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GAO

Report to Congressional Requesters

April 2005

NUCLEAR REGULATORY COMMISSION

NRC Needs to Do More to Ensure that Power Plants Are Effectively Controlling Spent Nuclear Fuel

GAO-05-339

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NRC Needs to Do More to Ensure that Power Plants Are Effectively Controlling Spent Nuclear Fuel

GAO Accountability·Integrity·Reliability

Highlights

Highlights of GAO-05-339, a report to congressional requesters

Why GAO Did This Study

Spent nuclear fuel—the used fuel periodically removed from reactors in nuclear power plants—is too inefficient to power a nuclear reaction, but is intensely radioactive and continues to generate heat for thousands of years. Potential health and safety implications make the control of spent nuclear fuel of great importance. The discovery, in 2004, that spent fuel rods were missing at the Vermont Yankee plant in Vermont generated public concern and questions about the Nuclear Regulatory Commission's (NRC) regulation and oversight of this material.

GAO reviewed (1) plants' performance in controlling and accounting for their spent nuclear fuel, (2) the effectiveness of NRC's regulations and oversight of the plants' performance, and (3) NRC's actions to respond to plants' problems controlling their spent fuel.

What GAO Recommends

GAO recommends that NRC (1) establish specific requirements for the control and accounting of loose rods and fragments and plants' conduct of their physical inventories and (2) develop and implement appropriate inspection procedures to verify plants' compliance with the requirements.

Commenting on the draft report, NRC generally agreed with GAO's conclusions and recommendations.

www.gao.gov/cgi-bin/getrpt?GAO-05-339.

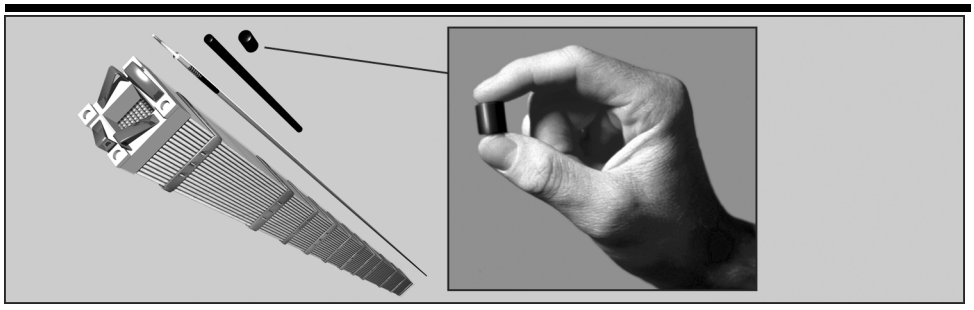
To view the full product, including the scope and methodology, click on the link above. For more information, contact Jim Wells at (202) 512-3841 or wellsj@gao.gov.

What GAO Found

Nuclear power plants' performance in controlling and accounting for their spent fuel has been uneven. Most recently, three plants—Vermont Yankee and Humboldt Bay (California) in 2004 and Millstone (Connecticut) in 2000—have reported missing spent fuel. Earlier, several other plants also had missing or unaccounted for spent fuel rods or rod fragments.

NRC regulations require plants to maintain accurate records of their spent nuclear fuel and to conduct a physical inventory of the material at least once a year. The regulations, however, do not specify how physical inventories are to be done. As a result, plants differ in the regulations' implementation. For example, physical inventories at plants varied from a comprehensive verification of the spent fuel to an office review of the records and paperwork for consistency. Additionally, NRC regulations do not specify how individual fuel rods or segments are to be tracked. As a result, plants employ various methods for storing and accounting for this material. Further, NRC stopped inspecting plants' material control and accounting programs in 1988. According to NRC officials, there was no indication that inspections of these programs were needed until the event at Millstone.

NRC is collecting information on plants' spent fuel programs to decide if it needs to revise its regulations and/or oversight. In addition to reviewing specific instances of missing fuel, NRC has had its inspectors collect basic information on all facilities' programs. It has also contracted with the Department of Energy's Oak Ridge National Laboratory in Tennessee to review NRC's material control and accounting programs for nuclear material, including spent fuel. It further plans to request information from plant sites and visit over a dozen of them for more detailed inspection. These more detailed inspections may not be completed until late 2005, over 5 years after the instance at Millstone that initiated NRC's efforts. However, we believe NRC has already collected considerable information indicating problems or weaknesses in plants' material control and accounting programs for spent fuel.



Source: Nuclear Energy Institute.

Nuclear fuel rods are filled with ceramic pellets of uranium and grouped into fuel assemblies, typically 5 to 10 inches square and 12 to 14 feet long.

Contents

Abbreviations

DOE	Department of Energy
ISFSI	independent spent fuel storage installation
NRC	Nuclear Regulatory Commission
OIG	Office of the Inspector General
TI	temporary instruction

GAO
Accountability * Integrity * Reliability

United States Government Accountability Office
Washington, D.C. 20548

April 8, 2005

The Honorable James M. Jeffords
Ranking Minority Member
Committee on Environment and Public Works
United States Senate

The Honorable Patrick Leahy
United States Senate

The Honorable Bernie Sanders
House of Representatives

The Honorable John Olver
House of Representatives

Spent nuclear fuel—the used fuel periodically removed from reactors in nuclear power plants—is one of the most hazardous materials made by humans. Without protective shielding, the fuel's intense radiation can kill a person within minutes if directly exposed to it or cause cancer in those exposed to smaller doses. The nation's 103 operating nuclear power plants, which generate about 20 percent of U.S. electricity, annually produce over 2,000 metric tons of spent fuel. Absent a national repository, these materials must be stored on site. Given the potential harm to human health and the environment, the Nuclear Regulatory Commission (NRC) requires licensees or operators of commercial nuclear power plants to strictly control and account for their spent fuel. However, several recent discoveries of missing or unaccounted-for spent fuel have raised concerns about nuclear power plants' control over these materials and NRC's oversight. The terrorist attacks of September 11, 2001, heightened these concerns by raising questions about whether these highly radioactive materials could be diverted or stolen and used maliciously.

A commercial nuclear power plant's reactor is fueled by small ceramic pellets of uranium, roughly the size of the tip of one's little finger. These pellets are placed end-to-end inside hollow metal tubes (made today of zirconium alloy), which are then gas pressurized and welded closed. The filled metal tubes are called fuel rods or pins. Rods are grouped together into fuel assemblies (also known as fuel bundles), typically about 5 to 10 inches square and 12 to 14 feet long, and placed in the reactor core. Depending on the type of reactor, an assembly consists of 36 to 289 rods

and the core contains from 150 to 800 assemblies.[1] An assembly can weigh over half a ton. About every 12 to 18 months, the reactor must shut down for refueling. During this time, about one-fourth to one-third of the fuel assemblies are removed from the reactor core and replaced with new fuel assemblies. Removed assemblies are those that have become too inefficient to power the nuclear reaction (but which have become intensely radioactive and will continue to generate some amount of heat for tens of thousands of years).

When removed from the reactor, spent fuel assemblies are placed in racks in a spent fuel pool. Spent fuel pools are typically 40-foot deep, steel-lined, concrete vaults filled with water. Water is a natural barrier to radiation, and it allows the fuel to cool as it becomes less radioactive. Over the course of years, the spent fuel within the pools has been typically moved or rearranged to accommodate more spent fuel while maintaining safety. At some nuclear power sites, spent fuel has also been transferred to dry storage casks to await permanent disposition at a national repository for spent fuel, such as the deep underground repository planned at Yucca Mountain, Nevada. Spent fuel is typically cooled for 5 years before it can be moved to dry storage casks, which are extremely large and heavy containers made of steel or steel surrounded by additional concrete that can hold from 7 to 68 fuel assemblies. However, the majority of spent fuel at nuclear power plants remains within spent fuel pools. In addition, at a number of nuclear power plants, fuel assemblies have been disassembled or reconstituted[2] due to damaged or leaking fuel rods or for inspection and testing purposes. Disassembly or reconstitution is a delicate process involving heavy machinery. These individual fuel rods and, if broken, rod fragments are also stored in the spent fuel pool, either placed at the bottom or in special containers, repackaged, or in some cases, put back into the parent spent fuel assembly.

This report discusses (1) nuclear power plants' performance in controlling and accounting for their spent nuclear fuel, (2) the effectiveness of NRC's

[1]In the United States, there are two types of nuclear power reactors (boiling water and pressurized water) and several designs for each. With the inclusion of modifications over time, specifications regarding the number and length of fuel rods and the number of assemblies required to fuel a reactor core will vary. Specifications may also be influenced by the type of reactor design.

[2]Reconstitution in this sense refers to the process by which fuel rods are removed from complete fuel assemblies and the replacement of these rods with good ones.

regulations and oversight of nuclear power plants' performance in controlling and accounting for spent nuclear fuel, and (3) actions that NRC is taking in response to licensees' spent fuel control and accounting difficulties. In the context of this report, control and accounting for spent nuclear fuel refers to plants' tracking of and record-keeping for the movement and storage of their spent nuclear fuel. We did not assess plants' safety procedures for the handling or storage of spent fuel or plant security and the vulnerability of spent fuel to theft or terrorist attacks.

To assess nuclear power plants' performance in controlling and accounting for their spent nuclear fuel, we reviewed and analyzed relevant documents, including NRC and nuclear power plant licensees' event reports, NRC studies and investigations of missing fuel rods, and other related documents. We also interviewed NRC and nuclear power plants officials. To assess NRC's material control and accounting requirements for spent fuel stored at nuclear power sites, we reviewed and analyzed relevant regulations, NRC orders and policies, and interviewed NRC and industry officials to identify the key NRC requirements and how they are implemented. To determine how NRC performs oversight of nuclear power plant material control and accounting activities, we reviewed NRC inspection policies, instructions, and reports; analyzed relevant Inspector General reports and internal NRC analyses and studies; interviewed appropriate NRC program and regional officials; and conducted an e-mail survey of all NRC lead/senior inspectors located on site at plants about inspection practices, management controls, and suggestions for improvements, if viewed necessary. To determine the status of NRC actions and plans in response to licensees' spent fuel control and accounting problems, we reviewed internal NRC memoranda, instructions, and reports and interviewed appropriate program officials.

