Dominion Nuclear Connecticut, Inc.
Millstone Power Station
Rope Ferry Road
Waterford, CT 06385

Dominion

OCT 29 2001

Docket No. 50-245
B18510

RE: 10 CFR 70.52
10 CFR 20.2201

Director
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Millstone Power Station, Unit No. 1
Issuance of Root Cause Investigation
Pertaining to Unaccounted for Spent Fuel Rods

Dominion Nuclear Connecticut, Inc. (DNC) hereby forwards a copy of the Root Cause Investigation Report (Attachment 1) pertaining to the loss of accountability of two spent fuel rods at Millstone Unit No. 1.

The two fuel rods that are the subject of the Root Cause Investigation were determined to be unaccounted for by the Northeast Nuclear Energy Company prior to the March 31, 2001, sale of Millstone Station to DNC. The Root Cause Investigation Report was completed by Northeast Utilities Service Company.

DNC has reviewed the Root Cause report and established corrective actions to address the report's recommendations in accordance with the Millstone Corrective Action Program.

There are no regulatory commitments contained within this letter.

If you have any questions regarding this matter, please contact Mr. David A. Smith, at (860) 437-5840.

Very truly yours,

DOMINION NUCLEAR CONNECTICUT, INC.

J. Alan Price, Vice President
Nuclear Technical Services - Millstone

cc: See next page

A001

Attachment: (1)

cc: H. J. Miller, Region I Administrator
J. B. Hickman, NRC Project Manager, Millstone Unit No. 1
T. J. Jackson, NRC Inspector, Region I, Millstone Unit No. 1

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555

Director
Bureau of Air Management
Monitoring and Radiation Division
Department of Environmental Protection
79 Elm Street
Hartford, CT 06106-5127

Docket No. 50-245
B18510

Attachment 1

Millstone Power Station, Unit No. 1

Root Cause Investigation

Root Cause Investigation

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

Prepared By:
Team Members

P L Reagan 10/24/01
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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.

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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.

[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

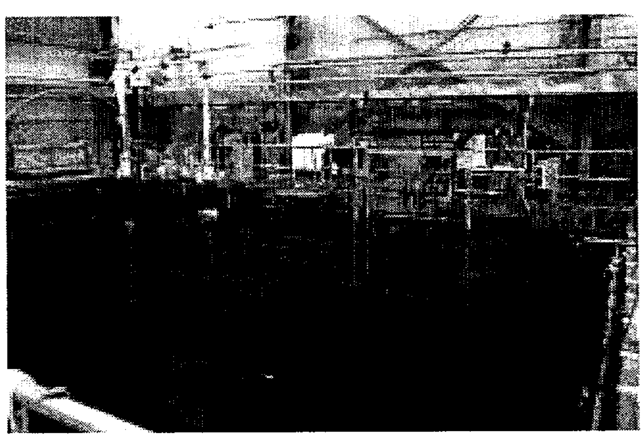
A full MP1 core consisted of 580 nuclear fuel assemblies, each of which was composed of either 49 fuel rods (for the "7x7" fuel used early in plant life) or between 60 and 63 rods (for "8x8" fuel used more recently). MP1 7x7 fuel rods were 13'2" long by 0.57" diameter.

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:

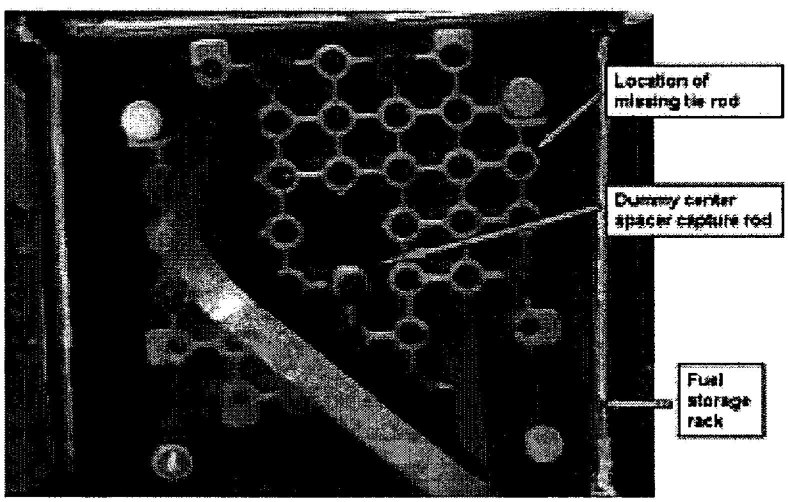
- 10CFR20 - Standards for Protection Against Radiation
- 10CFR61 - Licensing Requirements for Land Disposal of Radioactive Waste
- 10CFR70 - Domestic Licensing Of Special Nuclear Material
- 10CFR71 - Packaging and Transportation of Radioactive Material
- 10CFR72 - Licensing Requirements For The Independent 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

