracking of individual test rod segments was identified and communicated by GE,[132] documented in an inspection report by the NRC,[133] and discussed in an audit report.[134] The incident involved loading

[130] The RCAT limited its consideration of the CAP to its direct impact on the event, and did not evaluate contemporaneous management expectations for CAP utilization, or how CAP utilization during this event compared with contemporaneous usage in other areas of station operation.

[131] "Audit of Special Nuclear Material—SNM Inventory and Control R.E. No. 1001/21001", 07/22/77

[132] GE letter ADV: 81-070, "Notification of Millstone-1 STR Bundle Loading Error", 05/08/81.

[133] NRC Inspection Report 50-245/81-06 and 50-336/81-05, 07/14/81

two fuel rod test segments scheduled for shipment to VNC into the core (as part of the SRP test assembly, MSB-125), and shipping two segments that should have gone into the core to VNC. The audit report documented remarks by the RE concerning unresolved difficulties in tracking fuel rod test segments. This incident provided an opportunity for MP1 to have evaluated the then-current SNM control and inventory process, identified and corrected the vulnerability, and performed an extent of condition assessment to evaluate the impact. Such a response might have either prevented the loss of physical accountability of the two MS-557 rods, or have discovered the loss sooner.

- A 1994 NRC inspection report noted an "...inability to locate two previously used intermediate range monitors which contained small amounts of special nuclear material (SNM)."[135] A more thorough assessment of the extent of condition, including reconciliation of all SNM, would have been likely to identify the loss of physical accountability of the two individual MS-557 fuel rods at an earlier date.

The RCAT observed improved focus on CAP utilization during the investigation, including increased CAP documentation of SNM control and accountability issues and the current management's articulation of expectations for the CAP.

[134] Audit Report, NE-82-F-004, "Audit of SNM Inventory and Control Procedure RE 1001", 01/01/82; this audit was discussed in Section 4.2.2, "Internal Oversight Assessments".

[135] NRC Inspection Report No. 50-245/94-19, 07/21/94

4.3 BARRIER ANALYSIS

"A threat is any phenomenon that can adversely affect a target. A target is any entity that needs to be protected. A barrier is any physical structure, any device, any configuration, or any measure that can delay the affect of a threat on a target or can reduce its likelihood or severity. A barrier is anything that tends to protect a target from a threat by making the consequences less adverse, reducing the probability or delaying the impact to a more favorable time.

"In terms of the four types of factors affecting consequences a barrier can reduce vulnerability, a barrier can reduce the likelihood of initiation, a barrier can reduce the effects of exacerbating factors or a barrier can be a mitigating factor."[136]

The RCAT identified and evaluated a number of barriers associated with this event, and classified them according to the following categories:

- Effective barriers
- Missing barriers
- Ineffective barriers

The RCAT concluded that the impact of effective barriers during this event was much greater than the impact of those that were missing or ineffective. Barriers in place prevented the two individual rods from going to an unlicensed facility and protected public and worker health and safety. Rods were appropriately and effectively handled as radiological material throughout this event. Physical security of MP1 was protected, and the issue was self-identified.

Note that ineffective or missing barriers, setup factors, missed opportunities, and event causation are closely related, as are effective barriers and mitigating factors. The RCAT barrier evaluation is summarized below:

EFFECTIVE BARRIERS

Radiation Protection Program:	Maintained public and worker health and safety throughout this event.[137]
Individual Performance:	MP1 staff identified a discrepancy in fuel inventory, initiated a CR to document the issue. Management review of that CR led to the FRAP investigation.
Control of Fuel Assemblies:	MP1 accurately controlled and accounted for fuel assemblies for the life of the plant.
Physical Security:	Protected MP1 SNM from unauthorized removal.[138]

[136] *The Phoenix Handbook*, © 2000 W. R. Corcoran, NSRC Corp.

[137] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 8)

UNCHALLENGED BARRIER

Criticality Control:	Criticality control was not challenged by the two fuel rods associated with this event.

INEFFECTIVE BARRIERS

Individual Performance:	MP1 RE did not effectively communicate existence of two individual fuel rods. The 1980 turnover between REs did not include effective exchange of knowledge of the two rods to his successor and others who had a need to know. This made consideration of rods in subsequent inventories much less likely. Other examples include failure to initiate MTFs for every SNM movement within the SFP, decision not to track individual MS-557 fuel rods, and choice of document basis for physical inventories.
SNM Procedure:	MP1 SNM Control and Inventory procedures throughout the 1970s and 1980s did not specifically identify individual fuel rods as SNM.
Inventory Practices:	SNM inventories of SFP contents were generally limited to confirmation of SNM relocated since the last inventory. This substantially reduced the likelihood that unexpected SNM would be noticed, particularly outside fuel racks.
SNM Audits:	Internal audits did not identify inventory process vulnerabilities or lack of full SNM reconciliation. Responses to audit deficiencies did not include broad "extent of condition" evaluations. Questions about accuracy of inventory records and effectiveness of inventory practices could have stimulated SNM reconciliation.
Response to NRC:	"Extent of condition" evaluations in response to NRC findings and NOV did not consider all potentially affected SNM. Questions about accuracy of inventory records and effectiveness of inventory practices could have stimulated SNM reconciliation.
Coordination of SFP Work:	Ownership of SFP and associated SFP evolutions was distributed among several MP1 organizations without effective coordination.

[138] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (pages 6-8)

Management of SFP Work:	The level of NNECo supervision and oversight of SFP waste processing evolutions varied, particularly in the late 1970s through the mid 1980s. In addition, direct oversight by knowledgeable individuals was inconsistently applied.
Radwaste Characterization:	Historically irradiated hardware intended for disposal was not always well identified and remained in the SFP for extended periods of time prior to shipment. Even after characterization substantially improved, legacy waste characterizations were often limited; fuel rods (if previously cut up) would not have differed visibly from LPRM segments or other rod-like material to be shipped.
Corrective Action Program:	Inconsistent use of the CAP delayed recognition and correction of SNM control and inventory program weaknesses (based on numerous examples from the mid-70s that indicated problems were often not identified and corrected).

MISSING BARRIERS

Fuel Storage Location:	Two MS-557 rods were stored outside fuel racks. Storing the fuel rods in the fuel racks would have offered a barrier to inadvertent disposal; there was wide-spread understanding among nuclear workers at MP1 that fuel rack contents were off-limits to all but select individuals.
"Inventory of Record":	MP1 lacked a single, integrated, readily retrievable "inventory of record" against which to compare physical SNM inventories. Without an accurate basis, accurate physical verification could not be performed.
Inventory Reconciliation:	SNM inventories performed prior to 2001 were insufficient to identify the two missing fuel rods. Had a full SNM reconciliation been performed earlier, the loss of two fuel rods would have been detected sooner.

Note: The Quality Assurance Program was not included above as a barrier. Based on reviewing 10CFR50, 10CFR70, and various MP1 licensing basis documents (FSAR,[139] regulatory commitment reviews, etc.), the RCAT found no regulatory basis requiring quality assurance program requirements (10CFR50, Appendix B or equivalent) to be applied to any aspect of SNM control and accountability at Millstone Station. Although Regulatory Guide RG-5.29 was issued and available prior to 1975 through 1997, MP1 had no docketed commitment to its provisions. Further, the RCAT found no evidence

[139] Final Safety Analysis Report

that RG-5.29 was considered for application to the SNM control and accountability process.

4.4 EVENT CONSEQUENCES

"Consequences are the impact that the event has already caused, (e.g., death, damage, (radiation) dose, delay, dollar loss, discredit to the organization, discharges to the environment, demotion of personnel). Significance is what the event means for the future of the organization."[140]

4.4.1 EVALUATION OF CONSEQUENCES

Consequences are the tangible, measurable, describable adverse effects of an event or condition adverse to quality. The primary consequences of this event are listed below, followed by a chart indicating the RCAT's assessment of the relative severity of consequence types:

Type	Description	Remarks
Physical	Loss of physical control and possible shipment of two fuel rods to LLRW facility.	Physical impact was negligible; public and employee health and safety were not compromised.
Physical	Criticality control at MP1 SFP	Not adversely impacted by this event.
Radiological	Dose to station and LLRW facility personnel if removed from SFP	Negligible; fuel rod radiation levels were comparable to (or less than) many non-fuel components removed from SFP. Radiological impact at all locations was enveloped by magnitude of radwaste handling evolutions.
Radiological	Exposure from 2000 and 2001 MP1 SFP physical inspections.	About 2 man-rem
Environmental	Environmental impact of possible burial of irradiated fuel at LLRW facility.	None (enveloped by site isotopic content authorized by site licenses) See FRAP report.
Health & Safety	Health & safety impact to the public and workers.	None. All possible rod locations are facilities licensed to possess and protect the public and workers from radioactive material. Potential radiological and environmental impacts of the two fuel rods were enveloped by provisions of existing licenses at all four potential locations.
Schedule	MP1 Decommissioning.	None; FRAP activities had no impact on decommissioning schedule.

[140] *The Phoenix Handbook*, © 2000 W. R. Corcoran, NSRC Corp.

Type	Description	Remarks
Personnel	None identified.	None likely, impact on station personnel was limited to participation in interviews and occasional interface with other investigation activities.
Financial	Cost of Fuel Rod Accountability Project.	Moderate; approximately $9 million and 50,000 staff hours.
Regulatory	Regulatory response from NRC, state agencies in Washington and South Carolina	Unknown—still unfolding.

4.4.2 SEVERITY OF CONSEQUENCES

DEGREE → TYPE ↓	MINOR	MODERATE	SEVERE	CATASTROPHIC
Physical	X			
Radiological	X			
Environmental	X			
Health & Safety	X			
Schedule	X			
Personnel	X			
Financial		X		
Regulatory	Unknown			

DEGREE	EXAMPLES
MINOR	Financial &/or schedule impact absorbable within current budget/operating schedule
MODERATE	Financial &/or schedule impact that substantially deviated from current operating schedule &/or budget; "Near Miss" of personnel injury; Reportable low impact environmental violation Minor energy regulation violation
SEVERE	Serious injury; Financial impact that adversely affected credit rating; Serious energy regulation violation Serious environmental violation
CATASTROPHIC	Death; Bankruptcy; Governmental or corporation-ordered plant closing

4.4.3 *INFLUENCES ON CONSEQUENCES*

"In order to arrive at corrective action options to reduce the frequency or severity of consequences, the investigators need to find out what influenced the consequences. Clearly there would have been no event, hence no consequences, if the situation had not been vulnerable to the event. Furthermore, the vulnerability alone does not cause an event. Something that consummates or triggers the event is needed. Since most events are more consequential than they could have been, one looks for exacerbating factors that made the consequences as bad as they were. Finally, with possible exceptions, no event is as bad as it could have been, so that one looks for mitigating factors that limited or reduced the potential consequences to yield the actual consequences."[141]

Four types of factors influence the consequences of an event:

Factors that created the vulnerability (set-up factors)

Factors that triggered the event (converted vulnerability into a consequential event)

Factors that made the consequences as bad as they were or worse than might have been (exacerbating factors)

Factors that kept the consequences from being more severe (mitigating factors)

Events that take place over extended periods of time are typically shaped by numerous set-up and exacerbating factors with varying degrees of influence. This event was no exception. Many of the major factors that made MP1 vulnerable to this event align closely with event causation, ineffective or missing barriers, and missed opportunities. Mitigating factors and effective barriers tend to similarly align. The major factors that shaped this event are summarized below:

SETUP FACTORS

Lack of "Inventory of Record":	Neither procedures nor inventory practices established, maintained, and utilized an SNM "inventory of record" as the basis for physical inventories of SNM.[142]
Inventory Practices:	Some inventories either tacitly assumed the previous inventories were accurate and were partial inventories of changes since the previous inventory, or did not accurately compare physical inventory with an established "inventory of record."

[141] *The Phoenix Handbook*, © 2000 W. R. Corcoran, NSRC Corp.

[142] See Appendix 5, "Definitions" for definition of "SNM Inventory of Record"

Lack of Periodic Reconciliation: There was no requirement for a periodic reconciliation[143] of physical inventory with "inventory of record"; full SNM reconciliations were not accomplished.

Procedural Weaknesses: Procedures did not adequately specify requirements for inventories; were somewhat confusing in content, logic, and format; did not require full reconciliation of SNM inventory to inventory records; did not interface with vendor procedures; were not always rigorously followed.

Flexible Process: Procedures allowed various history of movement forms and various methods for defining "inventory of record".

Fuel Rods Not Stored in Racks: The MP1 RE stored the two individual MS-557 fuel rods in an "8-rod container" tied to the SFP railing, rather than placing them in the SFP fuel storage rack. This made those fuel rods vulnerable to loss of physical control, including inadvertent disposal. In part, that was because the 8-rod container design could not be moved by fuel handling grapples (eye-bolt on top vs. lifting bale).

Ineffective SFP Coordination: Ownership of the SFP and associated evolutions was distributed among several MP1 organizations without effective coordination. For example, the "owner" of fuel (including individual rods) differed from the "owner(s)" of LPRM disposal activities.

Inconsistent Supervision: Direct NNECo supervision and oversight of SFP waste processing evolutions was inconsistent with respect to work-site presence, particularly in the late 1970s through the mid 1980s. In addition, direct oversight by knowledgeable individuals was inconsistently applied. This increased the potential for inadvertent disposal of the two fuel rods.

Radwaste Characterization: Historically irradiated hardware intended for disposal was not always well identified and remained in the SFP for extended periods of time prior to shipment. Even after characterization substantially improved with the establishment of 10CFR61 requirements, prior legacy waste characterizations were often limited; fuel rods (if previously cut up) would not have differed visibly from LPRM segments or other rod-like material to be shipped.