A more detailed description of our scope and methodology is presented in appendix I. More detailed results of our survey of NRC resident inspectors is presented in appendix II. We performed our work between July 2004 and February 2005 in accordance with generally accepted government auditing standards.

Results in Brief

Nuclear power plants' performance in controlling and accounting for spent nuclear fuel has been uneven. Most recently, three nuclear power plants have reported missing or unaccounted-for spent nuclear fuel to NRC. These plants were the Millstone Nuclear Power Station in Connecticut in 2000, the Vermont Yankee plant in Vermont in 2004, and the Humboldt Bay Power

Plant in California in 2004. The Millstone and Vermont Yankee plants are still operating, while the Humboldt Bay plant has been shut down since 1976. The unaccounted-for material from Millstone was never found, while the unaccounted-for material at Vermont Yankee was found 3 months later in its spent fuel pool but in a location other than that indicated by the inventory records. At Humboldt Bay, NRC and licensee officials are still investigating the plant's missing spent nuclear material. In all three cases, the missing spent fuel was in loose fuel rods or segments of fuel rods that had been removed from the fuel assemblies. NRC is also aware of several earlier instances of lost or unaccounted-for spent fuel at other facilities. In 1990, a nuclear power plant shipped one more spent fuel rod than planned. The licensee discovered the discrepancy in 1991, then notified NRC and corrected its records. On several occasions, licensees reported "lost" or "missing" spent fuel but, according to NRC, in each case, the spent fuel was known to be contained within the facility, either in the reactor coolant system, the spent fuel pool, or a refueling pathway. Moreover, information NRC has collected in response to the unaccounted-for spent fuel at Millstone indicates that spent fuel rods outside of fuel assemblies are an issue at additional nuclear power sites. NRC inspectors often could not confirm that containers that were designated as containing loose fuel rods in fact contained the fuel rods. The containers, in some cases, were closed or sealed and, in other cases, the contents were not visible when looking into the spent fuel pool. Thus, spent fuel may be missing or unaccounted for at still other plants.

Although NRC requires plants to maintain an accurate record of all their spent fuel and its location, NRC regulations do not specify how licensees are to conduct physical inventories nor how they are to control and account for loose spent fuel rods and fragments. NRC regulations require licensees to perform a physical inventory at least once every 12 months. However, NRC guidance for material control and accounting does not characterize what constitutes a physical inventory or how to conduct one. Consequently, implementation is inconsistent among the licensees. Physical inventories of spent fuel in spent fuel pools may include anything from comparing a map with the actual assembly racks in the pool to identify misplaced fuel assemblies to performing a comprehensive identification of fuel assemblies according to their serial numbers. Additionally, NRC regulations do not specifically require licensees to track individual fuel rods or fragments, and individual rods, fragments, or other controlled nuclear material may or may not be accounted for in the inventory. Licensees also employed various methods of storing and accounting for this material. In 1988, NRC decided to no longer conduct

routine inspections of plants' compliance with material control and accounting regulations for spent fuel because it considered the potential risk for spent fuel to be lost or stolen from a plant to be very low. According to NRC officials, the agency viewed spent fuel assemblies as "self protecting" because of the extremely high level of radiation they emit and their large size and weight.

In light of the missing spent fuel rods at Millstone and subsequent concerns, NRC is re-assessing its decision to no longer conduct routine inspections of plants' compliance with material control and accounting regulations for spent fuel. For example, NRC is using a three-phase approach under which its inspectors are collecting information on the status of material control and accounting programs at plants. It has also contracted with the Department of Energy's Oak Ridge National Laboratory in Tennessee to review NRC's material control and accounting programs for nuclear materials, including spent fuel. The third phase under which NRC inspectors will collect more detailed information at selected plants will not likely be completed until late in 2005, over 5 years after the spent fuel rods were discovered to be missing at Millstone. However, these efforts, along with the more recent instances of missing spent fuel at Vermont Yankee and Humboldt Bay as well as a 2003 NRC Office of the Inspector General report outlining weaknesses in NRC's oversight of nuclear materials (including spent fuel), have already provided NRC with considerable information on nuclear power plant licensees' control and accounting programs, and NRC officials anticipate that changes in NRC's regulations and oversight activities will be necessary. According to NRC officials, this spring they plan to present the results of the Oak Ridge review and other information to the NRC Commissioners, who will decide whether the agency will take any action.

We are making recommendations to NRC aimed at improving its regulation and oversight of spent fuel by defining how licensees are to conduct physical inventories, specifying control and accounting requirements for loose rods and rod fragments, and taking timely action to monitor licensees' compliance with material control and accounting requirements. In commenting on a draft of this report, NRC generally agreed with the report's conclusions and said that it will develop guidance concerning control and accounting of spent fuel rods and pieces and the conduct of physical inventories. NRC also said that it will revise its existing procedures for inspecting material control and accounting of spent nuclear fuel to include instructions on inspecting control and accounting of rods and pieces. NRC's comment letter is included in appendix III.

Background

NRC is an independent agency established by the Energy Reorganization Act of 1974 to regulate civilian uses of nuclear materials. It is responsible for ensuring that those who use radioactive material—in generating electricity, for experiments at universities, and for other uses such as in construction and medicine—do so in a manner that protects the public, the environment, and workers. NRC has issued licenses to the 103 operating nuclear power plants and the 7 facilities that produce fuel for these plants.[3] In addition, NRC, or the 33 states that have agreements with NRC, regulates about 22,000 other entities that use nuclear materials. For example, in the medical field, nuclear material licensees annually perform millions of diagnostic and therapeutic procedures using radioactive material.

NRC is headed by a five-member commission appointed by the President and confirmed by the Senate. The President designates one commissioner as Chairman and official spokesperson. NRC has over 3,000 employees who work in its headquarters office in Rockville, Maryland, and its four regional offices. NRC is financed primarily by fees it imposes on commercial users of the nuclear material that it regulates. For fiscal year 2005, NRC's appropriated budget of $669 million included approximately $540 million financed by these fees.

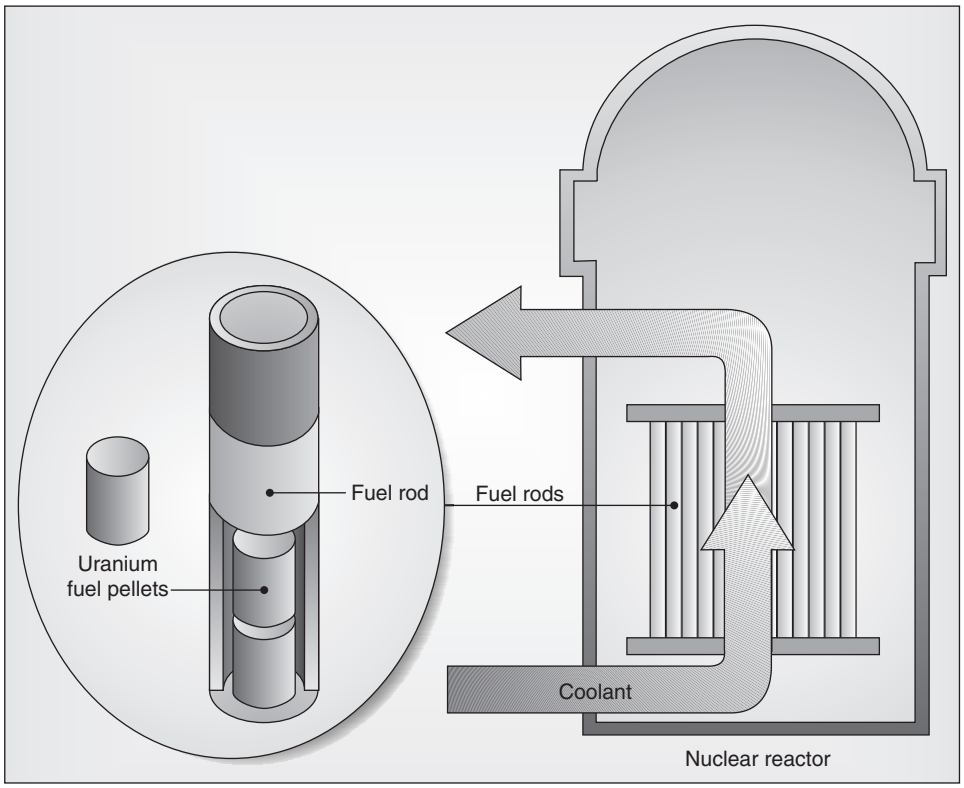
NRC regulates the nation's commercial nuclear power plants by establishing requirements for plant owners and operators to follow in the design, construction, and operation of nuclear reactors. NRC also licenses the reactors and the people who operate them. To ensure that nuclear reactors are operated within their licensing requirements and technical specifications, NRC oversees them by inspecting activities at the plants and assessing plant performance. NRC's inspections consist of both baseline inspections and supplemental inspections to assess particular licensee programs or issues that arise at a particular power plant. Inspections may also occur in response to a specific operational problem or event that has occurred at a plant. NRC maintains from two to three inspectors at every operating nuclear power site in the United States and supplements the inspections conducted by these resident inspectors with inspections conducted by staff from headquarters and/or its regional offices. Generally,

[3]NRC has licensed 104 commercial nuclear power plants to operate. One of these plants has been shut down since 1985. Other nuclear power plants are in the decommissioning phase. These decommissioning plants and a wet storage facility not associated with a nuclear power plant (GE Morris) also still have spent nuclear fuel and are licensed by NRC for these purposes.

inspectors verify that the plant's operator qualifications and operations, engineering, maintenance, fuel handling, security, emergency preparedness, and environmental and radiation protection programs are adequate and comply with NRC requirements. An important part of NRC's regulatory strategy is that licensees have programs that include monitoring, maintenance, and inspection to ensure safe operations.

