CHARACTERIZATION OF THE NUCLEAR BARGE *STURGIS*

Hans B. Honerlah, CHMM
U.S. Army Corps of Engineers, Baltimore District
10 South Howard Street, Baltimore, Maryland 21201

Brian P. Hearty, CHP
U.S. Army Corps of Engineers, HTRW Center of Expertise
12565 West Center Road, Omaha, Nebraska 68144

ABSTRACT

The Department of the Army is authorized to build and operate nuclear reactors for defense purposes under Paragraph 91b of the Atomic Energy Act of 1954 (1). As part of the Army Reactor Program, the United States Army Corps of Engineers (Corps) is responsible for nuclear reactor engineering and design, reactor construction, and decommissioning design and implementation (2). The Corps is currently focused on ensuring the safety and security of the Army's three deactivated power reactors and planning for their final decommissioning. To support decommissioning cost projections, the Corps is gathering information on the residual radiological and chemical hazards associated with each reactor, starting with the MH-1A reactor on the *Sturgis* Barge (3). Because the *Sturgis* Barge is moored in the James River Reserve Fleet, there were unique challenges that had to be overcome during the characterization survey and others that will become a concern when final decommissioning is to be performed.

INTRODUCTION

Army Nuclear Power Program

Research performed by the Corps in the early 1950's indicated that nuclear power plants were technically feasible, and that they could prove economically sound for future power requirements. The Corps, working jointly with the Atomic Energy Commission, explored the application of atomic energy to military power needs, particularly at remote locations (4). When the Atomic Energy Act was revised in 1954, Paragraph 91b authorized the Department of Defense to obtain special nuclear material for use in defense utilization facilities. The focus of the Army Nuclear Power Program was on power production facilities while the Naval Reactors Program concentrated on nuclear propulsion for submarines and ships.

The reactor designs investigated by the Corps included pressurized water, boiling water, and both liquid metal and gas cooled. A research goal to design nuclear power plants that could be transported by air, erected quickly, and operated under adverse environmental conditions was achieved. Several reactor prototypes were designed, built, and operated at Army, Navy, Air Force, and national laboratory facilities. The Corps holds permits issued by the Army Reactor Office for three nuclear reactors. These reactors have been deactivated -- the nuclear fuel removed and radiological contamination minimized and contained. The three reactors are monitored to ensure the protection of human health and the environment near the facilities.

These reactors include the stationary pressurized water reactor SM-1 at Fort Belvoir, VA; a sister design, the SM-1A, at Fort Greely, AK; and the MH-1A reactor on the *Sturgis*, now moored at the Maritime Administration's James River Reserve Fleet facility, near Fort Eustis, VA.
None of these reactors are currently in operation. The last power reactor operation took place in 1977. Maintenance issues and costs, fuel/core replacement, and military funding at the time marked the end of the Army nuclear power program.

Development and Operation of a Mobile Nuclear Power Plant

In March, 1963, the World War II Liberty Ship *Charles H. Cugle* was selected from the Mobil Reserve Fleet for conversion to a mobile power source containing a high power (>10,000 kW) pressurized water nuclear reactor designated MH-1A. The propulsion plant was removed from the vessel and the midsection was replaced with a new midsection containing the power plant, a 350-ton steel containment "spheroid," and a concrete collision barrier. This new midsection was approximately eight feet wider than the original vessel, and contained not only the nuclear reactor, but also the main components of the primary and secondary cooling systems, as well as the electrical equipment. The vessel, which essentially became a barge, was renamed *Sturgis*. It began operation in 1967 at Ft. Belvoir, Virginia (Figure 1) and after one year was towed to Gatun Lake in the Panama Canal Zone where it was used to generate electricity for military and civilian use.

Fig. 1. Operational testing of the *Sturgis* at Ft. Belvoir, VA. (Corps photo)

The Panama Canal Company acquired additional land based electrical capacity and in 1976 it was determined that the *Sturgis* was no longer needed. During December 1976 – January 1977, the *Sturgis* was taken under tow with Ft. Belvoir as its final destination. Encountering severe weather in route, the vessel was diverted to the Military Ocean Terminal at Sunny Point, North Carolina, where it subsequently underwent temporary structural repairs. Following repairs, the *Sturgis* was again taken under tow arriving at Ft. Belvoir in March of 1977. At that point, a decision was made to deactivate the reactor on board due to a variety of reasons, including a closer inspection and assessment of damages from the recent trip through the severe weather, costs, and military funding. The reactor operated at an overall capacity factor of 0.54 for a total of nine years, giving a total operating time (effective full-power years irradiated time) of 4.86 years. The reactor was de-fueled, portions were decontaminated, and other areas sealed before being towed to the James River Reserve Fleet for safe storage.

MH-1A Reactor Deactivation

The decommissioning strategy that was developed in the 1970's recommended that the deactivated reactors be placed into a safe storage mode that would allow the shorter-lived radionuclides to decay. It was expected that delaying decommissioning would reduce radioactive waste volumes and worker exposures. Early plans estimated that decommissioning of the *Sturgis* would begin in 2027.