[143] See Appendix 5, "Definitions", for definition of reconcile.

Waste Similarity to Rods: Some irradiated hardware was similar in appearance and radiation level to fuel rods.

Turnover Between REs: The RE who identified the rods with GE did not conduct an effective turnover with his successor. Specifically, the incoming RE did not understand that individual rods were present in the MP1 SFP. As a result, subsequent REs and personnel involved in SFP work were not aware of the two MS-557 fuel rods.

EVENT TRIGGER

The MP1 chloride intrusion from a condenser tube failure in 1972 triggered the event by creating the need to disassemble a fuel bundle for off-site examination of non-fuel hardware.

Fuel rods were removed from bundle MS-557 in 1972, and then reassembled into a "scrap bundle" in 1974. Two rods could not be incorporated into the scrap bundle; the first, because it was a center spacer capture rod that could not be reinserted, and the second because it had been damaged during fuel handling.

EXACERBATING FACTORS

Exacerbating factors are the influences that made the event even more consequential than the minimal event. The RCAT concluded that the consequences of this event were minor, except in the areas of financial (moderate) and regulatory (unknown). In part, this conclusion was based upon the small number of exacerbating factors and a number of significant mitigating factors that combined to greatly limit event consequences. Exacerbating factors in this event were limited to those that delayed recognition of fuel rod loss.

Inconsistent Use of CAP: Inconsistent use of the CAP delayed recognition of physical loss and inventory program weaknesses (based on numerous examples from the mid-1970s into the 1990s that indicated problems were often not effectively identified, documented, and corrected).

Response to Identified Problems: Closely related to inconsistent use of the CAP were the often limited responses to problems identified by audits, NRC inspections, and NOV. Lack of effective "extent of condition" evaluations, which could have stimulated confirmatory SNM inventory reconciliation delayed identification of physical loss.

MITIGATING FACTORS

Self-identification of the event: Millstone station self-identified the loss of two fuel rods during MP1 decommissioning activities.

Radiological Controls:	Effective radiological controls protected public and workers from radiation exposure; dose rate from the two rods was less than from a large number of other irradiated items shipped from MP1.
Assembly of "Scrap Bundle":	Assembly of "scrap bundle" MS-557 in 1974 reduced number of individual fuel rods in the MP1 SFP from 49 to 2.
MP2 and MP3 SFP Practices:	Both MP2 and MP3 stored individual fuel rods in spent fuel racks, unlike MP1. This reduced vulnerability to inadvertent loss.[144]
Fuel Inventory Reconciliation:	All three Millstone units established and verified "inventories of record" and compared them to fuel physically on-hand in 2001. Loss was confirmed as limited to two fuel rods from MP1.
Fuel Design:	Fuel rods were of low enrichment (SNM of low strategic significance).

[144] Other differences in historical practices at MP2 and MP3 compared to MP1 may have also mitigated this event; RCAT examination of past MP2 and MP3 activities was limited to that necessary to support "extent of condition" determination.

4.5 EVENT SIGNIFICANCE

4.5.1 SIGNIFICANCE EVALUATION

The significance of an event is its meaning for the future, especially if appropriate changes are not made to the way business is done. The main considerations when examining significance are:

- What the potential consequences *could* have been
- How extensive the issues were
- What had to break down for the event to have happened the way that it did
- The effective and unchallenged measures intended to limit the consequences
- The extent to which the company has already campaigned against the weaknesses involved

Based upon the interviews conducted and documents reviewed, the RCAT considered the following to be the most significant topics related to this event:

- Physical
- Radiological
- Environmental
- Health and Safety
- Schedule
- Impact on Personnel
- Financial
- Regulatory
- Generic Implications

The investigation used the following guideline for estimating the magnitude of significance for each topic:

DEGREE	EXAMPLES
MINOR	Financial &/or schedule impact absorbable within current budget/operating schedule
MODERATE	Financial &/or schedule impact that substantially deviated from current operating schedule &/or budget; "Near Miss" of personnel injury; Reportable low impact environmental violation Minor energy regulation violation
SEVERE	Serious injury; Financial impact that adversely affected credit rating; Serious energy regulation violation Serious environmental violation
CATASTROPHIC	Death; Bankruptcy; Government-ordered or corporation-ordered plant closing

PHYSICAL SIGNIFICANCE

Level of Significance: Minor

Basis: The extent of undetected fuel rod loss was limited to the two fuel rods actually lost.

Fuel inventory reconciliation efforts in 2001 at MP1, MP2, and MP3 demonstrated that this event was limited to two MS-557 rods.[145] The likely physical consequence of this event was the potential, unauthorized disposal of the two fuel rods at a facility licensed to receive LLRW. The other possible physical locations were a vendor facility licensed to receive fuel, or the MP1 SFP.

RADIOLOGICAL SIGNIFICANCE

Level of Significance: Minor

Basis: Radiological impact of two fuel rods was less than impact of other MP1 irradiated material.

Radiation levels and curie content of the two fuel rods fell well below levels of other irradiated material stored in the MP1 SFP and/or shipped to LLRW facilities. Neither the presence of the fuel rods in the SFP, nor their presence in radwaste shipments (if they were shipped) measurably affected the existing radiological environment.[146]

ENVIRONMENTAL SIGNIFICANCE

Level of Significance: Minor

Basis: Radionuclides present in two fuel rods already existed in substantially greater quantities at all possible fuel rod locations.

If shipped to a LLRW facility, the presence of the two fuel rods did not introduce any different radioactive element than was already present in substantially greater quantities at either LLRW facility. The sites already contain these same radionuclides in greater amounts than both rods contained. Accordingly, the potential environmental impact of the two rods on the LLRW facilities was enveloped by existing environmental analyses.[147]

The environmental impact from the possible presence of the two fuel rods at either the VNC or the MP1 SFP was similarly insignificant in comparison to the much greater amount of irradiated fuel in storage at either location.

HEALTH AND SAFETY SIGNIFICANCE

Level of Significance: Minor

Basis: All credible rod locations were facilities licensed to possess and protect the public from radioactive material with far greater activity than that contained in the two fuel rods.

[145] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report"; NE-01-F-280, "Millstone 2 and 3 Special Nuclear Material Reconciliation (CR-01-0863)", 10/05/01

[146] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 8)

[147] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 8)

Provisions of existing licenses at all four potential rod locations enveloped potential radiological and environmental impacts of the two fuel rods. Radiological and environmental controls throughout the life of MP1 were adequate to protect the health and safety of the public and employees.

SCHEDULE SIGNIFICANCE

Level of Significance: Minor

Basis: FRAP investigation was completed.

Further impact of this event is limited to implementation of corrective actions in response to this Root Cause Analysis Report (RCAR). These actions should be accommodated within the normal course of future business.

PERSONNEL

Level of Significance: Minor

Basis: FRAP investigation was completed.

Further impact of this event is limited to implementation of corrective actions in response to this RCAR. These actions should be accommodated within the normal course of future business.

FINANCIAL

Level of Significance: Minor

Basis: No costs identified beyond the minor incremental cost of recommendations; these costs are expected to be absorbable within existing operating budgets.

REGULATORY SIGNIFICANCE

Level of Significance: Unknown

This event has potential regulatory significance beyond Millstone Station that was not completely identified at the conclusion of this investigation. The possibility that fuel rods may have been buried in Agreement State LLRW facilities may raise regulatory issues that could involve appropriate regulatory agencies and affected licensees.

GENERIC IMPLICATIONS (MILLSTONE STATION)

Level of Significance: Minor

Basis: MP2 and MP3 storage practices for individual fuel rods, SFP work control, and fuel inventory practices differed substantially from those at MP1. (See Section 4.5.2, "Extent of Condition/Generic Implications" for details.)

4.5.2 EXTENT OF CONDITION/GENERIC IMPLICATIONS

"Generic implications are the answer to the question, 'Given this problem, what other problems are likely to exist?' These other problems are of two types: 1) more problems like the one we have and 2) problems caused by the one we have. The same concept is sometimes called 'extent of condition'. A reasonable exploration of on-site generic implications seems to be a necessary part of 'measures to assure that conditions adverse to quality... are promptly identified'" [148]

4.5.2.1 MILLSTONE STATION

The RCAT expended substantial effort in the course of this investigation evaluating the current vulnerability of MP2 and MP3 to a similar event. The RCAT concluded that as of RCAR publication:

- None of the Millstone Units were vulnerable to a similar event;
- Loss of fuel control and accountability was limited to the two MS-557 fuel rods for the entire Millstone station;
- The way in which SNM was controlled and inventoried in 2001 was substantially different than at MP1 when the event occurred in the 1970s.

The basis for this conclusion is summarized in the table below and the discussions that follow. The RCAT reiterates that the investigation had the benefit of hindsight. The historical "baseline" shown below was developed to compare current Millstone practices to the vulnerabilities that shaped this event. It does not purport to be a balanced assessment of performance, and should not be taken out of context.

Issue	MP1 (Then)	MP1 (Now)	MP2 (Now)	MP3 (Now)
Fuel Rod Storage	[illegible]	Green	Green	Green
Fuel Assembly Storage[149]	White	White	Green	Green
Inventory Records	[illegible]	White	White	White
Inventory Reconciliation	[illegible]	White	White	White
SNM Item Designation	Yellow	Green	Green	Green
Procedures	Yellow	White	White	White
SFP Material Condition	[illegible]	Green	Green	Green
SFP Work Control	[illegible]	Green	White	Green
Ownership (SNM & SFP)	Yellow	White	White	White
Oversight (Internal)	Yellow	White	White	White

Red = Not Fully Effective   Yellow = Improvement Needed
White = Meets Requirements   Green = No obvious improvement opportunities identified

[148] *The Phoenix Handbook*, © 2000 W. R. Corcoran, NSRC Corp.

[149] The area of "Fuel Assembly Storage" was considered from the perspective of fuel assembly accountability. Evaluation of criticality control was beyond the scope of this investigation.

FUEL ROD STORAGE

MP2, MP3: MP2 and MP3 stored individual fuel rods in containers placed in the respective SFP fuel racks on a continuous basis since disassociation from fuel bundles. Neither MP2 nor MP3 stored individual fuel rods in non-fuel rack locations.

MP1 (now): MP1 currently has no individual fuel rods; all fuel rods were incorporated into fuel assemblies (or the SRP-2D storage bundle) and stored in fuel racks, with the exception of damaged bundle MS-508, which was stored in a special canister and placed in a control rod blade storage tube.[150]

MP1 (then): The two MS-557 fuel rods were stored outside of fuel racks and tied to the SFP railing.

FUEL ASSEMBLY STORAGE[151]

Now: All fuel assemblies in all units are stored in fuel racks except as noted above. At MP1, MS-508 was stored in control rod blade rack (using an operability determination as an interim justification pending final resolution), and 57 fuel assemblies were not fully seated in fuel storage racks.

Then: All fuel assemblies were stored in fuel racks, except for MS-508 at MP1. However, MP1 did not always use history of movement forms to document fuel moves (including fuel assemblies) within ICAs.

INVENTORY RECORDS

Now: Fuel inventory records were verified for MP1, MP2, and MP3, as part of the reconciliation described in the "inventory reconciliation" discussion below. NFSA conducted a self-assessment[152] of SNM in Fall 2001 that focused on defining the "inventory of record" for fuel. Non-fuel SNM was not within the scope of that self-assessment. MP1, MP2, and MP3 designated in a memo[153] their respective "inventories of record", but that definition was not yet incorporated into a procedure.

Then: MP1 did not formally identify the "inventory of record" (a single, integrated, readily retrievable basis against which to compare physical SNM inventories). Without an accurate basis, accurate physical verification could not be performed for all SNM. The way in which MP1 performed inventories did not preserve the integrity of documents against which physical entities were compared. (Note: this deficiency did not noticeably impact ability to account for fuel assemblies. Fuel assemblies were the

[150] The FRAP Final Report included the possibility that the missing MS-557 fuel rods might still be in the MP1 SFP.

[151] The area of "Fuel Assembly Storage" was considered from the perspective of accountability. Criticality control was beyond the scope of this investigation.

[152] Self Assessment MP-SA-01-046, "Self Assessment Report, Special Nuclear Material", September 2001

[153] NE-01-F-279, "SNM Inventory of Record", 10/05/01

common unit of property, and fuel assembly inventory records were adequately maintained for the purposes of physical inventory.)

INVENTORY RECONCILIATION

Now: MP1[154], MP2[155], and MP3[156] fuel inventories were reconciled with their respective "inventories of record." The inventories for MP1,[157] MP2, and MP3 included fuel rods that were not part of intact fuel assemblies. The two fuel rods missing from MP1 were the only discrepancies. MP2 and MP3 included non-fuel SNM items of reportable quantity in their SNM inventory reconciliation.[158]

MP1 (then): MP1 did not maintain a single, integrated, readily retrievable "inventory of record"; therefore, SNM inventory could not have been readily reconciled.

SNM ITEM DESIGNATION

Now: All three units specifically define fuel rods disassociated from fuel assemblies as SNM in the SNM control and inventory procedure. Current SNM control and inventory processes accommodate individual fuel rods as well as non-fuel SNM items (e.g., fission detectors). Inventory procedures address all SNM items (fuel and non-fuel).