[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

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[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]

[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]

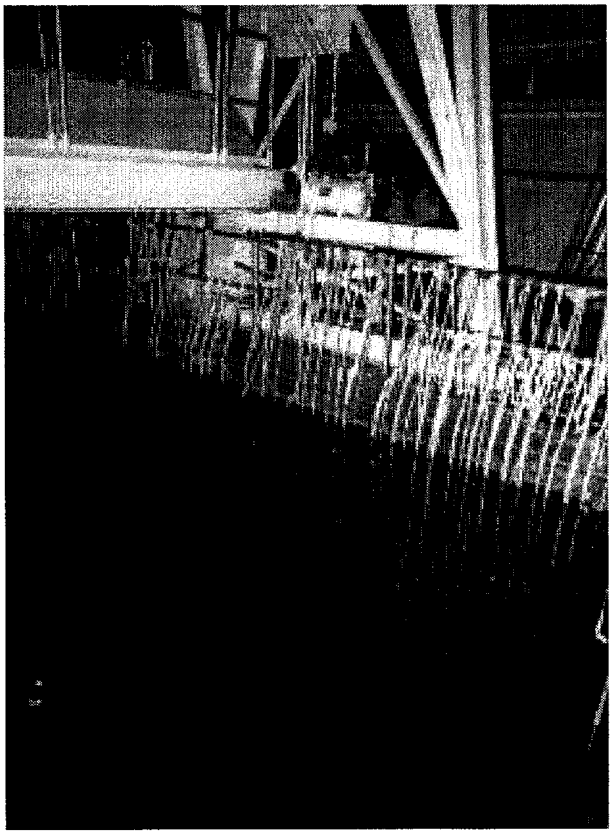
The picture below shows conditions of the MP1 SFP (circa 1985). Note the many ropes tied to the railing, attached to objects submerged below the water surface:

[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.

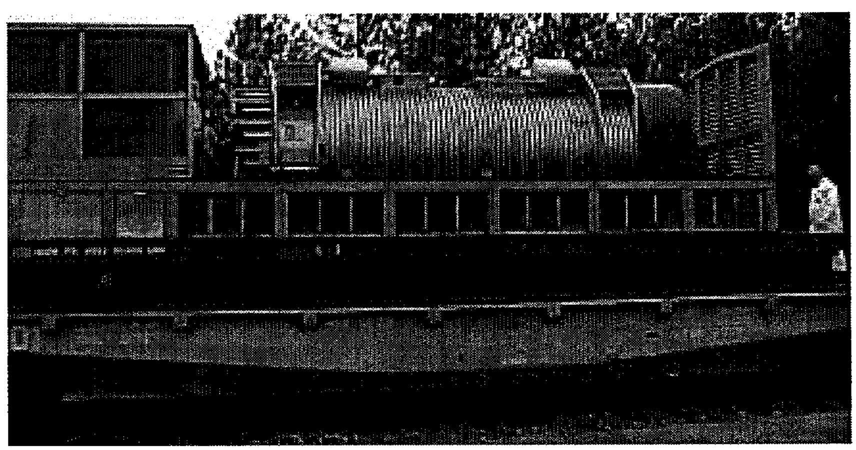
[42] Interview 31

[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]

[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

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[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.

[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 *any* 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]

[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."

[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;

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[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]

[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."

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[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.

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[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	Red	Green	Green	Green
Fuel Assembly Storage[149]	White	White	Green	Green
Inventory Records	Red	White	White	White
Inventory Reconciliation	Red	White	White	White
SNM Item Designation	Yellow	Green	Green	Green
Procedures	Yellow	White	White	White
SFP Material Condition	Red	Green	Green	Green
SFP Work Control	Red	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

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[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