In addition to the construction and operation of commercial nuclear power plants, NRC regulates the storage, transportation (together with the Department of Transportation), and disposal of spent fuel. Although nuclear power licensees ship a small amount of spent fuel off site for storage and some fuel is stored in dry casks on site, most spent fuel is taken from the reactor and moved directly to the nuclear power site's spent fuel pool.

Figure 1: Example of Fuel Rods in a Nuclear Power Reactor



Source: Nuclear Regulatory Commission.

Spent fuel pools are constructed according to NRC requirements, typically with 4- to 6-foot thick steel-lined concrete walls and floors. Pools are typically 30 to 60 feet long, 20 to 40 feet wide, and 40 feet deep. The location of these pools is dependent on the type of reactor. Essentially, all commercial nuclear power reactors in the United States are one of two types, either a boiling water reactor or a pressurized water reactor.[4] For most boiling water reactors, the pools are located close to the reactors, several stories above ground. For pressurized water reactors, the pools are located in structures outside the reactor building, on the ground or partially embedded in the ground. Regardless of reactor type, these pools are required by NRC to be constructed to protect the public against radiation exposure, even after a natural disaster, such as an earthquake. The water in the pool is constantly cooled and circulated, and the fuel assemblies are generally 20 feet below the surface of the water.

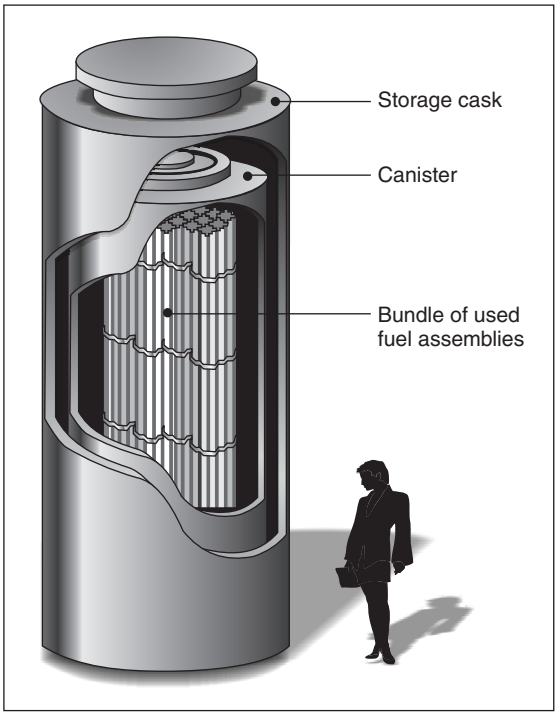
In 1982, under the Nuclear Waste Policy Act, the Congress directed the Department of Energy (DOE) to construct an underground repository for the disposal of spent fuel and other high-level radioactive waste. The Congress amended the act in 1987 and required DOE to only consider Yucca Mountain, Nevada, as a potential site for the repository. In 2002, the President recommended to the Congress, and the Congress approved, Yucca Mountain as a suitable site for the development of a permanent high-level waste repository. For a variety of reasons, DOE is unlikely to open the repository in 2010 as planned.

Lacking a long-term disposal option now, some nuclear utilities must move a portion of their spent fuel into dry storage or face shutting down their plants because their spent fuel pools are reaching capacity. The majority of dry storage facilities are located on site but licensed at a different time from the power plant. These facilities are known as independent spent fuel storage installations, or ISFSIs. Once dry storage is approved by NRC, spent fuel is loaded into dry storage casks, which are steel containers surrounded by additional steel, concrete, or other material meant to provide radiation shielding, and are backfilled with inert gas. The full casks are welded or bolted shut and placed either horizontally or vertically in

[4]A boiling water reactor uses radioactive steam that is generated in the reactor to drive a turbine that generates electricity. The water is returned to the reactor core where it is reheated to steam, driving the turbines as the cycle is repeated. Pressurized reactors send slightly radioactive pressurized water to a steam generator, which creates steam from nonradioactive water kept separated by tubes. The steam drives the turbine and the slightly radioactive water returns to the reactor where it is reheated and the cycle repeated.

concrete vaults or on a concrete pad, depending on the design. Dry storage casks are very large. According to NRC, a vertical cask may be 20 feet tall and 9 feet in diameter and could weigh 125 tons fully loaded. Once in place, the fuel is cooled by air. NRC requires these storage systems to be capable of protecting against radiation exposure and surviving natural disasters. Because the move to dry storage is time consuming and expensive, utilities are, wherever possible, modifying wet pool storage capacity so they can store larger quantities of spent fuel in these pools.

Figure 2: Example of Dry Cask Storage



Source: Nuclear Regulatory Commission.

To ensure that all spent fuel is accounted for and that unauthorized acts such as theft or diversion are detected, NRC regulations require each licensee to (1) establish, maintain, and follow written procedures that are sufficient to enable the licensee to control and account for the material in storage; (2) conduct a physical inventory of the spent fuel; and (3) maintain records of receipt as well as records on the inventory (including location), disposal, and transfer of the material. The physical inventory is required to

be performed at intervals not to exceed 12 months. Compliance with these requirements is a condition of each plant's operating license.

There is a high public perception and fear that spent nuclear fuel, if lost or stolen, could be used maliciously. According to NRC, the control of spent fuel is of great importance because of the potential health and safety implications. However, NRC stated that the very high radiation level of spent fuel makes its theft difficult, dangerous, and very unlikely. NRC also explained that individual spent fuel rods contain only a very small amount of nuclear material, making it unlikely that stolen rods could be used to manufacture a weapon. Theft of many rods would be necessary to acquire enough material to manufacture a weapon. To expose a large number of people to the harmful effects of radiation, the spent fuel would have to be released from its protective containers and dispersed over a wide or densely populated area. Unlike many other hazardous materials, spent fuel is neither explosive nor volatile.[5] Putting the material in a dispersible form would be a difficult and dangerous task involving extensive preparation using special equipment and radiation shielding. In the event of a dispersal, the most significant health effects would involve persons who inhaled very small particles. Such particles would be absorbed into the body and possibly remain there for many years.

According to NRC officials, protective systems at nuclear power reactors are designed using the concept of "defense in depth." The officials pointed out that it is very unlikely that pieces of spent fuel could be out in the public domain because power reactors have layers of protection and controls to detect and prevent spent fuel from leaving the spent fuel pool. Material control and accounting is one of these layers. Physical security, another layer, relies on measures such as portal radiation monitors, fences, guards, locks, and limited access. Additional layers relate to safety. For example, reactors store spent fuel under at least 20 feet of water because of the heat and radiation. If an item of spent fuel is raised out of the spent fuel pool, extremely sensitive detectors in the pool area alarm. The officials said that NRC requires licensees to respond to these alarms and keep records of them. All parties agree that it is very important to fully account for this material.

[5]Spent fuel rods recently discharged from a reactor also contain some radioactive gases that are a by-product of the nuclear fission process—these gases account for a small fraction of the total quantity of radioactive material in spent fuel rods, but because of the short half lives of the material, the gases decay quickly and may not be present in older spent fuel.

Nuclear Power Plants Have Had Unaccounted-For Spent Nuclear Fuel

Three nuclear power plants have recently reported the discovery of missing or unaccounted-for spent nuclear fuel to NRC. These plants were the Millstone Nuclear Power Station in Connecticut in 2000, the Vermont Yankee plant in Vermont in 2004, and the Humboldt Bay Power Plant in California in 2004.[6] NRC's actions in response to the missing or unaccounted-for spent fuel at Millstone led directly to identifying the problems at Vermont Yankee and help identify the problems at Humboldt Bay. In all three cases, the missing or unaccounted-for spent fuel was in loose fuel rods or segments of fuel rods that had been removed from the fuel assemblies. Other plants have also identified possible instances of lost or unaccounted-for spent fuel.

Millstone

At Millstone, two nuclear fuel rods were discovered to be missing when, in November 2000, the licensee, Northeast Utilities, was involved in a records reconciliation and verification effort to support preparations to move spent fuel into dry cask storage. The location of the two full-length fuel rods was not properly reflected in special nuclear material records. The licensee reported that in 1972, a fuel assembly was disassembled after it was removed from the reactor during a shutdown. In 1974 when the fuel assembly was reassembled, two rods that were damaged were not placed back into the assembly. Instead, they were placed in a container for individual rods and stored in the spent fuel pool. Records dated 1979 and 1980 show the individual fuel rods in the container in the spent fuel pool. However, spent fuel pool map records after 1980 do not show either the fuel rods or the container. Records do not indicate what happened to these rods. The licensee's investigations of the loss centered on the significant spent fuel pool activities that occurred between 1980 and 1992, which potentially related to the missing fuel rods. These activities included two re-racks, which modified the racks to accommodate more fuel assemblies, and several shipments to facilities licensed to receive irradiated nonfuel components. The unaccounted-for material from Millstone was never found; the licensee concluded that the rods were shipped to a low-level waste disposal facility in Barnwell, South Carolina. NRC undertook a special inspection to review the licensee's efforts to locate the missing fuel rods and in February 2002 agreed with the licensee that the two missing rods were most likely shipped to the Barnwell facility. In June 2002, NRC

[6]The Millstone and Vermont Yankee plants are still operating, while the Humboldt Bay plant has been shut down since 1976.

took enforcement action against the licensee and fined the licensee $288,000 for failure to adequately account for the special nuclear material contained in the two fuel rods and for failure to report missing material to NRC in a timely manner.