Then: MP1 SNM control and inventory procedure was silent with respect to individual fuel rods. Treatment of individual rods as SNM required recognition of their presence and designation as SNM by the RE. In the 1970s, there was evidence that the RE did not effectively include individual fuel rods (i.e., STR rods and MS-557 fuel rods) in the SNM control and accountability program. Regarding non-fuel SNM items, there was historical evidence that physical accountability was not always maintained for every item.[159]

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[154] NE-01-F-269, "Verification of Unit 1 SFP and Core Shuffleworks vs SNM Card File", 09/27/01

[155] NE-01-F-253, "MP2 Special Nuclear Material (SNM) On-site Inventory Validation for MP2 and MP3 SNM Reconciliation Project", 09/12/01

[156] NE-01-F-254, "MP3 Special Nuclear Material (SNM) On-site Inventory Validation for MP2 and MP3 SNM Reconciliation Project", 09/12/01

[157] MP1 had two "less than complete" assemblies as of this report—the SRP-2D storage bundle and MS-557. For all intents and purposes, these two items were controlled and inventoried as if they were intact assemblies.

[158] NE-01-F-271, "MP3 Special Nuclear Material (SNM) DOE/NRC Form 741 Reconciliation for MP2 and MP3 SNM Reconciliation Project", 09/28/01

[159] NRC Inspection Report No. 50-245/94-19, 07/21/94 [reported inability to locate two IRMs in LER 94-016-00 "Loss of Special Nuclear Material Accountability", 05/23/94]

PROCEDURES

Now: Procedures governing SNM inventory and control at all three units:

- Identify individual fuel rods as SNM
- Have greater degree of commonality among units
- Are centrally controlled
- Have improved through increased adherence to management expectations for procedural compliance and correction of procedural problems
- More clearly implement regulatory requirements

Then: MP1 procedural requirements for SNM control and inventory:

- Were silent with respect to SNM status of individual fuel rods
- Were difficult to implement as written

SFP MATERIAL CONDITION

MP2, MP3: MP2 and MP3 SFPs historically contained substantially less highly irradiated waste. MP2 and MP3 are Pressurized Water Reactors (PWRs); MP1 is a BWR. PWRs generate substantially less irradiated waste that is subsequently treated separately from spent fuel, compared with BWRs during routine operation.

MP1: MP1 SFP material condition was historically much more difficult to manage than at MP2 and MP3 for the reasons stated above. Past material condition deficiencies were adequately addressed. MP1 is "cold and dark" and no longer generating irradiated waste, with remaining SFP contents well documented.

SFP WORK CONTROL

Now: SFP activities are closely managed at all three units through the work control process, with Automated Work Orders (AWOs) or job orders used to control the work. The amount of SFP cleanup required at MP2 and MP3 has been substantially less than for MP1, due to the volume of waste material present. MP1 and MP3 had specific procedures that governed SFP work beyond the AWO process; MP2 does not have a specific procedure for SFP work.

Then: The level of NNECo supervision and oversight of SFP waste processing evolutions varied, particularly in the late 1970s through the mid 1980s. In addition, direct oversight by knowledgeable individuals was inconsistently applied.

COORDINATION AND OWNERSHIP (SNM & SFP)

Now: Station RE personnel demonstrate a greater degree of active involvement and ownership of SFP activities than in the past at MP1 (e.g., verification of non-fuel SFP inventory). Evidence of recent management observation of work in and around the SFPs is also greater. Work control enhancements support active ownership by making it much easier to monitor SFP work activities. Evidence of program (and procedure) ownership is available via the intra-net based "Passport" document system.

MP1: Past SFP and SNM program ownership was divided, with communication and coordination weaknesses. [160]

INTERNAL OVERSIGHT

Now: The RCAT concluded that quality assurance oversight of SNM control and accountability has been effective from 1997 through the date of this report.[161]

Then: Audits prior to 1997 (and management responses to them) were less thorough and intrusive in a number of respects (see Section 4.2.2, "Internal Oversight Assessments"). That said, line management had sufficient evidence to have questioned the adequacy of SNM inventory practices, even given oversight weaknesses.

Given that oversight functions operated by observing samples of performance, the RCAT did _not_ believe that QA could reasonably be expected to have identified that two fuel rods were missing except by chance. However, internal oversight should have been capable of clearly identifying and reporting weaknesses in inventory practices.

4.5.2.2 U S NUCLEAR INDUSTRY

The causes of and factors that influenced this event at MP1 are discussed elsewhere in this report and are plant-specific. The extent to which they may apply to other generating plants was beyond the scope of this investigation.

4.5.3 REGULATORY REPORTABILITY AND METRICS

4.5.3.1 LICENSEE EVENT REPORT

NNECo notified the NRC of its inability to locate two spent fuel rods soon after the initiation of the November 2000 condition report, and again on December 14, 2000 via the Emergency Notification System (ENS) in accordance with the requirements of 10CFR20.2201(a)(1)(ii) and 10CFR50.72(b)(2)(vi). NNECo also notified NRC Region I and State of Connecticut on the same date. NNECo submitted Licensee Event Report (LER) 2000-01-00 to the NRC on January 11, 2001 as required by 10CFR20.2201(b). NNECo submitted updated information in supplemental LER 2000-02-01 on March 30, 2001.

[160] Interviews 5, 9, 16, 17, 18, 24, 28, 31

[161] Based upon review of audit reports from 1997, 1999, 2001; interview 39; and extensive RCAT member experience in managing, evaluating, and improving nuclear QA programs.

DNC acquired Millstone Station and assumed licensee responsibilities on March 31, 2001. DNC forwarded a copy of the final NUSCo report of the investigation of fuel rod location to the NRC on October 5, 2001, and notified the NRC on October 5, 2001 via the ENS, in accordance with requirements of 10CFR70.52(a), that two fuel rods had been lost.

4.5.3.2 IMPACT ON NRC PERFORMANCE INDICATORS AND REGULATORY CORNERSTONES

As part of evaluating this event, the RCAT considered how the NRC's risk-informed inspection process might evaluate the significance of this event.

The NRC's risk-informed inspection process relies on two primary inputs: Performance Indicators and NRC Inspection Findings. Performance indicators are measured and self-reported by generating plants in strict compliance with NRC-endorsed industry guidance.[162] The safety significance of Inspection Findings is determined through the Significance Determination Process (SDP), using risk insights where appropriate.[163] The SDP determinations for Inspection Findings and the Performance Indicator information are combined to assess licensee performance[164] through the NRC Reactor Oversight Process.

The oversight process is designed to monitor plant performance in three broad areas: reactor safety (avoiding accidents and reducing the consequences of accidents if they occur); radiation safety for plant workers and the public during routine operations; and protection of the plant against security threats. The three areas are divided into "cornerstones": initiating events, mitigating systems, barrier integrity, emergency preparedness, public radiation safety, occupational radiation safety, and physical protection.

Performance area ratings did not change when this event was evaluated using "risk-informed" regulatory guidance.[165] That outcome was consistent with FRAP conclusions that the event posed no health and safety risk.[166] This was primarily an issue of regulatory compliance.

[162] Nuclear Energy Institute document NEI 99-02, Rev. 1, "Regulatory Assessment Performance Indicator Guideline", 04/23/01

[163] Described in NRC Inspection Manual Chapter 0609. The NRC also uses traditional methods as necessary to compliment the SDP.

[164] As described in NRC Inspection Manual Chapter 2515

[165] Memo FRAP-01-093, "The Applicability of the Risk-Informed Inspection Process to Missing Millstone Unit-1 Fuel Rods", 10/09/01

[166] "Millstone Unit 1 Fuel Rod Accountability Project, Project Number M1 0063, Final Report" (page 2)

5. RECOMMENDED EVENT RESPONSE

The recommended event response includes lessons to be learned (5.1), corrective and preventive actions (5.2), and the relationship of recommendations to causation (5.3).

5.1 LESSONS TO BE LEARNED

> *"The only way one can tell that a lesson has been learned is by noticing a change in behavior that reflects the lesson learned. Until that happy day we call them 'lessons to be learned' ".* [167]

Lessons to be learned address the question, "What is it about the way we do business that produces errors and fails to detect them at the appropriate points in the process?" The lessons to be learned are more than just what corrective actions are needed, and should result in widespread organizational learning. The lessons to be learned are targeted to current Millstone Station personnel, and not the majority of individuals with actual involvement in this event who are no longer employed at Millstone. In the RCAT's opinion, the following were the principal lessons to be learned by the organization from this event.

WHO	WHAT
All	Important material that is stored near waste might be considered just that.
Line management	Without clear line management ownership and involvement, station programs might take their own potentially undesirable course.
SNM program owner	An effective SNM control and accountability program is needed to ensure physical accountability of all SNM entities.
SNM program owner	Periodic SNM inventory-records reconciliation is essential to demonstrate that accountability has been maintained.
All	Performance areas not covered by 10CFR50, Appendix B may still warrant oversight commensurate with their importance to the organization.

[167] "Phoenix Handbook" © 2000, by William R. Corcoran, Ph.D., P.E., NSRC Corp

5.2 CORRECTIVE AND PREVENTIVE ACTIONS

Events consist of:

- Undesirable conditions (consequences);
- The factors that made the event happen in the way that it happened (influences on consequences); and
- The cause(s) of the event.

Below is a table that lists RCAT recommendations for:

- Remedial corrective actions;
- Interim compensatory measures;
- Corrective actions to prevent recurrence;
- Enhancement corrective actions; and
- Effectiveness review.

Corrective actions to enhance performance (CACA) were recommended for areas that were not directly involved in event causation, but for which the RCAT believes there are business reasons to consider taking action to improve performance in areas affected by this event.

Following that table is a tabulation of the relationship between those recommendations and the causes of this event.

CORRECTIVE AND PREVENTIVE ACTIONS			
ACTION [168]	WHAT[169]	WHO	REMARKS
CORRECTIVE ACTIONS TO PREVENT RECURRENCE (CACP)			
SNM Program & Implementing Procedures (CACP-1)	Strengthen SNM control & accountability program and implementing procedures as necessary to address weaknesses noted in Section 3.1.1. Per Master Manual 5, update MP-13-SNM-PRG and implementing procedures. (3.1.1)	PO NFSA	Addresses both lost accountability and delayed recognition of lost accountability. Strengthening procedures will reduce organizational reliance on RE individual performance. (See Appendix 5 for definitions.)
	Precisely define and maintain in a station procedure exactly what is the "SNM inventory of record" at each Millstone unit. (3.1.1)	PO NFSA	The result should be a readily retrievable list of fuel and non-fuel SNM inventory that is maintained in a timely manner to be current and accurate.[170] (See Appendix 5 for definitions.)
	Define in a station procedure a requirement to periodically reconcile the SNM inventory with an "inventory of record" at intervals that satisfy business needs and regulatory requirements. (3.1.1)	PO NFSA	This is designed to detect any possible future fuel or non-fuel SNM inventory discrepancies before an excessive amount of time elapses. (See Appendix 5 for definitions.)
MP2 SFP Operations Procedure (CACP-2)	Either develop a MP2 procedure for "Spent Fuel Pool Operations" or develop a site-wide standard procedure to ensure adequate control of SFP-related work (including expectations for supervision and oversight). (3.1.1)	PO NFSA	MP1 and MP3 now have specific procedures (RE 1074 and EN 31013, respectively) for SFP operations.
Irradiated Hardware Disposal Procedures (CACP-3)	Review and revise as necessary procedures for disposal of irradiated hardware (e.g., waste characterization, QC of liner loading) to ensure they preclude the possibility of unauthorized and/or inadvertent shipment of SNM. (3.1.1)	Deputy MPO Operate The Asset	This should include (but not be limited to) accuracy, completeness, and retrievability of records, and provisions for appropriate characterization of legacy waste (i.e., radwaste processed prior to major changes in characterization standards or requirements).

[168] In the "action" column, numbers in parenthesis designate specific corrective actions to allow cross-referencing to causation. Designations of the type of corrective and preventive actions (e.g., CACR, CACC) were assigned based upon procedure RP 6, "Root Cause Analysis", Rev. 002-02, 05/22/01.

[169] In the "what" column, numbers in parenthesis refer to the specific root cause element(s) the action targets. Refer to section 3.1, "Root Cause" for specific elements.

[170] Memo NE-01-F-279, "SNM Inventory of Record", 10/05/01, appeared to define the SNM "inventory of record". However, it was unclear to the RCAT if that definition specifically included non-fuel SNM since MP-SA-01-046, "Special Nuclear Material", September 2001 previously excluded non-fuel SNM from its scope.

CORRECTIVE AND PREVENTIVE ACTIONS			
ACTION [168]	WHAT [169]	WHO	REMARKS
MP1, MP2 and MP3 Non-Fuel SNM Inventory (CACP-4)	Reconcile non-fuel SNM physical inventory with records at MP1, MP2 and MP3. This should be a detailed comparison of the SNM "inventory of record" with the actual physical SNM inventory at each unit. (3.1.1)	PO NFSA	The RCAT found no recent documentation of non-fuel SNM inventory reconciliation at MP1.[171] Determine if the recent reconciliation of non-fuel SNM inventory at MP2[172] and MP3[173] was done against the "inventory of record". (See Appendix 5 for definitions.)
SFP Coordination (CACP-5)	Clearly define and communicate "ownership" of spent fuel pools and associated activities, including responsibility for activity coordination (and other current or future SNM storage areas) at Millstone. (3.1.2)	VP Nuclear Operations	Maintaining good material condition of SNM storage areas and adequately controlling work in those areas will help ensure proper SNM physical control and accountability.
SNM Program "Ownership" (CACP-6)	Clearly define and communicate "ownership" of SNM control and accountability program and expected results. (3.1.2)	PO NFSA	There was some current information available to help define SNM control and accountability program ownership, but that information was not always consistent and readily retrievable.
Work Observations (CACP-7)	Increase the frequency of documented supervisory observations of SFP activities and SNM control and accountability program activities. Ensure that processes and procedures do not over-rely on individual performance and that individuals meet station standards for procedural adherence. (3.1.2, 3.1.3)	VP-Technical and VP-Operations	The station work observation program has flexibility to assign observers from outside the cognizant work group. The RCAT recommends taking advantage of this flexibility. This also serves as an interim compensatory measure.
REMEDIAL CORRECTIVE ACTIONS (CACR)			
MP1 Fuel Inventory (CACR-1)	Reconcile MP1 fuel inventory with an "inventory of record" This should be a detailed comparison of the SNM "inventory of record" with the actual physical SNM inventory. (3.1.1)	FRAP	Complete.[174] See Appendix 5, "Definitions", for definitions of reconcile and inventory of record.