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

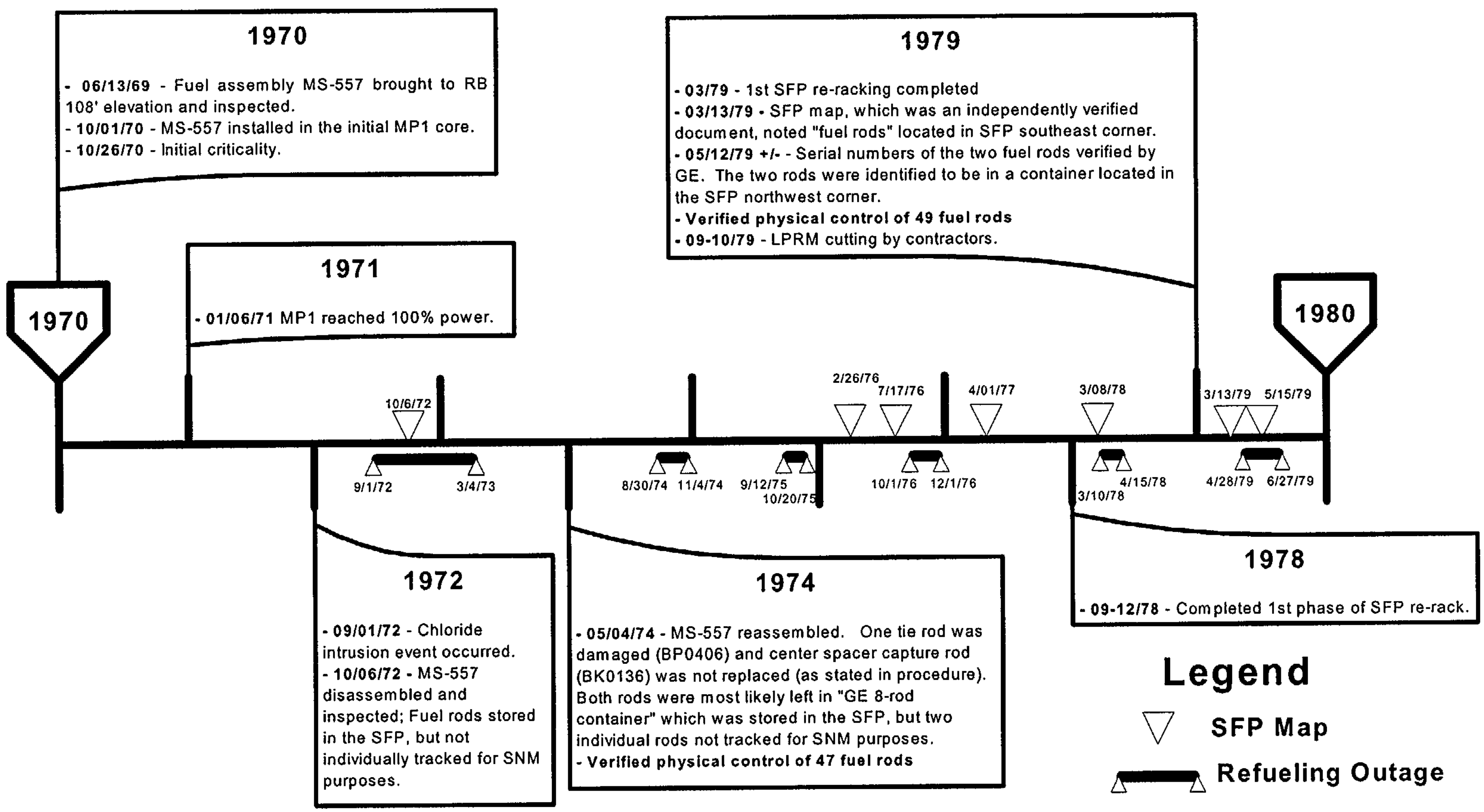
Below are three flow charts that summarize the chronology of major elements of this event. Triangular shapes indicate the dates of available MP1 SFP maps. Horizontal bars immediately below the timeline indicate refueling outage periods.

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:

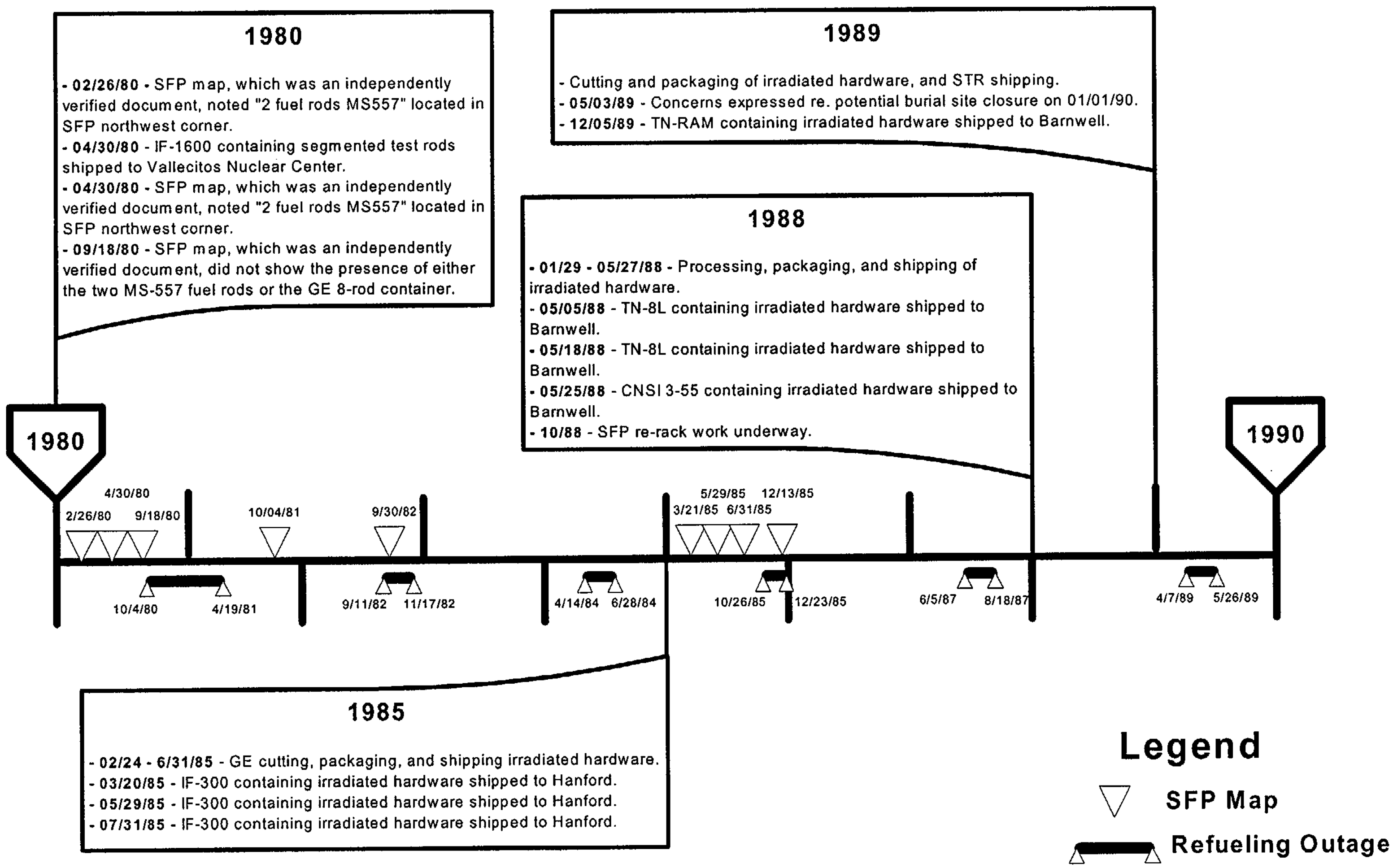
- 09/01/72 – Chloride intrusion into reactor coolant system
- 10/06/72 – Took apart and inspected fuel assembly MS-557, but fuel rods not individually tracked for accountability purposes
- 05/13/74 - Reassembled fuel assembly MS-557 with a dummy center spacer capture rod. The original center spacer capture 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)