Vermont Yankee

Spent fuel at Vermont Yankee was discovered missing in April 2004, as the NRC resident inspectors at the plant conducted an inspection required by NRC headquarters in response to the lost spent fuel rods at Millstone. The resident inspectors found that although the licensee had been performing an annual physical inventory of the spent fuel pool, the inventory did not verify that two fuel rod segments contained in a special container stored on the bottom of the pool were still present in the container. In responding to the NRC senior resident inspector's questions, the licensee determined that two spent fuel rod pieces, the product of a 1979 fuel reconstitution to replace corroded fuel rods that had failed, were not in the storage location identified in the inventory records. The two fuel rod pieces were approximately one-half inch in diameter by approximately 9 inches and 17.75 inches in length.

The Vermont Yankee licensee formed an investigation team to search for the fuel rod pieces. According to the licensee, the investigation included inspecting the spent fuel pool, reviewing documents, interviewing past and present Vermont Yankee employees, and interviewing contractors that had been associated with spent fuel pool activities and radioactive waste operations at Vermont Yankee. In July 2004, after identifying an aluminum cylinder in the spent fuel pool as potentially containing the two fuel rod pieces, the licensee opened and inspected the cylinder, which in fact contained the two fuel rod pieces. The licensee concluded that the root causes of this event were that (1) the special nuclear material account devices used in inventorying the material had not been properly maintained and (2) the plant's special nuclear material inventory and accountability procedures did not provide guidance for controlling pieces of special nuclear material as they do for whole fuel assemblies. According to a licensee representative, it cost the licensee several million dollars to locate the spent fuel rod pieces and review the plant's material control and accounting procedures and activities to determine the root causes of this incident. The licensee representative also told us that the plant has already taken or is in the process of taking various corrective actions. For example, the plant has revised its material control and accounting procedures to reflect the findings of the root cause analysis.

NRC conducted a special inspection to review the results of the licensee's investigation at Vermont Yankee, assess the licensee's determination of the root cause, determine whether the licensee and its predecessor were in compliance with applicable regulations, and identify which findings or observations may have implications for other nuclear power plants. The inspection was performed from April through August 2004, and a report was issued to the licensee in December 2004.[7] NRC inspectors concluded that the licensee and its predecessor did not keep adequate special nuclear material inventory records of the two spent fuel rod pieces, did not follow the licensee's written procedures when the two spent fuel rod pieces were moved to a fuel storage container, and did not conduct adequate periodic physical inventories of the two spent fuel rod pieces. NRC inspectors also concluded that because the two spent fuel rod pieces remained in the Vermont Yankee spent fuel pool the entire time the apparent violation existed, no actual safety consequence resulted from this apparent violation. Nevertheless, NRC considered the apparent violation a potentially significant failure of the licensee's material control and accounting program. Enforcement action against the licensee for its apparent violation of material control and accounting regulations is currently under review by NRC management. A decision is expected sometime in 2005.

Humboldt Bay

In July 2004, Humboldt Bay officials reported to NRC that in the process of reviewing records and verifying the contents of the spent fuel pool in preparation for dry storage operations, the licensee identified a discrepancy in plant records that questioned the location of three 18-inch fuel rod segments removed from a single spent fuel rod. A plant record from 1968 indicated that the three fuel rod segments were stored in the spent fuel pool in a small container. However, licensee spent fuel shipment records indicated that the entire fuel assembly, including the rod segments, had been sent off site for reprocessing in 1969. The licensee notified NRC of the record discrepancy in the records and the apparent loss of accountability records for the special nuclear material. The licensee implemented a program to search the spent fuel pool for the fuel rod

[7]In June 2004, NRC issued Information Notice 2004-12 to all holders of operating licenses for nuclear power reactors, research and test reactors, decommissioned sites storing spent fuel in a pool, and wet spent fuel storage sites. The notice's purpose was to inform these licensees of the problems at Millstone and Vermont Yankee. Although no specific action or written response was required, NRC indicated that it expected the licensees to review the information for its applicability to their facilities and consider action, as appropriate, to avoid similar problems with their spent fuel inventories.

segments, review additional plant records, and interview plant personnel who were on site during the 1968 to 1969 time period.

In November 2004, NRC officials initiated a special inspection that included a review of the licensee material control and accounting procedures. According to an NRC official, current material control and accounting procedures appear to be adequate, but there were some problems with past accounting practices. The licensee has completed its physical search of the spent fuel pool and other areas of the plant for the three rod segments and has not conclusively identified the missing three 18-inch segments. The licensee is continuing its review of plant records as well as interviewing plant personnel who may have knowledge of the whereabouts of the three fuel rod segments. The licensee issued an interim report of its search results and evaluations at the end of February 2005. NRC plans to issue an interim inspection report after reviewing the licensee interim report. A final inspection report will not be issued until the licensee completes its investigation, currently expected in May 2005.

Other Facilities

Another example of an inaccurately accounted-for fuel rod occurred at a plant that is being decommissioned. The material from its spent fuel pool is being moved to dry cask storage. In 1974, a failed fuel assembly was being disassembled because it was leaking. A fuel rod from this assembly was found to be completely broken in two. The broken rod was supposed to have been put in a fuel rod storage basket in the spent fuel pool. In 1997, an attempt was made to verify the presence of the 16-inch fuel rod segment before the basket was placed into a dry storage cask. The attempt failed, and because the basket was too tall, it was not placed into the dry storage cask at that time. In October 2001, because of the case of the lost fuel rods at Millstone, the licensee decided to again inspect the basket to verify the presence of the fuel rod segment. While the licensee successfully examined the basket, it did not find the fuel rod segment. The licensee undertook a complete review of the site's spent fuel records and concluded that the accounting failure resulted from (1) the poor visual clarity in the spent fuel pool at the time the fuel rod fragment was being placed in the basket and (2) inadequate care by the operators performing the task. The licensee also concluded that the fuel rod segment did not contain any fuel pellets because when the fuel rod broke, the pellets were ejected into the reactor cooling system and ultimately ground into powder. In January 2002, when NRC regional inspectors performed a special inspection at the plant concerning this issue, the inspectors did not take issue with the licensee's conclusions concerning the missing fuel rod. However, they did find that—

since the same procedures were being used at the other operating plants on site—the licensee should examine the fuel assembly and fuel rod storage baskets at these locations to determine that the fuel rods that are supposed to be in them are actually present. In February 2004, NRC inspectors reported that the licensee had inspected the baskets and determined that the existing inventory sheets were correct. NRC closed this matter.

NRC is also aware of additional instances of lost or unaccounted-for spent fuel. In 1990, a nuclear power plant shipped one more spent fuel rod than planned. The licensee discovered the discrepancy in 1991, then notified NRC and corrected its records. On several occasions, licensees reported "lost" or "missing" spent fuel, but, according to NRC, in each case, the spent fuel was actually known to be contained within the facility, either in the reactor coolant system, the spent fuel pool, or a refueling pathway.

The potential exists for missing or unaccounted-for spent fuel rods to be discovered at additional plants. NRC's inspections at plants in response to the Millstone incident revealed that many nuclear power sites (a site may consist of more than one plant) had removed spent fuel rods from fuel assemblies or had reconstituted fuel assemblies.[8] In performing these inspections, NRC inspectors were to obtain from the licensee a list of all irradiated or spent fuel rods that have been removed from their parent assembly. Using the current fuel pool map, the inspectors were to identify the presumed location of the separated rods. Then, by observing from the edge of the pool, the inspector was to answer whether there were rods in all of the locations on the map identified as containing separate rods. At some of these sites, this was not possible. Some containers where rods were presumably stored were closed or their contents were not visible. Even when containers were not closed, some contents were unverifiable because of poor water clarity and lighting and container design. According to NRC officials, the agency has preliminarily chosen these sites for further inspection.

[8]These 70 sites include 65 operating and 4 decommissioning nuclear reactor sites and 1 wet storage site.

NRC Regulations and Oversight Activities Are Insufficient to Ensure Control of All Spent Fuel

Although NRC requires nuclear power plants to maintain an accurate record of their spent fuel and its location, agency regulations do not specify how licensees are to conduct physical inventories of this material nor how they are to control and account for loose or separated spent fuel rods and fragments. In addition, NRC oversight does not include routine monitoring of plants' compliance with its material control and accounting regulations.

NRC Regulations to Control and Account for Special Nuclear Materials Have Several Shortcomings

Under NRC regulations, reactor licensees are required to maintain and follow written procedures sufficiently to enable them to control and account for their special nuclear material. They are to keep records showing the receipt, inventory (including location), disposal, and transfer of all special nuclear material. Each record of receipt, acquisition, or physical inventory of special nuclear material must be retained as long as the licensee has possession of the material and for 3 years following any transfer of such material. Physical inventories of special nuclear material must be performed at least annually. However, NRC guidance for material control and accounting of spent nuclear fuel does not characterize what constitutes a physical inventory nor how to conduct one.