[171] Limited availability of historical MP1 records could make MP1 non-fuel SNM reconciliation difficult. The RCAT suggests that a "bounding" analysis could be accomplished within a reasonable amount of time to establish the extent (if any) to which the non-fuel SNM "inventory of record" may be uncertain. Due consideration and action with respect to potential reportability of identified discrepancies is part of this recommendation.

[172] NE-01-F-253, "MP2 Special Nuclear Material (SNM) On-site Inventory Validation for MP2 and MP3 SNM Reconciliation Project", 09/12/01

[173] NE-01-F-254, "MP3 Special Nuclear Material (SNM) On-site Inventory Validation for MP2 and MP3 SNM Reconciliation Project", 09/12/01

[174] Memo NE-01-F-269, "Verification of Unit 1 SFP and Core Shuffleworks vs. SNM Card File", 09/27/01

CORRECTIVE AND PREVENTIVE ACTIONS			
ACTION[168]	WHAT[169]	WHO	REMARKS
MP2 and MP3 Fuel Inventory (CACR-2)	Reconcile fuel physical inventory with records at MP2 & MP3. This should be a detailed comparison of the SNM "inventory of record" with the actual physical SNM inventory at each unit. (3.1.1)	PO NFSA	Complete.[175] See Appendix 5, "Definitions", for definitions of reconcile and inventory of record.
INTERIM COMPENSATORY MEASURES (CACC)			
Self-Assessment (CACC-1)	Conduct periodic self-assessment of key SNM control and accountability program activities. *[These actions should be tightly focused with emphasis on observations, not "report writing".]* Topics should include (but not be limited to): CAP implementation, use of history of movement forms, procedural adherence, records retention and retrieval, consistency among physical piece counts and gram accountability reports, SFP mapping practices, and use of industry operating experience (OPEX). (3.1.1, 3.1.2, 3.1.3)	PO NFSA	Also serves as an interim check on corrective and preventive action effectiveness. Self-assessments should be sensitive to identifying processes or procedures that are excessively dependent upon individuals to compensate for process/procedure weaknesses.
EFFECTIVENESS REVIEW (CATE)			
C/A Effectiveness (CATE-1)	About 6-12 months after completion, verify effectiveness of corrective actions to prevent recurrence.	VP Nuclear Technical Services	Long term improvement and event prevention required by MP-16-CAP-FAP0.13, step 2.4.1. If possible, that review should include the status of all recommendations.
ENHANCEMENT CORRECTIVE ACTIONS (CACA)			
QA Oversight Of SNM Program (CACA-1)	Enhance QA oversight of SNM control and accountability program. In particular, explicitly include consideration of fuel that is not in intact fuel assemblies in oversight activities.	PO Oversight	This is not intended to suggest placing SNM control and accountability activities under the formal nuclear QA program.

[175] Memo NE-01-F-280, "Millstone 2 and 3 Special Nuclear Material Reconciliation (CR-01-08963)", 10/05/01

CORRECTIVE AND PREVENTIVE ACTIONS			
ACTION [168]	WHAT[169]	WHO	REMARKS
Basic Knowledge (CACA-2)	Ensure that personnel who might encounter SNM understand that it can occur in various forms (not just intact fuel assemblies), and has special requirements for control and accountability.	MPO Nuclear Training	Determine the extent to which existing training and orientation needs enhancement, and develop any new or revised training that might be needed as a result of strengthening the SNM control and accountability program and procedures. Education and training is a barrier that can help promote appropriate actions (behavior) or conditions, and/or discourage inappropriate action (behavior) or conditions.
Licensing Basis (CACA-3)	Document and maintain the current licensing basis for Millstone SNM control and accountability in a readily retrievable form.	PO NFSA	The intent of this recommendation is to facilitate checking future changes to the SNM control and accountability program against the licensing basis. Ideally, this should be a prerequisite to updating Master Manual 13 (and associated implementing procedures).

5.3 RELATIONSHIP OF RECOMMENDATIONS TO CAUSATION

The following table correlates the causes of the event, as described in Section 3, "Causation", of this report, with the recommendations listed in Section 5.2, "Corrective and Preventive Actions".

RELATIONSHIP OF RECOMMENDATIONS TO CAUSATION				
CAUSE	RECOMMENDATION	DETAIL ADDRESSED	EXPECTED RESULT	COMMENTS
Process Weaknesses (3.1.1)	Strengthen SNM control & accountability program and implementing procedures as necessary to address weaknesses noted in Section 3.1.1. Per Master Manual 5, update MP-13-SNM-PRG and implementing procedures. (CACP-1)	Correct existing historical weaknesses (if any) described in Sections 3.1 and 3.1.1 to the extent present in current procedures.	Address historical procedure weaknesses. Comply with existing station requirements for process and program structure. Verify that SNM-related procedures are consistent with licensing basis.	
	Precisely define in a station procedure and maintain the "SNM inventory of record" at each Millstone unit. (CACP-1)	Procedures did not clearly define basis for inventory; basis used was not integrated or readily retrievable.	A consistent, integrated, readily retrievable basis for future SNM inventory reconciliation would be available.	Defined by memo NE-01-F-279, 10/05/01 AR[176] initiated to document this definition in future procedure revision.
	Define in a station procedure a requirement to periodically reconcile the SNM inventory with an "inventory of record" at intervals that satisfy business needs and regulatory requirements. (CACP-1)	Maintain SNM accountability	Detect any future SNM inventory discrepancies in a timely manner; comply with regulatory requirements.	Periodic reconciliation addresses a cause of delayed detection of lost SNM physical accountability.
Process Weaknesses (3.1.1)	Either develop a MP2 procedure for "Spent Fuel Pool Operations" or develop a site-wide standard procedure for that subject (including expectations for supervision and oversight). (CACP-2)	SFP work control and oversight (MP2).	Written standards and expectations for MP2 SFP activities; possible site-wide standardization.	MP1 and MP3 had specific procedures to control SFP work as of this assessment.

[176] AR means "Action Request"

RELATIONSHIP OF RECOMMENDATIONS TO CAUSATION				
CAUSE	**RECOMMENDATION**	**DETAIL ADDRESSED**	**EXPECTED RESULT**	**COMMENTS**
Process Weaknesses (3.1.1)	Review and revise as necessary procedures for disposal of irradiated hardware (e.g., waste characterization, QC of liner loading) to ensure they preclude the possibility of unauthorized and/or inadvertent shipment of SNM. (CACP-3)	Identify extent (if any) to which historical weaknesses broadly described in Section 3.1.3 might exist in current procedures.	Confirm adequacy of current practices; identify and implement improvements as appropriate.	Review of radwaste procedures was beyond the scope of this RCAR. This action should include provisions to address legacy waste.
Process Weaknesses (3.1.1)	Reconcile non-fuel SNM physical inventory with records at MP1, MP2 and MP3. This should be a detailed comparison of the SNM "inventory of record" with the actual physical SNM inventory at each unit. (CACP-4)	Determine "extent of condition"	Determine if the weakness in physical accountability of MP1 fuel rods extended to non-fuel SNM items at MP1, or MP2, or MP3.	Perform for MP1. Determine if recent non-fuel SNM reconciliations at MP2, MP3 were performed against "inventories of record."
Process Weaknesses (3.1.1)	Reconcile MP1 fuel inventory with an "inventory of record". This should be a detailed comparison of the SNM "inventory of record" with the actual physical SNM inventory. (CACR-1)	Determine "extent of condition"	Verify SNM loss was limited to two fuel rods from MP1.	Successfully completed per NE-01-280, 10/05/01. Loss of physical accountability at MP1 was limited to two MS-557 fuel rods.
Process Weaknesses (3.1.1)	Reconcile fuel SNM physical inventory with records at MP2 & MP3. This should be a detailed comparison of the SNM "inventory of record" with the actual physical SNM inventory at each unit. (CACR-2)	Determine "extent of condition"	Verify SNM loss was limited to two fuel rods from MP1.	Successfully completed per NE-01-280, 10/05/01. Loss of physical accountability was limited to two MS-557 fuel rods from MP1.

RELATIONSHIP OF RECOMMENDATIONS TO CAUSATION				
CAUSE	RECOMMENDATION	DETAIL ADDRESSED	EXPECTED RESULT	COMMENTS
3.1.1, 3.1.2, 3.1.3	Conduct periodic self-assessment of key SNM control and accountability program activities. Topics should include (but not be limited to): CAP implementation, use of history of movement forms, procedural adherence, records retention and retrieval, consistency among physical piece counts and gram accountability reports, SFP mapping practices, and use of industry operating experience (OPEX). (CACC-1)	Verification that deficiencies remained corrected, and that detection of future problems happens at the "discrepancy" level, and not through another event.	SNM control and inventory program performance level maintained at acceptable level; timely identification and correction of future discrepancies.	Provides interim effectiveness check of corrective actions, in the event that full implementation requires an extended period of time.
SFP Coordination (3.1.2)	Clearly define and communicate "ownership" of spent fuel pools and associated activities; including responsibility for activity coordination (and other current or future SNM storage areas) at Millstone. (CACP-5)	Historical SFP activity coordination and ownership weaknesses.	Clearly defined responsibilities for performance and coordination of activities that impact SNM storage locations. Simple method for station personnel to identify program, activity, and physical area owners.	
SNM Program "Ownership" (3.1.2)	Clearly define and communicate "ownership" of SNM control and accountability program and expected results. (CACP-6)	Program ownership at MP1 was historically split between SNM Accountant and Reactor Engineers without a well defined interface.	Clearly defined responsibilities and interfaces between individuals assigned SNM control and accountability. Simple method for station personnel to identify program owner.	RCAT noted identification and communication of current program ownership could be improved.
Procedural Adherence (3.1.2); Inconsistent Knowledgeable Oversight & Supervision (3.1.3)	Increase the frequency of documented supervisory observations of SNM control and accountability program activities. Ensure that processes and procedures do not over-rely on individual performance and that individuals meet station standards for procedural adherence. (CACP-7)	Historically, supervisory observations were limited	Improved procedural adherence and performance of personnel doing SNM-related tasks, and prompt identification and correction of undesirable performance (if any).	

RELATIONSHIP OF RECOMMENDATIONS TO CAUSATION				
CAUSE	RECOMMENDATION	DETAIL ADDRESSED	EXPECTED RESULT	COMMENTS
Verify C/A effectiveness	About 6-12 months after completion, verify effectiveness of corrective actions to prevent recurrence. (CATE-1)	Verification that deficiencies were corrected.	Confirmation that corrective actions resolved the deficiencies, or identification of the need for additional action.	Required by MP-16-CAP-FAP01.3, step 2.4.1.

OTHER RECOMMENDATIONS				
AREA	RECOMMENDATION	DETAIL ADDRESSED	BENEFIT	COMMENTS
QA Oversight	Enhance QA oversight of SNM control and accountability program. In particular, explicitly include consideration of fuel that is not in intact fuel assemblies in oversight activities. (CACA-1)	QA oversight activities did not identify inventory process vulnerabilities.	Increased oversight of how individual fuel rods are inventoried and controlled.	This is not intended to place SNM accountability activities under the formal nuclear QA program.
Basic Knowledge	Ensure that personnel who might encounter SNM understand that it can occur in various forms (not just intact fuel assemblies), and has special requirements for control and accountability. (CACA-2)	Individuals did not expect to encounter fuel outside of fuel assemblies.	Heightened sensitivity that SNM items may exist in the SFP in other than fuel assemblies.	
Licensing Basis	Document and maintain the current licensing basis for Millstone SNM control and accountability in a readily retrievable form. (CACA-3)	Identify regulatory requirements applicable to Millstone.	Document the basis for line and oversight understanding of regulatory requirements applicable to SNM control and accountability process in a useable form.	Added confidence that SNM-related procedures are consistent with licensing basis. This should be considered for performance prior to updating Master Manual 13.

APPENDICES

A.1 Investigation Charter

A.2 Analysis Methodology

A.3 Event Timeline

A.4 Root Cause Team

A.5 Definitions

A.6 Abbreviations

A.7 References

- A.7.1 People Contacted
- A.7.2 Interviews
- A.7.3 Documents

A.1 INVESTIGATION CHARTER

Northeast
Utilities System

107 Selden Street

Northeast Utilities Service Company
P.O. Box 270
Hartford, CT 06141-0270
(860) 444-5466

Frank C. Rothen
Vice President - Nuclear Services

Date: March 29, 2001 (Revised April 20, 2001)

From: Mr. Frank Rothen, Vice President, Nuclear Work Services

To: Mr. Richard N. Swanson, Performance Management Initiatives, Inc.

Copy to: Mr. Robert V. Fairbank, Project Manager, Fuel Rod Accountability Project
Mr. Bruce Hinkley, Chairman, Independent Review Team
Mr. Jeff Jeffries, Independent Review Team
Mr. Hugh Thompson, Independent Review Team
Mr. Joseph Callan, Independent Review Team
Mr. Charles Thebaud, Legal Counsel

Subject: Charter for Root Cause Investigation Revision 1

You are appointed to conduct an inquiry into the causes and circumstances surrounding loss of accountability of two irradiated fuel pins at Millstone Unit 1. You will report administratively to Mr. Robert V. Fairbank and functionally to me for the duration of this assignment.