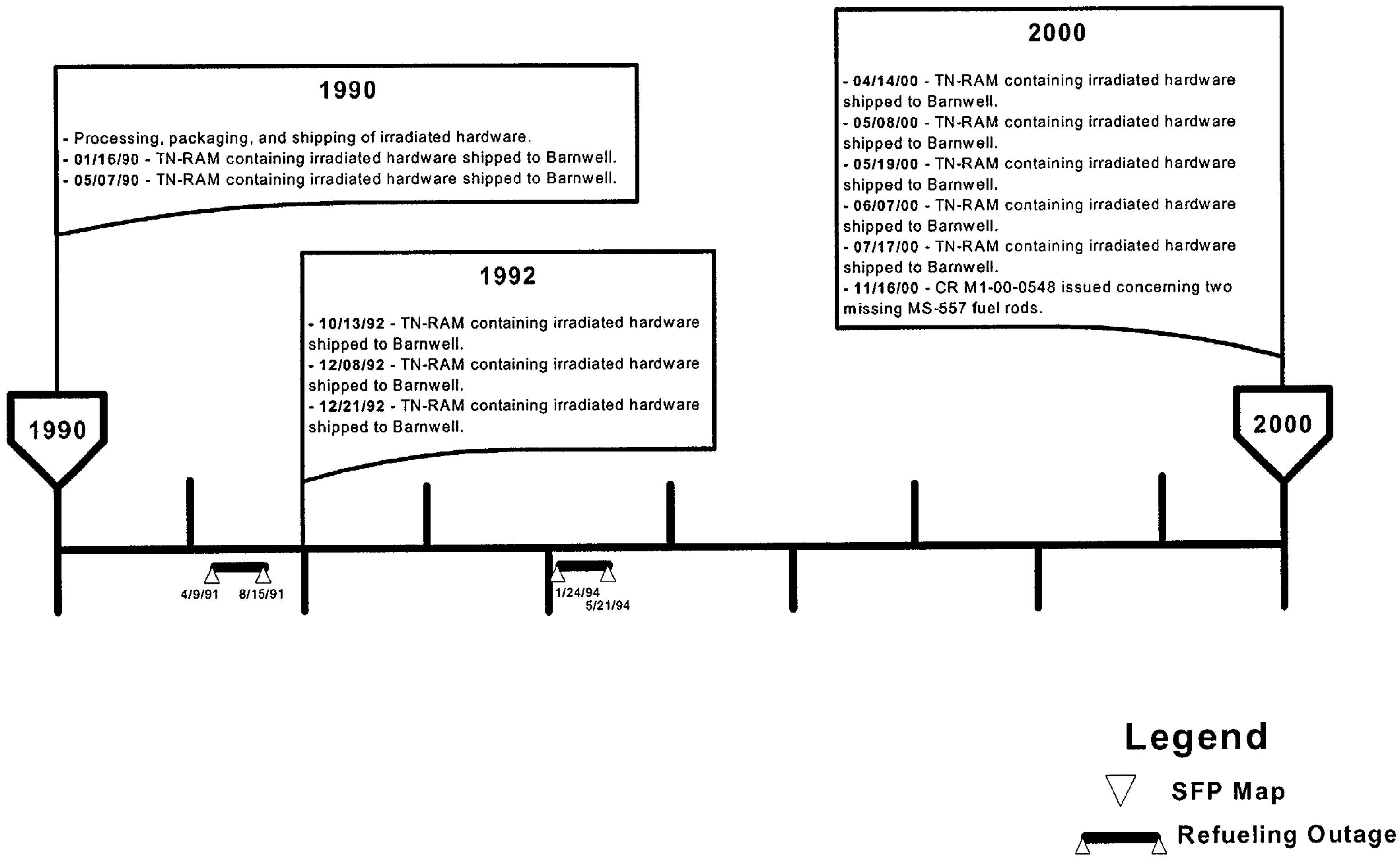
A.3.1 TIMELINE 1970-1980



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.

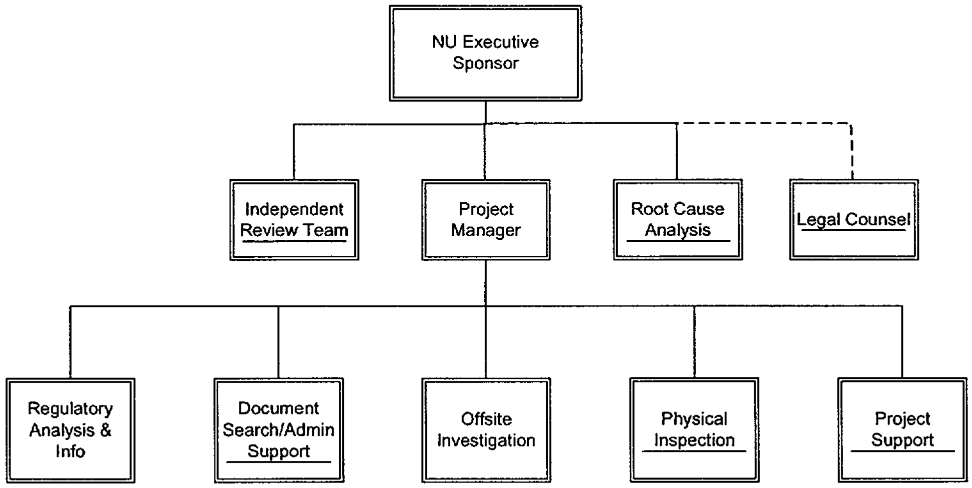
Both individuals are professionally active in the American Nuclear Society and have chaired numerous workshop panels and lectured on related subjects many times over the past several years. Panel and lecture subjects included event investigation, performance oversight, identification of limiting weaknesses, 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
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Rosicky, Edward	GE Nuclear Energy (Retired)

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Ross, Michael	Former MP1 Operator & Engineer
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Shiraisha, LeRoy	GE Nuclear Energy (retired)
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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.
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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
Harnal, Rajinderbir S.	Dominion Nuclear Connecticut	Harnal-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

[179] Interviewed by FRAP Team

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"