NRC regulations define physical inventory as the means to determine on a measured basis the quantity of special nuclear material on hand at a given time. The regulations also state that the methods of physical inventory and associated measurements will vary depending on the material being inventoried and the processes involved. As a result, licensees implement the physical inventory requirement in different ways. NRC resident inspectors found that inventories may include anything from comparing a map with the assembly racks in the spent fuel pool to performing a comprehensive identification of fuel assemblies according to their serial numbers. For example, at one site, the NRC resident inspector reported that the annual inventory is performed in a "piece counting" manner and does not specifically verify the bundle serial number and fuel pool location. At another site, the NRC resident inspector reported that the annual inventory is only conducted for special nuclear material that has been moved since the last audit. Further, according to an NRC program official, no definition of physical inventory is provided in NRC's regulatory guidance for spent fuel because the concept of physical inventory is a simple "first course in accounting" term. That is, a physical identification of items for the purpose of determining the number of items physically on hand and for comparison with a "book" record, which is the listing of items

according to the accounting records. This NRC official also stated that it's what large retailers do at least once a year, it's a well-understood concept, and it has never been thought to require clarification until now. An NRC resident inspector at still another site told us that the annual physical inventory was an office paperwork review to ensure that all the "i's were dotted and t's were crossed" from past material movements and transfers. The resident inspector added that the licensee had never actually opened its storage container to visually verify the accuracy of the paperwork. In responding to our survey, several resident inspectors suggested that if licensees sealed their containers—for example, with tamper-safe sealing—the containers would not have to be opened during the physical inventory. According to NRC officials, verification of items in spent fuel pools is difficult and time consuming, raises concerns about radiation exposure, and can be costly.

Additionally, although NRC regulations state that licensees are to control and account for all special nuclear material, the regulations do not specifically require licensees to track individual fuel rods or fragments that may be stored in their spent fuel pools. Further, individual rods, fragments, or other controlled special nuclear material may or may not be specifically accounted for in licensees' inventories.[9] As a result, licensees employed various methods of storing and accounting for this material. For example, according to an NRC resident inspector, at one plant the spent fuel rods are in a closed container in a designated area of the spent fuel pool. According to the licensee's procedures, the canister is opened every 6 years and the presence of the correct number of rods is verified. At another plant, the licensee told the resident inspector that it was not sure how many fuel rod fragments are in two storage baskets or how the fragments might be divided up between the baskets. In responding to our survey, several NRC resident inspectors described current practices and offered suggestions for best practices for storing and controlling loose rods and segments. Several respondents described placing loose spent fuel in "dummy" or "skeleton" fuel assemblies, which are empty of fuel, or only in specially designed and approved containers placed in designated cells and racks in the spent fuel pool. In addition, one resident inspector suggested that given that fuel rod breaks are often the result of reconstitution, a best practice would be for the reconstitution of fuel assemblies to be done off site.

[9]Fuel rods may fail for a variety of reasons, such as corrosion or gases leaking from the tubes that hold the rods.

Licensees of nuclear power plants also control and account for their inventories of spent fuel to help meet requirements relating to U.S. treaty obligations for the control of nuclear material. NRC regulations require power reactor licensees to submit a Nuclear Material Transaction Report to the Nuclear Materials Management and Safeguards System every time their facilities receive or transfer special nuclear material or make corrections to their material balances. At least once a year, licensees must also submit to the system material balance reports concerning special nuclear material received, produced, possessed, transferred, consumed, disposed of, or lost, and inventory composition reports. This system, which is managed by the DOE and partially supported by NRC, is operated by a DOE contractor. Because reporting to the system is done in the amount or weight of the nuclear material, such as plutonium, rather than the number of items of spent fuel, nuclear power plant licensees use complex computer programs to provide estimates of the amount of special nuclear material that these items contain. According to plant officials we spoke with, their sites send their annual inventory information to their corporate headquarters to be calculated and reported to the Nuclear Materials Management and Safeguards System contractor.

NRC Does Not Monitor Plants' Compliance with Its Material Control and Accounting Regulations

Since 1988, NRC inspections of power reactor licensees' compliance with material control and accounting requirements have been done on an exception-only basis—that is, if a particular problem or incident was reported by the licensee or identified by NRC that warranted investigating. Since 1988, NRC has not routinely monitored licensee compliance with material control and accounting regulations or verified that licensees' inventories are complete and accurate.

In 1984, NRC's overall inspection program for monitoring nuclear power plants' compliance with their licenses had three parts: (1) a minimum program to be completed at all operating nuclear facilities without exception, (2) a basic program to be completed at all operating facilities, but under some circumstances parts did not have to be completed because of extraordinary demands on limited inspection resources, and (3) a supplemental program of additional inspections to be done on the basis of an assessed need or problems at a facility. According to NRC, the basic program included material control and accounting inspections to be conducted once every 3 years. In 1988, according to NRC officials, this requirement for the periodic inspections of material control and accounting

was discontinued.[10] Officials said that although there is no written documentation available, these inspections were discontinued because spent fuel stored in spent fuel pools was considered to be "self protecting;" that is, the fuel bundles are heavy, highly radioactive, and contained in 40-foot deep pools of water. Spent fuel was viewed as a low-risk danger to public health and the environment and a low priority for use of NRC's resources.

NRC substantially revised its nuclear reactor oversight process in 2000, but did not reinstitute routine material control and accounting inspections. According to NRC, the new process—called the Reactor Oversight Process—uses more objective, timely, and safety-significant criteria in assessing nuclear plant performance. NRC stated that the revised program includes baseline inspections common to all nuclear plants and focuses on activities and systems that are risk significant—that is, those activities and systems that have a potential to trigger an accident, increase the consequences of an accident, or mitigate the effects of an accident. The Reactor Oversight Process also allows for inspections beyond the baseline program if there are operational problems or events that NRC believes require greater scrutiny. Material control and accounting fall under this criteria. When the new process was being developed, NRC officials continued to believe that the material in spent fuel pools was self protecting and that it was appropriate to perform material control and accounting inspections on an exception-only basis. NRC officials told us that there were no indications prior to the discovery of missing fuel rods at Millstone that routine inspections were needed.

According to NRC officials, a few Reactor Oversight Process inspections can indirectly involve NRC inspections of licensees' material control and accounting programs. One of these inspections is of licensee operations during refueling of the reactor. This inspection includes verifying that the location of fuel assemblies is being tracked and that discharged fuel assemblies are placed in permissible locations in the spent fuel pool. To perform such an inspection, NRC inspectors observe the movement of a sample of fuel bundles between the reactor core and the spent fuel pool. NRC officials told us that material control and accounting problems with spent fuel may also be reviewed under plant status inspections. These inspections involve a number of activities surrounding NRC resident

[10]Current NRC officials stated that the 1988 change was made because no problems with material control and accounting for spent fuel had been identified at that time.

inspectors' efforts to be aware of emergent plant issues, potential adverse trends, equipment problems, and other ongoing activities that may impact the plant's safety risks. These efforts include control room walkdowns, attending licensee meetings, and weekly plant tours. Inspectors generally would not learn of material control and accounting problems during one of these inspectors unless the licensee was aware of them and raised them during meetings with the inspectors. In addition, a few NRC resident inspectors that we surveyed mentioned some review of spent fuel records during the loading of dry storage fuel casks.

NRC Is Studying Spent Fuel Control and Accounting Problems but Has Yet to Revise Its Regulations or Oversight Policies

In light of the missing or unaccounted-for spent fuel at Millstone and subsequently at other locations, NRC has various activities under way to assess the need to revise its regulations and oversight of spent fuel. While final completion dates for these efforts have not been set, it will likely be late in 2005 before all of them will be completed. This date would be over 5 years after the spent fuel rods were first found missing at Millstone in 2000. We believe that after the more recent instances of missing spent fuel at Vermont Yankee and Humboldt Bay, the 2003 NRC Office of the Inspector General report outlining weaknesses in NRC's oversight of special nuclear materials (including spent fuel), and information collected during its ongoing efforts, NRC has considerable information that suggests the need to address nuclear power plants' material control and accounting problems, including compliance with NRC regulations. According to NRC officials, they plan to submit the results of these activities to the NRC Commissioners in the spring of 2005. The Commissioners will decide what, if any, actions will be taken in response to the findings.

NRC Is Using a Multifaceted, Phased Approach to Assess the Need to Revise Its Regulations and Oversight

NRC has three principal activities under way to assess the need to revise its regulations and oversight of spent fuel. These are (1) a three-phase project under which NRC inspectors are collecting information on the status of material control and accounting programs at individual plants; (2) a comprehensive program review of NRC material control and accounting programs for special nuclear materials, including spent fuel, through the contract with DOE's Oak Ridge National Laboratory; and (3) a bulletin issued on February 11, 2005, to nuclear power plant licensees requesting information concerning their compliance with NRC material control and accounting regulations.

In November 2003, NRC issued a temporary instruction (TI) to its inspection manual.[11] NRC's overall objective in issuing the TI was to gather site-specific information on nuclear power plants' material control and accounting programs to determine if the issues affecting the missing spent fuel rods at Millstone were present at other power plants. More specifically, NRC wanted to obtain enough information to determine if

- material control and accounting guidance for nuclear power plants should be modified to reduce the possibility of a licensee losing spent fuel rods in the future;
- licensees can account for all spent fuel, including any rods that have been separated from their parent assembly; and
- all items of spent fuel listed in the spent fuel inventory, including rods that have been separated from their parent assembly, can be located in the spent fuel pool.

The TI also called for obtaining site-specific data for the purposes of improving the plants' material control and accounting programs. According to the TI, several inspection activities were aimed at identifying conditions for future program improvement rather than inspections for compliance with regulatory requirements.

NRC is carrying out the TI in three phases. Phases I and II have been completed. In phase I, NRC regional and/or resident inspectors determined if nuclear power plant licensees had ever removed irradiated (spent) fuel rods from an assembly or had reconstituted fuel assemblies. For licensees that had removed rods or reconstituted assemblies, phase II was conducted. During phase II, inspectors used inspections and interviews to fill out a questionnaire about the licensees' material control and accounting programs. Among the questions were the following:

- Does the licensee have a program that tracks individual fuel rods from the point of removal from a fuel assembly to where they are stored in the spent fuel pool and to their final destination?

[11]NRC considers this instruction, *Spent Fuel Material Control and Accounting at Nuclear Power Plants* (Temporary Instruction 2515/154, Nov. 26. 2003), to be temporary because it provides for a one-time inspection and has a short-term expiration date, currently scheduled for November 2005.