You are to determine the causes of the loss of fuel pin accountability and to document your conclusions in a report as described below. This report will be used as a source of (a) what to learn from this event; and, (b) actions to prevent similar future events.

To the maximum extent possible, your inquiry should be based upon completed and planned Fuel Rod Accountability Project inspections, evaluations, and conclusions to avoid duplication. You are authorized to gather further data and to request support from project members as required, clearing such activities and requests through Mr. Fairbank.

If, in the conduct of your investigation, you discover significant conditions adverse to quality that could contribute to the initiation or exacerbation of a consequential event, you are to:

- Enter the condition(s) into the corrective action program via Condition Report(s); and,
- Recommend immediate interim compensatory measures to neutralize such threats while site management formulates and deploys permanent corrective action.

Your investigation is to focus on how and why Millstone 1 failed to maintain fuel pin accountability, given the results of the Fuel Rod Accountability Project investigation. Other project reports will document conclusions with respect to current fuel pin location.

Your report should include the following content:

- Executive summary that includes the most important messages to plant and executive corporate management, any specific actions that need to be taken at those levels, and any details and elaboration that you believe to be vital to our understanding of the message and action.

- A description of the event (covering the scenario(s) determined by the Project to be credible), including (for every condition and action that was not right, proper or expected) what in your view would have been the appropriate action or condition.

- Principal lessons to be learned by the organization from the event(s) (and condition(s)) you are investigating.

- The factors that affected the consequences of the event, including:

  1) The pre-existing causal factors that set the stage for the problem and made the plant vulnerable to the event;

  2) The triggering events or conditions that consummated the problem (i.e., that turned the vulnerability into a consequential event);

  3) The factors that exacerbated/aggravated the event or made the consequences worse; and

  4) The mitigating factors that kept the event from having more severe consequences.

  This section should discuss the underlying causal factors, including missed opportunities to have detected, corrected or avoided the factors contributing to vulnerability, consummation or exacerbation. Include missed opportunities involving oversight functions.

- Generic implications.

- Extraneous conditions adverse to quality (those things found in the course of the event or its investigation that were not right, yet did not contribute to the occurrence or severity of the matter being investigated).

- Quality and safety impact, including separate and distinct discussions of consequences and significance.

- Proposed corrective actions, including:
  - Interim compensatory measures,
  - Corrective action for problem effects,
  - Corrective actions for causes,
  - Corrective action for the generic implications (if any) of both the problem and its causes, and
  - Corrective actions for the self-assessment deficiencies (if any) and independent assessment deficiencies (if any) that allowed the causal factors or their underlying causal factors to lie unaddressed by the organization.

You are requested to use those methods you determine to be most effective in the conduct of your investigation, and to follow the direction contained in the current revision of Millstone Nuclear Power Station Administrative Procedure RP-6 ("Root Cause Analysis").

Your first investigation priority is to produce an investigation characterized by accuracy, thoroughness, relevance, and clarity.

You are to keep Mr. Fairbank closely informed as to the progress of your investigation and to brief me weekly.

A.2 ANALYSIS METHODOLOGY

The Root Cause Assessment Team (RCAT) used the event investigation process described in The Phoenix Handbook by Dr. W. R. Corcoran. This process is compatible with Millstone Station Root Cause Assessment procedures and methods. Team members reviewed station procedures associated with root cause assessment, problem reporting (Condition Reports), and the corrective action program (CAP), and were qualified to perform root cause assessments in accordance with station procedures prior to beginning the investigation.

RCAT members expended several months researching the facts associated with the event. This included reviewing applicable procedures, conducting interviews, analyzing key processes, and probing available documentation. The full Root Cause Assessment required approximately seven months from initiation through final report completion.

The RCAT approached this event by identifying both the consequences and the significance of the event. *Consequences* (as used in this report) are the tangible adverse impacts of the event in terms of damage, dollars, delay, discredit, and disruption. *Significance* is the collective set of implications for the future of the people, the companies, and the industries involved (directly or indirectly). The RCAT sought to understand the consequences of the event as distinct from the significance of the event.

Generally, events cannot happen unless organizational vulnerabilities make them possible. Thus, the RCAT sought to understand the "setup factors" that made the organization vulnerable to the event. Next, the RCAT investigated how the event was triggered, i.e., how the vulnerability was transformed into a consequential occurrence.

Realizing that events can range from very mild to severe, the RCAT sought to understand what made the consequences as bad as they were. That included investigating factors that exacerbated the situation.

Finally, the RCAT asked "What kept the event from being worse?" The RCAT did this because luck and other non-robust influences often intervene to limit the seriousness of an event. Non-robust barriers that go unrecognized and uncorrected may be involved in the setup of future events.

Standing back, the RCAT then asked two final questions:

- What should we learn from this event? (Lessons to be Learned)
- What should we do about this event? (Corrective and Preventive Actions)

This report meets station procedural requirements for root cause assessment. Both the charter (Appendix 1) and the nature of the event itself suggested format enhancements to more completely communicate the event.[177]

[177] Station procedures allow format enhancements.

A.3 EVENT TIMELINE

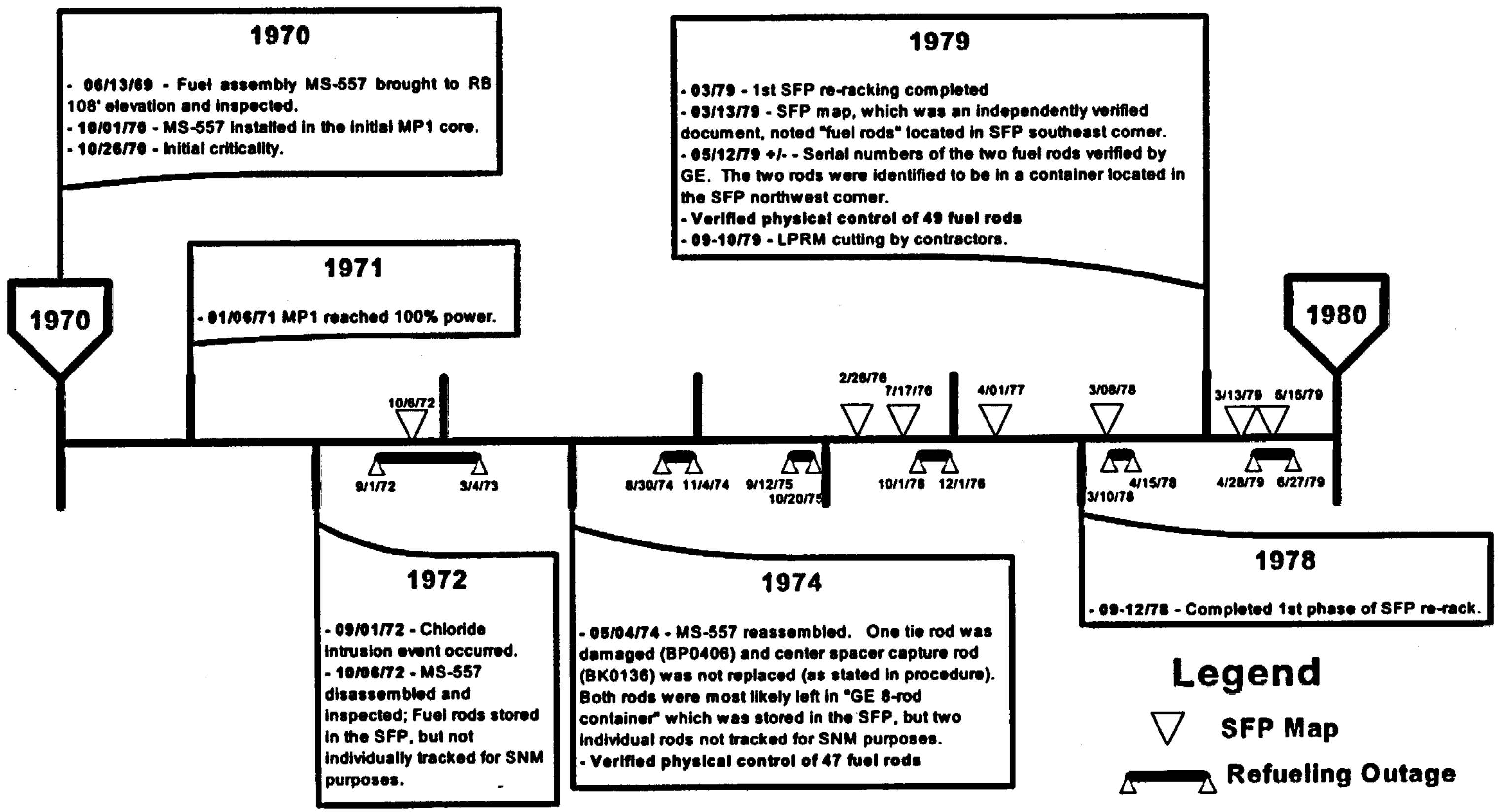
Below are three flow charts that summarize the chronology of major elements of this event. Triangular shapes indicate the dates of available MP1 SFP maps. Horizontal bars immediately below the timeline indicate refueling outage periods.

For convenience of display on the following charts, the RCAT segregated activities associated with this event into three ranges: 1970s, 1980s, and 1990s (including 2000). Activities shown on those charts included:

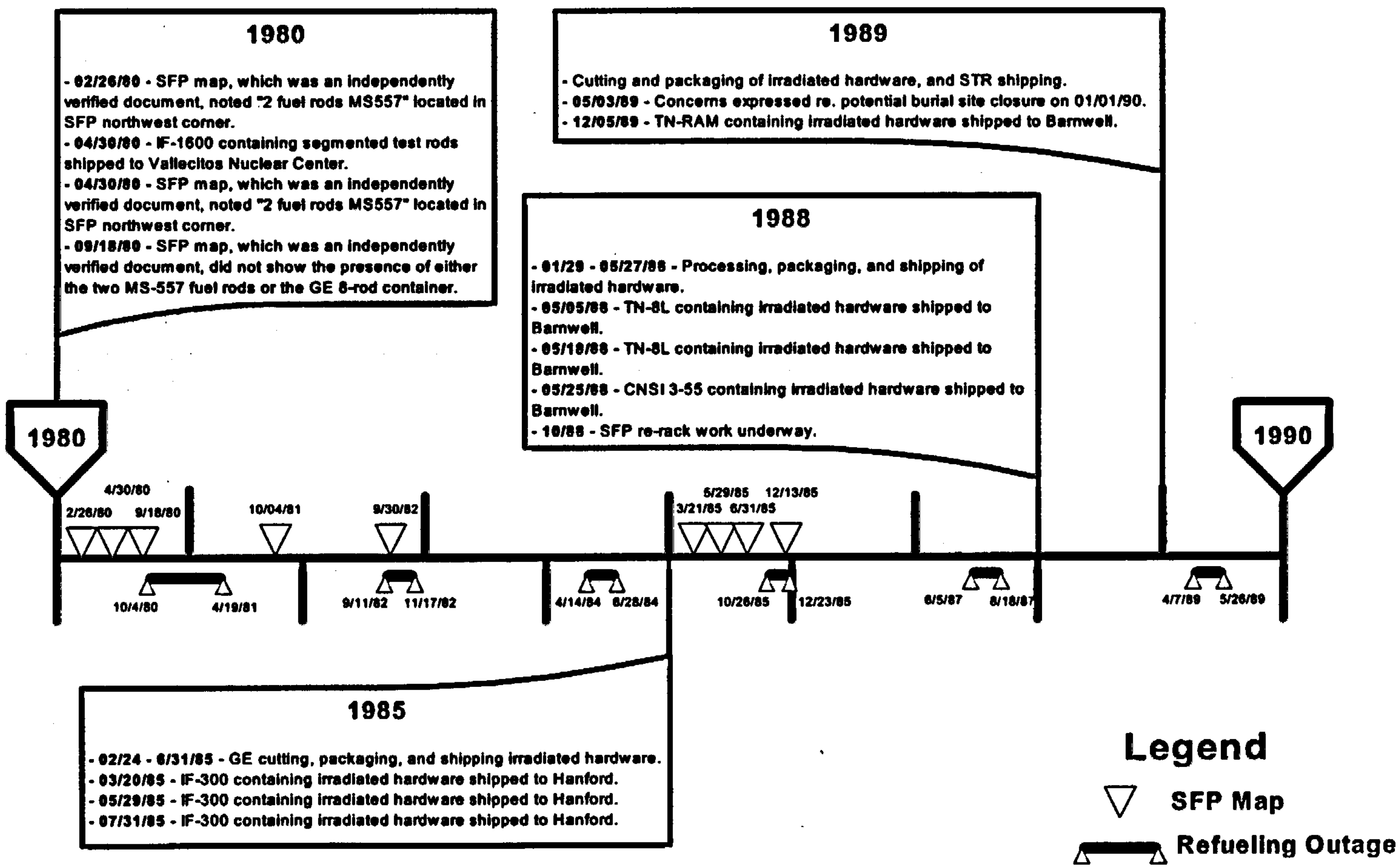
- 09/01/72 – Chloride intrusion into reactor coolant system
- 10/06/72 – Took apart and inspected fuel assembly MS-557, but fuel rods not individually tracked for accountability purposes
- 05/13/74 - Reassembled fuel assembly MS-557 with a dummy center spacer capture rod. The original center spacer capture rod and a damaged tie rod were not included in the MS-557 assembly. (Verified physical control of 47 MS-557 fuel rods.)
- 09/78-12/78 – Completed 1st phase of SFP re-racking; re-rack completed 03/79
- 03/13/79 - SFP map included unidentified "fuel rods"
- 05/12/79 - RE and vendor (GE) concluded two fuel rods stored in a GE 8-rod container were from MS-557; Kardex file card created for those fuel rods (verified physical control of 49 MS-557 fuel rods), but fuel rods not individually tracked for accountability purposes
- 09/79-10/79 – LPRM cutting by contractors
- 02/26/80 - SFP map included "2 fuel rods MS557"
- 04/30/80 – Segmented test rods shipped to Vallecitos; SFP map included "2 fuel rods MS557"
- 09/18/80 - SFP map did not include either "fuel rods" or GE 8-rod container
- 02/24-06/31/85 – GE cutting, packaging, and shipping irradiated hardware
- 03/20, 05/29, 07/31/85 – IF-300 cask containing irradiated hardware shipped to Hanford
- 01/29-05/27/88 – Processing, packaging, and shipping of irradiated hardware
- 05/05, 05/18/88 – TN-8L casks containing irradiated hardware shipped to Barnwell
- 05/25/88 - CNSI 3-55 cask containing irradiated hardware shipped to Barnwell
- 10/88 – SFP re-rack work underway
- 1989 (various times) – Cutting and packaging of irradiated hardware, and STR shipping
- 12/05/89 – TN-RAM cask containing irradiated hardware shipped to Barnwell
- 1990 (various times) - Processing, packaging, and shipping of irradiated hardware

- 01/16, 05/07/90 – TN-RAM casks containing irradiated hardware shipped to Barnwell
- 10/13, 12/08, 12/21/92 - TN-RAM casks containing irradiated hardware shipped to Barnwell
- 04/14, 05/08, 05/19, 06/07, 07/17/00 - TN-RAM casks containing irradiated hardware shipped to Barnwell
- 11/16/00 – Condition report (CR) M1-00-0548 issued concerning two missing MS-557 fuel rods (initiated 11/15/00, Operations screened 11/16/00)

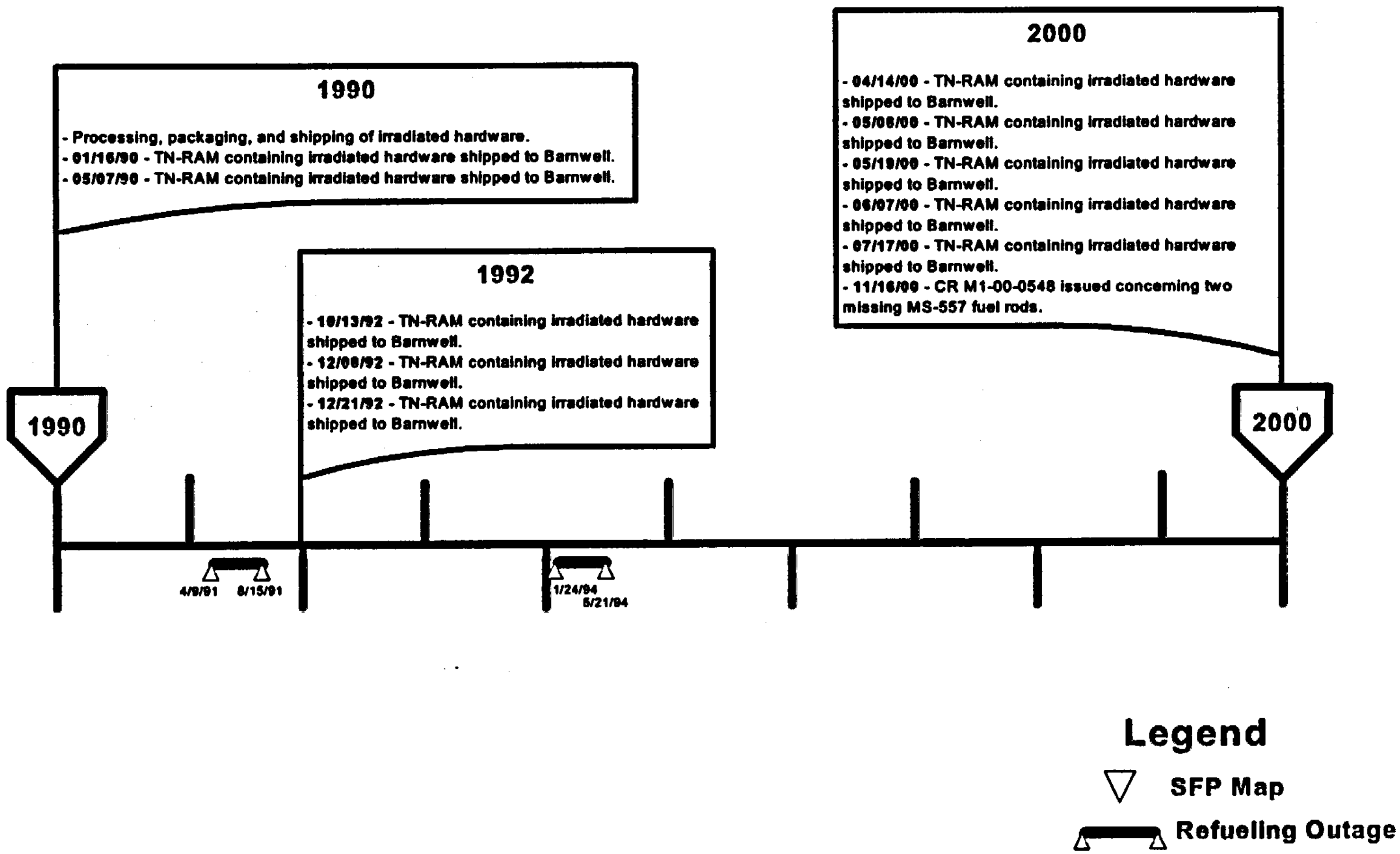
A.3.1 TIMELINE 1970-1980



A.3.2 TIMELINE 1980-1990



A.3.3 TIMELINE 1990-2000



A.4 ROOT CAUSE TEAM

The RCAT consisted of two independent consultants with collective nuclear experience in excess of 60 years, work experience at more than 50 nuclear sites, and involvement in more than 50 event investigations.

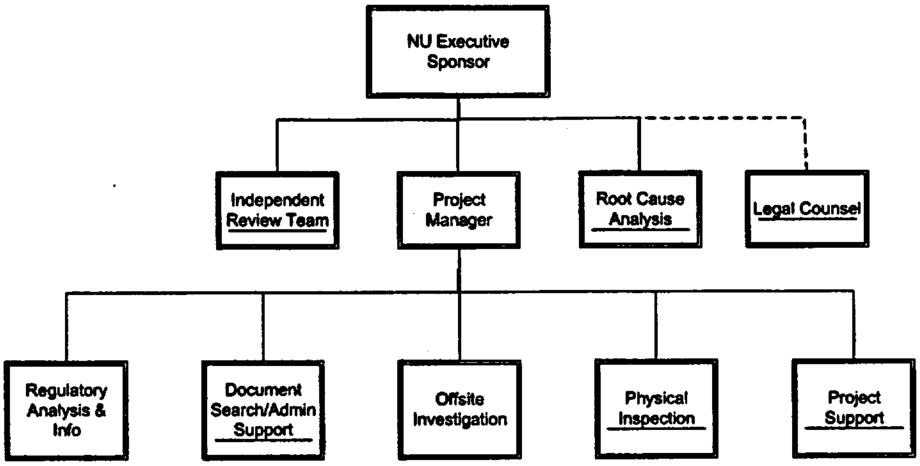
Both individuals are professionally active in the American Nuclear Society and have chaired numerous workshop panels and lectured on related subjects many times over the past several years. Panel and lecture subjects included event investigation, performance oversight, identification of limiting weaknesses, and nuclear safety.

Mr. Peter L. Reagan has been SRO licensed or certified at five different sites and is a licensed Professional Engineer (nuclear or mechanical) in three States. His more than 30 years of commercial nuclear power industry experience includes six years with General Electric Company (GE) and 16 years as an independent consultant. He earned a BS (Civil Engineering) from Northeastern University and MS (Engineering Management) from Drexel University.

Mr. Richard N. Swanson is a licensed Professional Engineer (mechanical) and has operated three different naval nuclear plants as Engineering Officer of the Watch. His experience includes 16 years with nuclear utilities (11 in senior management positions), and 6 years as an independent consultant. He earned a BS (Operations Analysis) from the US Naval Academy, MS (Engineering Management) from Northeastern University, and MBA from Babson College.

Mr. Reagan and Mr. Swanson have collaborated on several significant investigations in the past.

The relationship of the RCAT to the rest of the FRAP is shown in the organization chart below:


NU Executive Sponsor
Independent Review Team
Project Manager
Root Cause Analysis
Legal Counsel
Regulatory Analysis & Info
Document Search/Admin Support
Offsite Investigation
Physical Inspection
Project Support

A.5 DEFINITIONS

- *Legacy waste* means radwaste that was at least partially processed for shipment (but not shipped) prior to major changes in Station or regulatory waste characterization requirements.

- *Reconcile* means:

  To compare physical entities to an "inventory of record";

  Identify differences, if any, between entities physically present and the "inventory of record";

  Determine reason(s) for mismatches, if any, between documentation and physical entities; and

  Take appropriate action to address mismatches, including appropriate documentation and reports.

- *SNM Inventory of Record* means a single, integrated, readily retrievable listing of SNM entities ("pieces") that reflects SNM entities that should be on-hand and is updated in a timely manner to reflect additions and removals. SNM entities "that should be on-hand" are entities received less entities properly removed.

- *Strategic quantity* is the amount of nuclear material required to manufacture an explosive device. The two MS-557 rods together contained about 180 grams of U^{235}. The strategic quantity of this isotope is defined by the International Atomic Energy Agency as 75,000 grams.

SELECTED 10CFR70.4 DEFINITIONS [178]

- *Special nuclear material* means (1) plutonium, uranium 233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the Commission, pursuant to the provisions of section 51 of the act, determines to be special nuclear material, but does not include source material; or (2) any material artificially enriched by any of the foregoing but does not include source material;

- *Special nuclear material* of low strategic significance means:

  (1) Less than an amount of special nuclear material of moderate strategic significance as defined in paragraph (1) of the definition of strategic nuclear material of moderate strategic significance in this section, but more than 15 grams of uranium-235 (contained in uranium enriched to 20 percent or more in U-235 isotope) or 15 grams of uranium-233 or 15 grams of plutonium or the combination of 15 grams when computed by the equation, grams = (grams contained U-235) + (grams plutonium) + (grams U-233); or

[178] Source: NRC website 05/16/01 at URL: http://www.nrc.gov/NRC/CFR/PART070/part070-0004.html

(2) Less than 10,000 grams but more than 1,000 grams of uranium-235 (contained in uranium enriched to 10 percent or more but less than 20 percent in the U-235 isotope); or

(3) 10,000 grams or more of uranium-235 (contained in uranium enriched above natural but less than 10 percent in the U-235 isotope).

This class of material is sometimes referred to as a Category III quantity of material.

- *Special nuclear material of moderate strategic significance* means:

(1) Less than a formula quantity of strategic special nuclear material but more than 1,000 grams of uranium-235 (contained in uranium enriched to 20 percent or more in the U-235 isotope) or more than 500 grams of uranium-233 or plutonium, or in a combined quantity of more than 1,000 grams when computed by the equation, grams = (grams contained U-235) + 2 (grams U-233 + grams plutonium); or

(2) 10,000 grams or more of uranium-235 (contained in uranium enriched to 10 percent or more but less than 20 percent in the U-235 isotope).

This class of material is sometimes referred to as a Category II quantity of material.

- *Strategic special nuclear material* means uranium-235 (contained in uranium enriched to 20 percent or more in the U235 isotope), uranium-233, or plutonium.