- Are there rods in all of the locations identified on the spent fuel map (or equivalent) as containing separated rods? (The inspectors were instructed to obtain from licensees a list of all spent fuel rods that had been removed from their parent assembly and, to the extent possible, answer this question by observing from the edge of the spent fuel pool. If the rods were stored in a closed container, they were to report this under the "Comments" section of the questionnaire.)

- Does the licensee have written material control and accounting procedures approved by licensee management?

- Does the licensee have written procedures for the movement of individual spent fuel rods within the spent fuel pool?

- Does the licensee have procedures for performing oversight of all spent fuel pool operations?

- Does the licensee have records documenting spent fuel pool operations conducted by contractors or fuel vendors?

- Does the licensee perform an annual physical inventory of the spent fuel pool that includes resolution of all discrepancies?

The TI did not specify an approach to answering the questions but instead allowed the resident inspectors to use their best judgment and experience. Our survey of NRC's senior resident inspectors identified some differences in what the inspectors did to answer the phase II questions. The inspectors generally interviewed licensee staff and reviewed licensees' records and written procedures. For the most part, they also used the licensee's map to verify materials in the spent fuel pool. About half used visual tools such as binoculars or underwater cameras to verify materials in the spent fuel pool. About one-fifth observed licensee activities.

Phase III, which has not begun, is to expand on the questions in phase II with more detailed inspection and review of site documentation to verify that procedures or controls are implemented and that they are adequate. For a sample of sites, including those for which "no" was answered to any of the phase II questions, personnel with material control and accounting expertise, rather than the regional and on-site inspectors, are to carry out the activities.

The TI called for phases I and II to be completed within 6 months (by May 2004) and phase III within 18 months (by May 2005). Phases I and II were carried out from January 2004 to May 2004. The phase I review at 70 sites—all 103 operating nuclear power plants at 65 sites (a site may contain more than one nuclear power plant), decommissioning plants at 4 sites, and 1 wet storage facility—identified 65 sites that had removed irradiated fuel rods from an assembly or had reconstituted fuel assemblies.[12] Phase II was conducted for these sites. On the basis of the phase II results, NRC officials determined that at least 19 sites were candidates for more detailed phase III review because NRC inspectors identified that the site had two or more programmatic issues. As of February 2005, NRC officials told us that they are in the planning stages for phase III inspections. Because the TI expires 2 years after its November 2003 issuance, if the phase III inspection were to be performed before this, it would be late 2005 before the project would be completed.

In September 2001, shortly after the terrorist attacks on the World Trade Center and the Pentagon, the Chairman of NRC directed the staff to undertake a comprehensive review of all the agency's safeguards and security programs. NRC contracted with the Oak Ridge National Laboratory in August 2003 to review NRC's material control and accounting programs for special nuclear materials at all NRC licensees. This contract, which according to an NRC official was for about $500,000, was part of a broader NRC effort. The Oak Ridge laboratory, which was chosen because of its expertise in material control and accounting, began the work under the contract in September 2003. Its four principal tasks were to (1) review NRC's current material control and accounting requirements, (2) discuss material control and accounting with current and former employees involved in these activities, (3) visit selected facilities representing different types of special nuclear material licensees to explore current material control and accounting requirements and inspection practices at each site, and (4) develop a report that offers Oak Ridge's views on NRC's material control and accounting requirements across the range of NRC-licensed facilities, discusses any concerns or deficiencies with the current regulations and inspection practices, and provides specific recommendations for programmatic changes. Oak Ridge submitted its report in August 2004 and concluded its work with a management briefing in October 2004. NRC is currently reviewing the report. According to NRC

[12]The phase I review also included decommissioned power plants with wet storage and one wet storage facility.

officials, the staff will complete its review of the report and consider the results of its review, as well as additional recommendations from the staff, in developing a paper to the NRC Commissioners. The paper is due to the Commissioners by spring 2005.

In February 2005, NRC issued a bulletin to holders of operating licenses for nuclear power plants, decommissioning nuclear power plants storing spent fuel in a pool, and wet spent fuel storage sites. The bulletin, which requests information about procedural controls and inventories, responds to issues involving accounting and control of spent (and other irradiated) nuclear fuel, which were first identified at Millstone and then at Vermont Yankee and Humboldt Bay. The purpose of the bulletin is to gather specific information from the licensees about the status of control and accounting of special nuclear material at power reactors and other facilities with wet storage of irradiated fuel. NRC officials told us that results from the bulletin will contribute to assessing the need to revise the current NRC material control and accounting regulations and inspection program. The results from the bulletin will also determine where phase III inspections will be conducted.

NRC Has Considerable Information Indicating Problems with the Control and Accounting for Spent Fuel

The data collected by NRC inspectors during phases I and II of the TI identified material control and accounting problems or shortcomings. Of the sites that had removed fuel rods from their parent assemblies or had reconstituted fuel assemblies, the inspectors reported that some sites did not appear to be in compliance with all of NRC's material control and accounting requirements or otherwise had questionable material control and accounting practices involving procedures, physical inventory, accounting records, or tracking and control.

Additionally, in May 2003, NRC's Office of the Inspector General (OIG) issued its report, *Audit of NRC's Regulatory Oversight of Special Nuclear Materials*.[13] In its report, the OIG concluded that NRC's oversight did not provide adequate assurance that all licensees properly control and account for special nuclear material. The OIG found that NRC performed limited inspections of licensees' material control and accounting activities and could not assure the reliability of the tracking system for special nuclear material. It stated that NRC managers believed that most spent fuel is self-

[13]OIG-03-A-15, May 23, 2003.

protecting from a health and safety point of view and that the risk of undetected loss, theft, or diversion of special nuclear material at power reactors is low. Therefore, according to the OIG, NRC trusts power reactor licensees to implement their material control and accounting activities effectively. The OIG further concluded that without adequate routine inspections of these activities, NRC cannot reasonably ensure that licensees are controlling and fully accounting for special nuclear material. The OIG recommended, among other things, that NRC conduct periodic inspections to verify that licensees comply with material control and accounting requirements, including, but not limited to, visual inspection of licensees' special nuclear material inventories and validation of report information.

In its October 2003 response to the OIG recommendation, NRC said that its staff planned to perform a review of the agency's material control and accounting program (which it did by commissioning the Oak Ridge study) as part of a comprehensive review of the agency's safeguards and security program. NRC added that based on the results of the program review, the staff will determine what changes need to be made to the inspection program. According to NRC's response, any decision to change the inspection program would be made during fiscal year 2005, following completion of the program review. In February 2004, the OIG responded by stating that delaying any decision to make changes to the material control and accounting inspection program until fiscal year 2005 was untimely and did not reflect the importance of ensuring licensee's compliance with material control and accounting requirements. In March 2004, NRC replied that the staff considered the program review to be vital to developing and documenting the regulatory basis for subsequent permanent revisions to the inspection program. An NRC official told us that once the Oak Ridge study has been completed and its findings and recommendations have been addressed, the OIG's recommendation can be closed. The staff currently anticipates that it will develop specific recommendations and submit them to the NRC Commissioners during the spring of 2005.

Conclusions

The effectiveness of nuclear power plants' efforts to control and account for their spent fuel is uneven. A number of plants have experienced instances of missing or unaccounted-for spent fuel, and NRC has identified weaknesses in the material control and accounting programs at various other plants. Contributing to this unevenness is the fact that NRC regulations do not specifically require plants to control and account for loose rods or segments of rods. Although loose spent fuel rods do not

appear to have been a concern when NRC developed its regulations, recent information collected by NRC indicates that most plants have removed rods from their fuel assemblies or reconstituted fuel assemblies. NRC data further indicate that plants are treating loose rods and segments differently under their material control and accounting programs. The absence of specific guidance in NRC regulations for how licensees should conduct physical inventories has also resulted in unevenness in licensees' compliance with these important requirements.

Loose spent fuel rods and rod segments also were not an issue when NRC stopped inspecting licensees' compliance with material control and accounting regulations. Spent fuel was generally viewed in terms of fuel assemblies, which NRC considered to be, in effect, self-protecting because of their high radioactivity and large size and weight. However, individual rods, and especially rod segments, are also highly radioactive and are much smaller and lighter than fuel assemblies. This issue was first raised in 2000, with the loss of spent fuel rods at Millstone. The occurrences of missing or unaccounted-for spent fuel rods and the unevenness in licensees' compliance with material control and accounting requirements highlight the need for more effective oversight of these programs. In the aftermath of terrorist attacks on the United States, material control and accounting of spent nuclear fuel has become more important. Material control and accounting requirements are of great importance because of the potential health and safety consequences of failing to effectively account for and control spent nuclear fuel. While NRC's multifaceted and phased approach to these issues may have been appropriate in the initial context of a single incident at Millstone, waiting longer to make a decision on changes in the agency's regulations and oversight is—as the OIG stated in February 2004—not timely and does not fully reflect the importance of ensuring that licensees comply with control and accounting requirements for spent fuel. We believe that NRC has sufficient information about problems with material control and accounting at nuclear power plants to proceed with revising NRC's regulations and oversight.

Recommendations for Executive Action

To improve the effectiveness of nuclear reactor licensees' material control and accounting programs for spent nuclear fuel, we recommend that the NRC Commissioners take action, in a timely manner, on the following two items:

- Establish specific requirements for the control and accounting of loose spent fuel rods and rod segments and nuclear reactor licensees' conduct of their physical inventories.

- Develop and implement appropriate inspection procedures to verify compliance and assess the effectiveness of licensees' material control and accounting programs for spent fuel.