A.6 ABBREVIATIONS

ABBREVIATION	NOUN NAME	COMMENTS
AEC	Atomic Energy Commission	
ALARA	As Low As Reasonably Achievable	
ANSI	American National Standards Institute	
AR	Action Request	
ASLB	Atomic Safety And Licensing Board	
AWO	Automated Work Order	
BWR	Boiling Water Reactor	
CACA	Enhancement Corrective Action	
CACC	Compensatory Corrective Action	
CACP	Corrective Action To Prevent Recurrence or CATPR	
CACR	Remedial Corrective Action	
CAP	Corrective Action Program	
CAPR	Corrective Action To Prevent Recurrence or CACP	
CATE	Corrective Action Effectiveness Review	
CFR	Code of Federal Regulations	
CR	Condition Report	
CRB	Control Rod Blade	
DAW	Dry Active Waste	
DNC	Dominion Nuclear Connecticut	
DOE	Department of Energy	
DOT	Department of Transportation	
ENS	Emergency Notification System	
FRAP	Fuel Rod Accountability Project	
FSAR	Final Safety Analysis Report	
GE	General Electric Company	
gm. or g.	Gram	
ICA	Item Control Area	
IN	Information Notice	
INPO	Institute of Nuclear Power Operations	
IR	Inspection Report	
IRM	Intermediate Range Monitor	
IRT	Independent Review Team	
ISFSI	Independent Spent Fuel Storage Installation	
Kg	Kilograms	
LER	Licensee Event Report	
LLRW	Low Level Radioactive Waste	
LPRM	Local Power Range Monitor	
LSA	Low Specific Activity	
MBA	Material Balance Area	
MP1	Millstone Point Unit 1	
MP2	Millstone Point Unit 2	
MP3	Millstone Point Unit 3	
MPO	Master Process Owner	
MTF	Material Transfer Form	

ABBREVIATION	NOUN NAME	COMMENTS
NEI	Nuclear Energy Institute	
NFE	Nuclear Fuel Engineering	
NNECo	Northeast Nuclear Energy Co.	
NOV	Notice of Violation	
NRC	Nuclear Regulatory Commission	
NSAB	Nuclear Safety Assessment Board	
NU	Northeast Utilities	
NUSCo	Northeast Utilities Service Company	
OPEX	Operating Experience	
PI	Performance Indicator	
PONFSA	Process Owner Nuclear Fuel and Safety Analysis	
POPI	Process Owner Performance Improvement	
Pu	Plutonium	
PWR	Pressurized Water Reactor	
QA	Quality Assurance	
RCAR	Root Cause Assessment Report	
RCAT	Root Cause Assessment Team	
RCS	Reactor Coolant System	
RE	Reactor Engineer	
RWP	Radiation Work Permit	
SALP	Systematic Assessment of Licensee Performance	
SDP	Significance Determination Process	
SFP	Spent Fuel Pool	
SNM	Special Nuclear Material	
SRM	Source Range Monitor	
SRP	Segmented Rod Program	
STR	Segmented Test Rod	
TIP	Traversing In-core Probe	
TMI-2	Three Mile Island Unit 2	
U	Uranium	
URL	Uniform Resource Locator	
VNC	Vallecitos Nuclear Center or Vallecitos	
WT%	Weight Percent of Isotope	

A.7 REFERENCES

A.7.1 PEOPLE CONTACTED

NAME	ORGANIZATION
Adam, James D.	Manager, Field Delivery-Reactor Services, GE Nuclear Energy (San Jose)
Adey, Charles W.	TTX Associates
Allen, Glenn E.	Plant Equipment Operator, Millstone Station
Altvater, Jr., Frederick W.	Health Physics Technician, Dominion Nuclear Connecticut
Aquitante, Joseph	Maintenance Department, Dominion Nuclear Connecticut
Arcari, Patsy	Retired MP1 Maintenance Foreman
Atchison, Eugene	Field Supervisor, Duratek
Ball, Joseph R.	Maintenance Department, Dominion Nuclear Connecticut
Ballard, Charles	Former GE Nuclear Energy Engineer
Bartron, William D.	Team Lead, ISEG/OE, Dominion Nuclear Connecticut
Bassett, Charles	Regulatory Compliance Manager, Vallecitos, GE Nuclear Energy
Bell, C. Ted	Deputy Engineering Director, Quad Cities, Exelon Corp.
Berry, Clyde	GE Nuclear Energy (Retired)
Berry, Ed	Northeast Utilities (retired)
Bessard, Stuart	GE Nuclear Energy (Retired)
Bigiarelli, Michael	Training Department, Dominion Nuclear Connecticut
Black, Allen L.	Nuclear Fuel Specialist II, Dominion Resources Services, Inc.
Boies, Russell	GE Nuclear Energy (Retired)
Borchert, Robert A.	DNC, Senior Engineer - Reactor Engineering Team
Braun, Joseph	Argonne National Laboratory (International Atomic Energy Agency)
Brennan, Mark	Regulatory Analyst [for Radwaste Shipping], Bartlett Nuclear
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Buchheit, Mickey	Duke Engineering & Services
Calderone, Mary Lou	Nuclear Safety Engineering
Clark, William F.	C. N. Flagg Co. (Retired)
Cooper, Cliff	Northeast Utilities (Retired)
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Crisman, George B.	Supv. Nuclear Operations Support, North Anna, Dominion
Currier, James	Dominion Nuclear Connecticut
Dennison, Dave	EG&G, Los Alamos

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Dolter, Jack	Reactor Engineer, Exelon Corp. (Headquarters)
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Ewin, Jeffrey	INPO
Eykelhoff, Dirk M.	DNC, Corrective Action Coordinator
Factora, Robert	Northeast Utilities (Retired)
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Follett, John	Northeast Utilities (Retired)
Forrester, Kent	Supervisor, WasteChem
Galor, Briggie	Northeast Utilities (Retired)
Geluso, Frank	Northeast Utilities (Retired)
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Gonser, John	GE Nuclear Energy (Retired)
Guerci, John	Dominion Nuclear Connecticut
Hallahan, Dennis	Proto Power Corp (Retired)
Harnal, Rajinderbir S.	Dominion Nuclear Connecticut
Harran, George	MP1 Nuclear Engineering Technician (retired)
Hill, Charles	Supervisor-Materials Lab Operation, GE Nuclear Energy (Vallecitos)
Hill, Lee O.	Team Lead, Nuclear Fuel Supply, Dominion Nuclear Connecticut
Hills, Michael	Northeast Utilities (Retired)
Hoshi, Emory	Principal Engineer, GE Nuclear Energy (Vallecitos)
Hykys, Richard	Sr. Process Consultant, Northeast Utilities (Berlin)
Ikemoto, Robert	GE Nuclear Energy (Retired)
Jensen, Michael	Dominion Nuclear Connecticut
Johnson, David	GE Nuclear Energy (Retired)
Joyner III, James H.	NRC (Region I)
Kai, Michael S.	DNC, Nuclear Fuel, Principal Engineer
Kasic, James	Senior Engineer, GE Nuclear Energy (San Jose)
Kegel, Joel	Field Services, GE Nuclear Energy (San Jose)
Kiskunes, John	Northeast Utilities (Retired)
Kocon, Forrest	Dominion Nuclear Connecticut
Kong, Yeun	GE Nuclear Energy (Retired)
Koste, Wolf	Supervisor, Radwaste Shipping, Dominion Nuclear Connecticut
Laidlow, Mark S.	Fuel Accounting and Inspection Specialist, Fuel Performance Analysis – Innsbrook Staff, Dominion

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LaRue-Carrier, MaryJo	Manager, Licensing and Traffic, GE Nuclear Energy (San Jose)
Lemke, Jack	Northeast Utilities (Retired)
Lindsay, Edward	Vermont Yankee
Liss, Walter J.	Procedure Writer, Dominion Nuclear Connecticut
Lockett, Elena L.	Nuclear Technician, Dominion Nuclear Connecticut
Loring, Larry	Northeast Utilities (Retired)
Martinez, Carlos	Senior Engineer, GE Nuclear Energy (Vallecitos)
Mandigo, Carol	Scientist, Nuclear Fuel Supply Team, Dominion Nuclear Connecticut
McAndrew, Robert G.	Reactor Engineer, North Anna, Dominion
McCollom, William R.	Former MP1 RO, SRO, Shift Manager, Operations Manager
McGrath, Richard A.	Dominion Nuclear Connecticut
McKenney, Hugh E.	DNC, Team Lead Engineer - Reactor Engineering
McNamara, Michael P.	VP, Nuclear Projects, Holtec International
Mihal, William C.	Northeast Utilities (Retired)
Misak, Alex	Reactor Engineer, Quad Cities, Exelon Corp.
Moore, Ernest V.	Engineer III, Dominion Resources Services, Inc.
Mullin, Vic	GE Engineer
Newburgh, Gary	Former MP-1 Operations & Engineering Supervisor
Nocera, Mark A.	Engineering Analyst, Dominion Nuclear Connecticut
Opalenik, Charles	Mechanic
Palmeiri, Raymond	Former MP-1 Operations & Engineering Supervisor
Panzo, Mike	Boilermaker
Parillo, Joseph J.	Reactor Analysis Section, Dominion Nuclear Connecticut
Patterson, Peter	GE Nuclear Energy (retired)
Pernal, James	FIN Team, Dominion Nuclear Connecticut
Philbrick, Walter	Northeast Utilities (retired)
Piascik, Thomas	Former MP1 Reactor Engineer
Pomares, Raul	GE Nuclear Energy (Vallecitos)
Price, J. Alan	VP Nuclear Technical Services, DNC
Przkop, Peter	Northeast Utilities (retired)
Racicot, Paul E.	Dominion, Health Physics (NFE website developer)
Reck, Ron	Northeast Utilities (retired)
Rescek, Gerard E.	DNC, Performance Improvement, Trending Program Analyst
Romberg, Wayne	Exelon
Rosicky, Edward	GE Nuclear Energy (Retired)

NAME	ORGANIZATION
Ross, Michael	Former MP1 Operator & Engineer
Rothstein, Harold	Washington Group International
Roy, R. Bruce	Team Leader (Asset Strategy and Admin Support), Dominion Nuclear Connecticut
Russo, Ralph	Florida Power & Light
Scace, Stephen E.	DNC, Master Process Owner, Manage The Asset
Senior, Harry	Northeast Utilities (retired)
Sharma, Harry	Reactor Engineer, Oyster Creek, AmerGen/Exelon Corp.
Shedlosky, J. Tom	US NRC, Region I
Shiraisha, LeRoy	GE Nuclear Energy (retired)
Short, James	C N Flagg Co (Retired)
Slaga, Thomas	Northeast Utilities (retired)
Smith, Barbara J.	DNC, Admin. Proc/Docs, Engineering Analyst
Spahn, William E.	Shift Manager, Dominion Nuclear Connecticut
Spath, Buzz	Boiler Maker (retired)
Stafford, Carl P.	Reactor Engineer, OPPD
Stark, Shelia D.	Reactor Engineering, Nuclear Tech. A, Dominion Nuclear Connecticut
Tamai, Wes	GE Fuels Engineer
Thacker, "Gill"	GE Nuclear Energy (San Jose)
Thomas, Ken	Reactor Engineer
Thibeault, Richard F.	TTX Associates
Tobin, Robert	GE Nuclear Energy (Retired)
Tulba, Paul	Radwaste Services Group, Dominion Nuclear Connecticut
Vandermyde, Mark	Reactor Engineer, Clinton Power Station, Exelon Corp.
Varney, Walter	Northeast Utilities (Retired)
Vaughn, Arlie	GE Nuclear Energy (retired)
Wegener, Dan	Reactor Engineer, Monticello, XCEL Energy
Weise, Doug	Reactor Engineer, Dresden 2/3, Exelon Corp.
Wessling, Vincent M.	DNC, Team Lead – Corrective Action
Wheeler, James L.	Nuclear Fuel & Safety Analysis, Dominion Nuclear Connecticut
Whitaker, Carl	Dominion Nuclear Connecticut
Woldszym, Michael	Business Analyst, PSEG
Wolfhope, Norm P.	Supervisor, Fuel Performance Analysis – Innsbrook Staff, Dominion
Young, James H.	Quality Assessment Services, Dominion Nuclear Connecticut
Young, R.H. (Hal)	Reactor Engineering Senior Technician

A.7.2 INTERVIEWS

NAME	ORGANIZATION	REFERENCE	NO.
Altvater, Jr., Frederick W.	Health Physics Technician, Dominion Nuclear Connecticut	Altvater-PLR-DAB-06-07-01	1
Aquitante, Joseph	Maintenance Department, Dominion Nuclear Connecticut	Aquitante-PLR-DAB-05-24-01	2
Arcari, Patsy	Retired MP1 Maintenance Foreman	Arcari—PLR-RVF-06-20-01	3
Berry, Ed	Northeast Utilities (retired)	Berry'E-PLR-JAK-06-12-01	4
Bigiarelli, Michael	Training Department, Dominion Nuclear Connecticut	Bigiarelli-PLR-RVF-05-30-01 Bigiarelli-PLR-RVF-06-29-01	5 6
Boies, Russell	GE Nuclear Energy (Retired)	Boies-RNS-GG-05-31-01	7
Brennan, Mark	Regulatory Analyst [for Radwaste Shipping], Bartlett Nuclear	Brennan-RNS-DAB-05-22-01	8
Cretella III, Albert W.	Account Manager, Information Technology, Northeast Utilities	Cretella-RNS-09-18-01	9
Currier, James	Dominion Nuclear Connecticut	Currier-PLR-RVF-06-19-01	10
Forrester, Kent	Supervisor, WasteChem	Forrester-RNS-WVR-06-29-01	11
Hamal, Rajinderbir S.	Dominion Nuclear Connecticut	Hamal-RNS-DAB-06-05-01	12
Harran, George	MP1 Nuclear Engineering Technician (retired)	Harran-RVF-DAP-06-18-01 [179]	13
Hills, Michael	Northeast Utilities (Retired)	Hills-RNS-IM-06-26-01	14
Hykys, Richard	Sr. Process Consultant, Northeast Utilities (Berlin)	Hykys-PLR-DAB-05-30-01	15
Jensen, Michael	Dominion Nuclear Connecticut	Jensen-RNS-07-19-01-1153 Jensen-RNS-07-25-01-1724	16 17
Kasic, James	Senior Engineer, GE Nuclear Energy (San Jose)	Kasic-RNS-GG-05-24-01	18
Kiskunes, John	Northeast Utilities (Retired)	Kiskunes-PLR-DAB-06-06-01	19
Koste, Wolf	Supervisor, Radwaste Shipping, Dominion Nuclear Connecticut	Koste-RNS-DAB-05-21-01	20
Lemke, Jack	Northeast Utilities (Retired)	Lemke-PLR-RVF-06-06-01	21
Liss, Walter J.	Procedure Writer, Dominion Nuclear Connecticut	Liss-PLR-DAB-06-01-01	22
McCollom, William R.	Former MP1 RO, SRO, Shift Manager, Operations Manager	McCollum-PLR-DAB-07-26-01	23
McGrath, Richard A.	Dominion Nuclear Connecticut	McGrath-PLR-JAK-06-13-01	24
Mihal, William C.	Northeast Utilities (Retired)	Mihal-PLR-DAB-06-14-01	25