Agency Comments

We provided a draft of this report to NRC for review and comment. In its written comments (see app. III), NRC generally agreed with the report's conclusions and stated that, overall, the report is well written and balanced. Regarding our recommendation that NRC establish specific requirements for the control and accounting of loose spent fuel rods and rod segments and nuclear reactor licensees' conduct of their physical inventories, NRC stated that it will develop guidance concerning control and accounting of rods and pieces of spent nuclear fuel and the conduct of physical inventories. According to NRC, its current regulations are clear that licensees are required to keep complete records of and conduct annual physical inventories of all special nuclear material, but the implementation guidance does need to be enhanced. Regarding our recommendation that NRC develop and implement appropriate inspection procedures to verify compliance and assess the effectiveness of licensees' material control and accounting programs for spent fuel, NRC said that it plans to revise its existing procedures for inspecting material control and accounting for spent nuclear fuel to include instruction on inspecting control and accounting of rods and pieces.

In addition to comments directly relating to our recommendations, NRC offered a number of comments concerning the report's context. For example, NRC said that its development and issuance of its temporary instruction was postponed by the need to devote NRC's limited resources to areas requiring more immediate attention, especially the comprehensive security and radiological protection activities conducted after the September 11, 2001, terrorist attacks. NRC also said that the report needs to provide balance by giving credit to NRC for making prioritized decisions based on a variety of factors, including, but not limited to, risk of malevolent action, attractiveness of the material for potential malevolent activities, other controls, and available personnel resources. According to NRC, there is no reason to conclude that any of the missing fuel segments were removed for any malevolent purpose. NRC further stated that the report does not make sufficiently clear that the problems at Vermont

Yankee were identified as a direct result of NRC's implementation of its temporary instruction and that implementation of the temporary instruction also helped identify the problems at Humboldt Bay. We believe that our report provides sufficient context for the issues relating to the instances of unaccounted-for spent nuclear fuel. It also devotes considerable attention to describing NRC's actions in response to those instances, including efforts already under way when we began our review. We have added language to the report to emphasize that NRC's actions in response to the Millstone incident led directly to identifying the problems at Vermont Yankee and helped identify the problems at Humboldt Bay. While we also agree that there is no evidence that any of the missing fuel segments were removed for malevolent purposes, we note that it is still not certain what happened to the missing spent fuel at Millstone and Humboldt Bay.

As agreed with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of its issuance. At that time, we will send copies of this report to interested congressional committees, the Chairman of NRC, and other interested parties. We will make copies available to others upon request. In addition, the report will be available at no charge on the GAO Web site at http://www.gao.gov.

If you or your staffs have any questions about this report, please call me at (202) 512-3841 or contact me at Wellsj@gao.gov. Key contributors to this report are listed in appendix IV.

Jim Wells
Director, Natural Resources and Environment

Scope and Methodology

To assess nuclear power plants' performance in controlling and accounting for their spent nuclear fuel, we reviewed and analyzed relevant documents, including Nuclear Regulatory Commission (NRC) and nuclear power plant licensees' event inquiry reports and NRC studies and investigations of missing spent fuel rods. We also interviewed NRC and nuclear power plant officials and conducted two site visits to nuclear power plants. In the context of this report, control and accounting for spent nuclear fuel refers to plants' tracking of and recordkeeping for the movement and storage of their spent nuclear fuel. We did not assess plant safety procedures for handling or storage of spent fuel or plant security and the vulnerability of spent fuel to theft or terrorist attacks.

To assess NRC's material control and accounting requirements for spent fuel stored at nuclear power sites, we reviewed and analyzed relevant legislation, regulations, and NRC orders and policies and we interviewed NRC and industry officials to identify the key NRC requirements and how they are implemented.

To determine how NRC performs oversight of nuclear power plants' material control and accounting activities, we reviewed NRC inspection policies, instructions, and reports; analyzed relevant NRC Inspector General reports and internal NRC analyses and studies; and interviewed appropriate NRC program and regional officials. To determine the status of NRC's actions and plans in response to licensees' spent fuel control and accounting problems, we reviewed internal NRC memorandums, instructions, and reports and interviewed appropriate program officials.

To further explore how NRC performs oversight of control and accounting activities for spent fuel at nuclear power plants, we conducted an e-mail survey of all NRC lead/senior inspectors located on site at the plants about NRC inspection practices, management controls, and the inspectors' suggestions for improvements, if viewed necessary. There are no sampling errors because this was not a sample survey; rather, we sent and received a response from every lead/senior inspector at every site.

Nonetheless, the practical difficulties in developing and administering any survey may introduce errors, commonly referred to as nonsampling errors. For example, difficulties may arise in how a particular question is interpreted or from differences in experiences and information available to respondents when answering a question. We took steps in the development of the survey, its administration, and the data editing to minimize these nonsampling errors. We conducted three pretests of the survey instrument.

The first pretest was with two inspectors at one location by telephone; the second and third pretests were with expert NRC officials, both by telephone. We modified the survey instrument to reflect questions, comments, and concerns received during the pretests. The instrument was also internally reviewed by one of our survey methodologists. In addition, we edited all completed surveys for consistency and contacted NRC inspectors to clarify responses whenever necessary. While our survey responses reflect the opinions of NRC resident inspectors, to ensure the reliability that our survey data was accurate and complete and that spreadsheet calculations were correct, 100 percent of the data entry and all formulas were internally and independently checked and verified.

Through discussions with appropriate NRC officials, we determined in the course of developing our survey that although there are 103 plants currently in operation in the United States, some reactors are colocated on a total of 65 sites. Because only one of the two or three inspectors assigned to each site is designated as the lead NRC authority, we sent our survey to that person. Therefore, we sent our survey to a total of 65 senior/lead NRC inspectors. We expected that given their experience, the lead/senior inspector would obtain additional views and input from the other resident inspectors if they felt it was needed. For example, this additional input would be important if the other inspectors performed the requirements of the temporary instruction for inspection of material control and accounting at nuclear power sites, or if the senior resident was newer to and, therefore, less familiar with the practices and history of the material control and accounting program at the site. We received 67 responses to our survey. In one case, we received a response from the senior inspector and an additional resident inspector at the same site. We kept only the senior inspector's response in our analysis and deleted the other response from that site. In the second instance where we received two responses from one site, special circumstances at that site provided for two senior resident inspectors, but one of those inspectors is primarily responsible for the recovery effort of one of the units at that site. We excluded that inspector's response from our analysis, retaining only the response from the senior inspector with the more general role. This left us with 65 responses for a 100 percent response rate. The detailed results of our survey of NRC resident inspectors are presented in appendix II.

We performed our work primarily in Washington, D.C., between July 2004 and February 2005, in accordance with generally accepted government auditing standards.

Summary Results of GAO Survey of NRC Senior/Lead Resident Inspectors

Overall, we received 65 responses to our survey. Our detailed scope and methodology (Appendix 1) contains particulars regarding the development and administration of the survey. Not all of the respondents answered all questions. This may have been a result of either the respondent's choice or they may have been instructed to skip a question according to their previous response. Throughout this appendix, we will note the number of respondents answering each question by noting "n=number of respondents to this question".

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Introduction:

The Vermont congressional delegation, along with a member from a nearby Massachusetts district, has asked the U. S. Government Accountability Office to review the NRC's oversight of licensees' material control and accounting program for spent nuclear fuel at commercial nuclear power plants.

As part of our review, we have met with NRC officials in headquarters and at the regional level. We have spent a day touring a nuclear power plant, discussing and reviewing licensee procedures. With this survey, we are gathering information on resident inspectors' activities and views related to this issue. We are distributing the following survey to all NRC senior resident inspectors.

Your contribution to our efforts is gratefully appreciated. The information you provide will assist us in responding to Congressional interest on this important issue.

Please complete and return this survey by November 24, 2004

Instructions:

Simply reply to this email by selecting "Reply to Sender (include message)" and then type in your responses by the return date. Although we are sending this to senior resident inspectors, please feel free to include other resident inspectors at your site in developing your answers. If you do include other inspectors, please provide the contact information of all inspectors contributing to the survey in Question 1.