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NAME	ORGANIZATION	REFERENCE	NO.
Newburgh, Gary	Former MP-1 Operations & Engineering Supervisor	Newburgh-RVF-PLR-06-13-01 Newburgh-RVF-PLR-06-29-01	26 27
Parillo, Joseph J.	Reactor Analysis Section, Dominion Nuclear Connecticut	Parillo-PLR-DAB-06-04-01	28
Patterson, Peter	GE Nuclear Energy (retired)	Patterson-RVF-08-13-01-1130	29
Philbrick, Walter	Northeast Utilities (retired)	Philbrick-PLR-JAK-06-19-01	30
Piascik, Thomas	Former MP1 Reactor Engineer	Piascik-RVF-PLR-06-27-01 Rev 2	31
Przkop, Peter	Northeast Utilities (retired)	Przkop-RNS-JAK-06-08-01	32
Ross, Michael	Former MP1 Operator & Engineer	Ross-RVF-PLR-06-25-01	33
Shedlosky, J. Tom	US NRC, Region I	Shedlosky-RNS-DAB-07-20-01	34
Slaga, Thomas	Northeast Utilities (retired)	Slaga-RNS-JAK-06-07-01	35
Spahn, William E.	Shift Manager, Dominion Nuclear Connecticut	Spahn-RNS-DAB-06-06-01	36
Tulba, Paul	Radwaste Services Group, Dominion Nuclear Connecticut	Tulba-PLR-DAB-05-24-01	37
Vaughn, Arlie	GE Nuclear Energy (retired)	Vaughn-RNS-GG-5-24-01	38
Young, James H.	Quality Assessment Services, Dominion Nuclear Connecticut	Young-RNS-PLR-05-17-01	39

A.7.3 DOCUMENTS REFERENCED

TYPE	DOC. #	DATE	TO	FROM	TITLE
Accountability Card	MS-557	06/13/69			[Kardex file card for MS-557]
Accountability Card	MS-557 Fuel Rods	05/12/79			[Kardex file card for MS-557 Fuel Rods]
Audit	002	07/22/77	Unit 1 Superintendent	NUSCo Superintendent, Nuclear Production	"Audit of Special Nuclear Material—SNM Inventory and Control R.E. No. 1001/21001"
Audit	NE-82-F-004	01/05/82	Unit 1 Superintendent	Nuclear Fuels (SNM Accountant)	"Audit of SNM Inventory and Control Procedure RE 1001"
Audit	MP-97-A04-07 AE-97-4089	05/16/97	Distribution	Director, Audits and Evaluations	"Nuclear Oversight Audit MP-97-A04-07 'Special Nuclear and Byproduct Materials'" [Related to Sequence number 336A]
Audit	AE-97-4150 MP-97-A04-07	06/23/97	President and Chief Nuclear Officer	Director, Audits and Evaluation	'Nuclear Oversight Audit Package MP-97-A04-07, "Special Nuclear and Byproduct Material Control and Accountability "' [Related to Sequence number 332 package]
Audit	MP-99-A08 SES-NO-99-006	06/18/99	President & CEO, Nuclear Group; Sr. VP & CNO, Millstone	Director, Nuclear Oversight	"Northeast Utilities Quality Assurance Audit MP-99-A08 'Special Nuclear/Licensed Materials' Millstone Station"
Condition Report	M1-00-0548	11/15/00			"Historical Unaccountability Of Fuel Rods"
Field notes		04/18/74 to 05/31/74	File	Reactor Engineer	"1974 Fuel Reconstitution"
FSAR					Millstone Unit 1 Final Safety Analysis Report
Form	MTF 74-32	04/04/74			Material Transfer Form for MS-557 [Reassembly]
Guideline	NEI 99-02, Rev. 1	04/23/01		Nuclear Energy Institute	"Regulatory Assessment Performance Indicator Guidelines"
Handbook		2001		W. R. Corcoran, PhD., PE	"The Phoenix Handbook"
Information Notice	88-34	05/31/88		USNRC	"Nuclear Material Control and Accountability of Non-Fuel Special Nuclear Material at Power Reactors"
Inspection Manual	0609	02/27/01		USNRC	"Significance Determination Process"

TYPE	DOC. #	DATE	TO	FROM	TITLE
Inspection Manual	2515	03/06/01		USNRC	"Light-water Reactor Inspection Program—Operations Phase"
Inspection Report	50-245/76-08	05/25/76	President, NNECo	NRC Region I	Notice of Violation & Inspection Report; SNM Accountability (April 12-15, 1976)
Inspection Report	50-245/78-07	04/03/78	President, NNECo	USNRC	"NRC Inspection 50-245/78-07" [3/16-17/78, incl. refueling operations]
Inspection Report	50-245/81-06 50-336/81-05	07/14/81	Millstone Units 1 & 2	USNRC	Inspection 50-245/81-06 & 50-336/81-05 (4/5-5/16/81, Incl. Segmented Test Rods)
Inspection Report	50-245/94-19	07/21/94	NNECo	NRC Region I	"Notice of Violation (NRC Inspection Report No. 50-245/94-19)" [Inability to locate two IRMs]
Letter		12/19/72	US AEC	President, Millstone Point Company	"Submittal of Report on Chloride Intrusion Incident (AO-72-22), Millstone Unit No. 1, Docket No. 50-245"
Letter	ADV:81-070	05/08/81	NUSCo	GE Fuel Project Manager	"Notification of Millstone-1 STR Bundle Loading Error"
Letter	B14940	08/26/94	NRC Document Control Desk	NUSCo	"Millstone Nuclear Power Station Unit No. 1, Reply to Notice of Violation and Notice of Deviation, Inspection Report No. 50-245/94-19"
Licensee Event Report	94-016-00	05/23/94			"Loss of Special Nuclear Material Accountability"
Map		03/13/79			[Spent Fuel Pool Inventory Map "as of 3-13-79" corrected per 4/20/79 memo (seq. #181B); date of correction not shown] (shows rods)
Map		02/26/80			[Spent Fuel Inventory Map (shows rods)]
Map		04/30/80			[Spent Fuel Pool Inventory Map; "verified by [Rx Eng] April 30, 1980, Rev. 1"] (shows rods))
Map		09/18/80			[Spent Fuel Pool Inventory Map; "verified 9/18/80 rev. 2"] (no rods are shown)
Memo		07/23/69	File		"SNM Accountability"
Memo		08/27/69	Plant Superintendent		["Comments on SNM Accountability", name] to File, dated July 23, 1969
Memo		11/21/69	Plant Superintendent		"Filing System for Special Nuclear Material"
Memo		10/11/72		General Electric	"Millstone Chloride Intrusion Fuel Inspection Task" [with handwritten note attached]
Memo		12/06/77	Station Superintendent	SNM Accountant	"Audit of Special Nuclear Material - SNM Inventory; Audit of June 27, 1977" [Accepted 12/4/77 response to 6/27/77 audit]

TYPE	DOC. #	DATE	TO	FROM	TITLE
Memo		05/15/79	File	MP1 Reactor Engineer	"Fuel Rods" w/ MS-557 Bundle Loading Record attached
Memo	SYO-120	05/12/81		General Electric	"Millstone-1 STR Bundle Loading Analysis"
Memo	MP-1-1993	02/09/82	SNM Accountant	Unit 1 Superintendent	"Response to NUSCo Audit of Millstone 1 SNM Inventory and Control Procedure, RE 1001"
Memo	RAD3-88-49	05/31/88	MP1 Engineering	MP1 Re-Rack Project Manager	"Millstone Unit No. 1 Spent Fuel Pool Cleanup"
Memo	NE-01-F-253	09/12/01	RE Team Lead	Scientist, NFS	"MP2 Special Nuclear Material (SNM) On-site Inventory Validation for MP2 and MP3 SNM Reconciliation Project", with attachments: "Special Nuclear Material (SNM) Master List Millstone Point Unit 2", 09/11/01 "NMMSS Report TJ-23-HDQ-XBD-REQ", 01/16/01 "Fuel Assembly Inventory of MP2, Based on NFAS Data base as of Aug. 29, 2001", 09/10/01 "NMMSS TJ-23 Report", NMMSS Project Engineer to NFS Scientist, 09/07/01 NRC/DOE Form 741s [for natural uranium rods] Letter NE-01-F-252 from SNM Accountant to NMMSS Project Engineer, 09/10/01 "MP2 Non-fuel DOE/NRC 741 Forms", 09/10/01 "MP2 DOE/NRC 741 Form", 09/11/01
Memo	NE-01-F-254	09/12/01	RE Team Lead	Scientist, NFS	"MP3 Special Nuclear Material (SNM) On-site Inventory Validation for MP2 and MP3 SNM Reconciliation Project", with attachments: "Special Nuclear Material (SNM) Master List Millstone Point Unit 3", 09/10/01 "NMMSS Report TJ-23-HDQ-XVS-REQ", 01/16/01 "MP3 Fuel Inventory, Based on NFAS Data base as of Aug. 29, 2001", 09/10/01 "NMMSS TJ-23 Report", NMMSS Project Engineer to NFS Scientist, 09/07/01 "MP3 DOE/NRC 741 Form", 09/10/01 "MP3 Non-fuel DOE/NRC 741 Forms", 09/10/01
Memo	NE-01-F-269	09/27/01	SNM File	RE, MP1	"Verification of Unit 1 SFP and Core Shuffleworks vs SNM Card File"

TYPE	DOC. #	DATE	TO	FROM	TITLE
Memo	NE-01-F-271	09/28/01	RE Team Lead	Scientist, NFS	"MP3 Special Nuclear Material (SNM) DOE/NRC Form 741 Reconciliation for MP2 and MP3 SNM Reconciliation Project"
Memo	NE-01-F-279	10/05/01	Distribution	PO NFSA	"SNM Inventory of Record"
Memo	NE-01-F-280	10/05/01	PO NFSA	MP2 RE	"Millstone 2 and 3 Special Nuclear Material Reconciliation (CR-01-0863)"
Memo	FRAP-01-093	10/09/01	RCAT	FRAP	"The Applicability of the Risk-Informed Inspection Process to Missing Millstone Unit-1 Fuel Rods."
Notes of Conference	FRAP Group Interview 07-27-01, Rev. 1	08/10/01	File	FRAP	"Fuel Rod Accountability Project (FRAP) Expert Panel Review of Open Issues July 27, 2001 0815-1645"
NRC Inspection Procedure	85102	02/21/84		USNRC	"Material Control and Accounting - Power Reactor"
NRC Inspection Procedure	85102	03/29/85		USNRC	"Material Control and Accounting - Reactors"
NRC website		09/30/01 (date posted)	(Public posting)	NRC	"Three Mile Island 2 Accident" (URL: http://www.nrc.gov/OPA/gmo/tip/tmi.htm)
NUREG	NUREG-0725, Rev. 7	01/91		NRC	"Public Information Circular for Shipments of Irradiated Reactor Fuel"
Procedure	RE 1001/21001, Rev. 0	11/15/73			Reactor Engineering Procedure, SNM Inventory and Control
Procedure	RE 1001, Rev. 1	01/17/79			Reactor Engineering Procedure, SNM Inventory and Control
Procedure	RE 1001, Rev. 2	05/11/79			Reactor Engineering Procedure, SNM Inventory and Control
Procedure	EN 21001, Rev. 9	08/26/87		Millstone Unit 2	"Special Nuclear Material Inventory and Control"
Procedure	ACP-QA-4.10, Rev. 0	09/11/90			"Special Nuclear Material, Inventory and Control"
Procedure	MP-13-SNM-PRG	09/27/99			Millstone Special Nuclear Material Control and Accountability Program
Procedure	RP 6, Rev. 002-02	05/22/01			"Root Cause Analysis"
Program Description	MP-16-MMM, Rev. 004	09/06/01			"Corrective Action"
REG GUIDE	GR-5.29, Rev. 1	06/75		USNRC	"Nuclear Material Control Systems For Nuclear Power Plants"

TYPE	DOC. #	DATE	TO	FROM	TITLE
Report	AO-72-22	12/11/72		Millstone Nuclear Power Station	"Special Report, Chloride Intrusion Incident, Millstone Nuclear Power Station, Unit 1, December 11, 1972" [Sections I through III] [Forwarded to AEC by Letter dated 12/19/72]
Report	AO-72-22	12/11/72		Millstone Nuclear Power Station	"Special Report, Chloride Intrusion Incident, Millstone Nuclear Power Station, Unit 1, December 11, 1972" [Sections VII 1.0 and VII 2.0]
Report	NEDM-20809	07/75		General Electric	Millstone Fuel Inspection and Repair, April 1974 [No longer considered Proprietary Material per Global Nuclear Fuel email dated 09/17/01 09:42:48]
Self-assessment	Decomm-00-205	06/06/00	NNECo Decom. Project	MP1 RE	"Self Assessment of Special Nuclear Material Control at MP1 (MC-5)"
Self-assessment	MP-SA-00-112	01/03/01		Nuclear Fuel & Safety Analysis	"Special Nuclear Material Inventory And Control"
Self-Assessment Outline	MP-SA-01-046	10/03/01		NFSA	"Special Nuclear Material", including the following attachments: 1. "Special Nuclear Material Self Assessment Outline", 09/18/01 2. "Self Assessment Interview Questions MP-SA-01-046 Special Nuclear Material", 09/18/01 3. "SNM Self Assessment Telecons" 4. CR-01-09813, "This CR Documents SA MP-SA-01-046 Recommendations", 10/03/01
To The Point		10/05/01	Millstone Notes Users		"Northeast Utilities Completes Comprehensive Search For Missing Fuel Pins"