If you have any questions about this survey or have problems submitting your response, please contact Melissa A. Roye by phone at (202) 512-6426 or by email at RoyeM@gao.gov.

~~~~~~~~~~~~~~~~~~~~BEGIN SURVEY~~~~~~~~~~~~~~~~~~~~

Background Information:

1. In case we would like to clarify any of your responses, please provide the following information for ALL persons involved in submitting information requested in this survey (please copy and paste fields for Respondent 3+, if necessary):

Respondent 1 (n=65)
Name:
Title:
Phone number:
Site Name/Location:
Months at current site:
Months as SRI or RI at any site:
Months at NRC:

Respondent 2
Name:
Title:
Phone number:
Site Name/Location:
Months at current site:
Months as SRI or RI at any site:
Months at NRC:

Material Control and Accounting Related Activities:

2. What did you do to execute the requirements of "Spent Fuel Material Control and Accounting at Nuclear Power Plants," Temporary Instruction (TI) 2515/154? Please mark all that apply. (n=65)

[57] Interviews
[54] Records review
[53] Review of licensee's written procedures
[14] Observation of licensee activities
[49] Verification of materials in the spent fuel pool using a map
[30] Verification of materials in the spent fuel pool using visual aides such as binoculars or underwater cameras
[12] Only Phase I of the TI was completed at this site
[22] At this site, the TI was conducted by someone else. Name of Inspector(s):
22 provided a name and some also included an explanation.
[10] Other? Please explain: 10 provided explanation.

3. Do you routinely inspect or verify the licensee's material control and accounting program policies, records, or procedures for spent nuclear fuel? (n=65)
[23] Yes. *Please elaborate below, if you wish.*
[42] No. *Please elaborate below, if you wish.*
[0] Don't know (*Please go to question 4*).

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Elaboration: Overall, 42 respondents provided an elaboration.
Of that 42, 23 responded yes and 19 responded no.

4. Do you engage in inspection activities under the Reactor Oversight Process (ROP) that indirectly involve material control and accounting for spent fuel? (n=65)
[53] Yes. *Please elaborate below, if you wish.*
[12] No. *Please elaborate below, if you wish.*
[0] Don't know (*Please go to question 5*)

Elaboration: Overall, 53 respondents provided an elaboration.
Of that 53, 49 responded yes and 4 responded no.

5. Do you engage in additional oversight activities (beyond the requirements of the ROP) that aid you in assessing the licensee's abilities for material control and accounting of spent fuel? (n=65)
[14] Yes. *Please elaborate below, if you wish.*
[50] No. *Please elaborate below, if you wish.*
[1] Don't know (*Please go to question 6*)

Elaboration: Overall, 23 respondents provided an elaboration.
Of that 23, 13 responded yes and 10 responded no.

6. Do you think that the NRC should be doing more with regard to the oversight of material control and accounting for spent fuel? (n=65)
[24] Yes. *Please elaborate below, if you wish, and then go to question 7.*
[28] No. *Please elaborate below, if you wish, and then go to question 8.*
[13] Don't know (*Please go to question 8*)

Elaboration: Overall, 38 respondents provided an elaboration.
Of that 38, 20 responded yes, 12 responded no, and 6 responded that they did not know.

7. Would you need more training to perform oversight of the licensee's material control and accounting program? (n=26)
[7] Yes. *Please elaborate below, if you wish.*
[16] No. *Please elaborate below, if you wish.*
[3] Don't know (*Please go to question 8*)

Elaboration: Overall, 13 respondents provided an elaboration.
Of that 13, 5 responded yes and 8 responded no.
In addition, there were 23 respondents who should have skipped this question based on their previous response but chose to answer it anyway. Of that 23, 8 also provided us with further elaboration; 3 responded yes, 3 responded no, and 2 responded that they did not know.

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8. With regard to the material control and accounting of spent fuel, do you have any best practices or lessons learned to share? For example, the transferring of fuel pellets from broken pins into new pins, the insertion of pins into skeleton assemblies, or any recordkeeping improvements. (n=65)
[14] Yes. *Please elaborate below, if you wish, and then go to question 9.*
[47] No. *Please elaborate below, if you wish, and then go to question 10.*
[4] Don't know (*Please go to question 10*)

Elaboration: Overall, 17 respondents provided an elaboration.
Of that 17, 14 responded yes and 3 responded no.

9. Please indicate if these best practices or policies: (n=12; respondents could check all that could apply)
[9] Are in place at your current site. *Please elaborate below, if you wish.*
[1] Were learned or practiced elsewhere. *Please elaborate below, if you wish.*
[5] Are just something you believe can improve procedures and the oversight process.

Please elaborate, if you wish: 3 respondents provided elaboration. Of those three, all described practices or policies in place at their current site and one respondent stated that it is something they believe can improve procedures and the oversight process.

[1] Other. Please explain: One respondent provided an explanation to discuss a best practice or policy.

10. Please share with us any additional comments: (n=16)

16 respondents provided an elaboration.

~~~~~~~~~~~~~~~~~~~~END SURVEY~~~~~~~~~~~~~~~~~~~~

Thank you for your participation.

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Comments from the Nuclear Regulatory Commission

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 25, 2005

Mr. James E. Wells, Jr.
Director, Natural Resources
and Environment
U.S. Government Accountability Office
Washington, D.C. 20548

Dear Mr. Wells:

On behalf of the U.S. Nuclear Regulatory Commission (NRC), I am writing to thank you and your staff for providing us the opportunity to review and comment on your draft report concerning the material control and accounting (MC&A) of spent nuclear fuel. Your willingness to engage the NRC staff throughout the review process is very much appreciated.

Overall, the NRC believes the report to be well written and balanced. Although the NRC generally agrees with the conclusions reached by the U.S. Government Accountability Office (GAO), I would note that significant NRC attention had been redirected to the MC&A area prior to the commencement of the GAO review. The ongoing efforts by the NRC staff to address many of these same issues are worthy of mention.

Prior to September 11, 2001, spent fuel was well protected by physical barriers, armed guards, intrusion detection systems, area surveillance systems, access controls, and access authorization requirements for employees working inside the plants. Since September 11, 2001, NRC has significantly modified its requirements, and licensees have significantly increased their resources to improve security at spent fuel facilities and nuclear power plants. The results of security assessments completed to date clearly show that storage of spent fuel provides reasonable assurance that public health and safety, the environment, and the common defense and security are adequately protected.

The NRC believes that the likelihood that an adversary could steal spent fuel from a spent fuel pool or storage cask is extremely low, given the security and radiation protection measures in place and the ease of detectability and intense, physically disabling radiation from the spent fuel.[1] The actions the NRC has already taken, as well as the actions being taken, are adequate when considered in the full context of power plant security. Consequently, the NRC does not consider the threat of a knowledgeable, active insider stealing a spent fuel rod, or portion thereof, to be credible. The NRC believes that an insider could not overcome the multiple

[1]The systems and tools used to manipulate spent fuel in pools are designed to prevent an individual from inadvertently raising spent fuel to the surface of the pool, due to the dangerous levels of radiation. Consequently, an insider would have to circumvent specific design features of the tools and equipment, circumvent sensitive radiation detectors surrounding the spent fuel pool, circumvent radiation detectors in the remainder of the plant (e.g., the radiological control boundary), and circumvent radiation detectors at the protected area boundary egress points to remove a spent fuel rod successfully from a reactor site. Further, the sensitivity of these radiation detectors increases as one moves further away from the reactor since these systems are part of the licensee's personnel radiation protection program. Finally, the radiation levels from unshielded spent fuel rods would typically be physically incapacitating within a few minutes and lethal shortly thereafter.

physical issues and sensitive radiation detectors, both around the pool and throughout the plant associated with preventing the removal of spent fuel rods or pieces from the pool. Furthermore, the physically disabling radiation would prevent an insider from surreptitiously removing the spent fuel from the reactor site for use in a radiological dispersal device (RDD).

As the GAO review indicated, some spent fuel pieces have recently been reported missing or unaccounted for from spent fuel pools; but, for the reasons listed above, there is no reason to conclude that any of the missing or unaccounted for material was removed for any malevolent purpose. Additionally, for all the missing or unaccounted for fuel rods or pieces identified to date, the initiating events occurred decades ago. In response to these events, the NRC has implemented MC&A inspections under the Temporary Instruction (TI) 2515/154, "Spent Fuel Material Control and Accounting at Nuclear Power Plants," issued on November 26, 2003. The NRC is also scheduled to complete the following activities:

- development of guidance concerning control and accounting of rods and pieces;
- development of guidance concerning the conduct of physical inventories; and
- revision of existing procedures for inspecting MC&A of spent nuclear fuel to include instructions on inspecting control and accounting of rods and pieces.

In addition, the NRC plans to conduct additional, more detailed inspections under TI 2515/154 at plants where questions regarding potential weaknesses in MC&A practices still exist. On February 11, 2005, the NRC issued Bulletin 2005-01, "Material Control and Accounting at Reactors and Wet Spent Fuel Storage Facilities," to obtain additional information to assist the staff in deciding which facilities will be selected for these inspections.

In NRC's view, the GAO report does not make sufficiently clear that the problems at Vermont Yankee were identified as a direct result of NRC's implementation of TI 2515/154. Implementation of the TI also helped identify the problems at Humboldt Bay. Although NRC agrees with the report's conclusion that licensees' efforts to account for and control spent fuel are uneven, this knowledge also came from the NRC inspections and responses to the TI, as did the knowledge that the biggest problem is accounting for and controlling pieces of spent nuclear fuel as opposed to assemblies. Additionally, performance-based approaches are often more effective and efficient at achieving the desired outcomes than prescriptive approaches. As a result, dictating how licensees are to meet the MC&A requirements is not necessarily the most effective and efficient approach.

The draft report also stresses the importance of timely action. Providing the broader perspective of overall NRC activities that have occurred since the events of 9/11 is important contextual information. For example, development and issuance of the TI was postponed by the need to devote NRC's limited resources to areas requiring more immediate attention, especially the comprehensive security and radiological protection activities conducted after 9/11.

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With regard to the measures taken by the NRC since issuance of TI 2515/154, the report needs to provide balance by giving credit to NRC for making prioritized decisions based on a variety of factors, including but not limited to, risk of malevolent action, attractiveness of material for potential malevolent activities, other controls, and available personnel resources. Such a context is not present in GAO's report. As noted above, there is no reason to conclude that any of the missing fuel segments were removed for any malevolent purpose. There is an important accounting issue for fuel rod segments, but not a security or safety issue.

Finally, I would like to note that the current regulations (10 CFR 74.19) are clear and do not appear to need revision. Licensees are already required to keep complete records of and conduct annual physical inventories of all special nuclear material. "All special nuclear material" means not only large spent fuel items, but also loose rods and pieces. The NRC agrees that implementation guidance does need to be enhanced to address loose rods and pieces of spent nuclear fuel and the NRC is working to complete the guidance.

As you are aware, the NRC and GAO staffs have had multiple exchanges regarding the report's contents and context. These exchanges have been very beneficial. Should you have questions or concerns on these additional comments, please contact Ms. Melinda Malloy, of my staff at (301) 415-1785.

Sincerely,

Luis A. Reyes
Executive Director
for Operations

GAO Contacts and Staff Acknowledgments

GAO Contacts

Jim Wells, (202) 512-3841
Ray Smith, (202) 512-6551

Staff Acknowledgments

In addition to the individuals named above, Ilene Pollack and Melissa A. Roye made key contributions to this report. Also contributing to this report were John W. Delicath, Doreen Feldman, Judy K. Pagano, Keith A. Rhodes, and Barbara Timmerman.

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