After final shutdown the *Sturgis* was towed to Ft. Belvoir to deactivate the reactor for safe storage. Pursuant to section 102(3) of the National Environmental Policy Act of 1969, the Department of the Army prepared an Environmental Assessment. The assessment indicated that that Deactivation would not create significant adverse local, regional, or national impacts on the environment and that no significant controversy is associated with the project (5). The principal activities involved in deactivating the reactor of the *Sturgis* were:

- ***De-fueling and shipping of irradiated fuel and irradiated control rods***. De-fueling of the MH-1A reactor was completed on 9 June 1977. All spent fuel elements were shipped to Energy Research and Development Administration, Savannah River, Aiken, SC. Irradiated control rods were shipped to Chemical Nuclear Systems, Inc., Snelling, SC. Two new fuel elements were shipped to the Y-12 plant in Oak Ridge, TN. A total of ten shipments were required to accomplish these activities.

- ***Disposing of radioactive wastes/components and radioactive sources/samples***. There were a total of 13 shipments associated with these activities. Six shipments, totaling 3143.8 cubic feet, of radioactive waste were shipped to Chemical Nuclear Systems, Inc., Snelling, SC. Other shipments included transfer of sources or samples to other Federal Agencies, such as Bluegrass Army Depot, Lexington, KY, the US Military Academy, West Point, NY, U.S. Army Facilities Engineering Support Agency, Fort Belvoir, VA, Naval Research Lab, Washington, DC, and US Department of Energy, Hanford Plant, Richland, WA. There were also 96,000 gallons of liquid radioactive waste processed and discharged during the deactivation.

- ***Isolating the remaining radioactive materials from the public by appropriate physical barriers***. During deactivation, 229 long tons of material were removed from the ship. Forty-seven long tons of gravel shielding were added to the reactor vessel shield tank. The total net change in displacement of the light ship was 178 long tons removed. Containment vessel penetrations for primary systems, secondary systems, electrical and instrumentation systems, and the external purge systems were closed and sealed.

- ***Decontaminating all other plant areas to within prescribed limits for release as an unrestricted area.*** This entailed limiting removable contamination to < 1,667 Becquerel per square meter (< 1000 disintegrations per minute per 100 square centimeters) and exposure rates at one meter to less than 0.5 micro-Sieverts per hour (50 micro-Roentgens per hour).

Following completion of the reactor deactivation, the *Sturgis* was towed to Savannah, Georgia for dry-dock work prior to placement in safe storage at the James River Reserve Fleet. The basic work performed while in dry-dock was to make the barge air-tight, divide the *Sturgis* into three separate zones for dehumidification installation, install flooding and fire alarms, dry-dock and seal all openings below the water line, run ultrasonic hull thickness tests, and paint the entire vessel on the exterior. The majority of the deactivation tasks were completed in January 1978.

Environmental Monitoring and Safe Storage

Since deactivation, ensuring the safety of facility staff, the public, and the environment has been and is the Corps' primary responsibility. The Army Reactor Office, part of the U.S. Army Nuclear and Chemical Agency (USANCA), issued Nuclear Reactor Possession Permits to the Corps' Environmental Division. These permits detail what requirements must be met to protect workers, the general public, and the environment. A Radiation Protection Program (RPP) for each facility details safe procedures for working in or near the reactor facilities. The RPP outlines activities necessary to comply with the permits and to ensure the radiation dose from each facility to workers and the public is as low as reasonably achievable. Some of the RPP activities are quarterly radiation surveys, quarterly environmental monitoring, and quarterly intrusion alarm system checks and structural surveillance. Under an Interagency Agreement the Maritime Administration assists with the security and structural inspections as well as upkeep of the systems onboard the *Sturgis* necessary for continued storage in the Reserve Fleet. Since the deactivation dry-docking of the vessel has occurred twice. The first occurred in 1978 to initially prepare the *Sturgis* for safe storage. The second occurred in 1999 and included structural inspection and cleaning/painting of the hull (Figure 2).

ALL HAZARDS ASSESSMENT

In 1998, USANCA funded a study to review the status of the Army's reactors and to develop decommissioning alternatives (6). The study concluded that the levels of contamination present within the reactors would not be reduced by decay sufficiently to allow for release of the facilities without significant decontamination being performed. The study also indicated that maintaining the reactor in a safe storage condition may not be the most cost effective strategy due to escalating decommissioning costs, personnel/maintenance costs, waste disposal options, and changing regulations concerning decommissioning. These issues led the Army Reactor Office to recommend that an assessment be performed of the *Sturgis* to allow a more accurate decommissioning cost estimate to be developed that addresses projected changes in disposal options.

Fig. 2. Cleaning of the hull during 1999 dry dock. (Corps photo)

The U.S. Army Corps of Engineers, Baltimore District developed a Scope of Work (SOW) that contained provisions for four phases of work to be performed. Phase I included a Historical Records Review and Disposal Alternatives Investigation. Phase II, included a radiological and chemical characterization survey and a decommissioning cost estimate. Phases III and IV deal with decommissioning design and execution and are not yet awarded.

Phase I - Historical Records Review

Phase I of the All Hazards Assessment consisted of a historical review of relevant documents and a site visit to update the current status and assist with the development of additional phases. The information obtained from the historical documents was used in the preparation of the sampling and analysis plans for the hazards assessment/characterization survey of the *Sturgis*. The focus of the review was on residual radioactivity, as well as, other hazardous materials within the facility.

The historical assessment identified the only significant radioactivity remaining on board following the deactivation is neutron activation products, either in the form of low activity corrosion products or higher activity neutron activated components. Table 1 identifies a list of radionuclides, their concentrations calculated at the time of deactivation, and decayed concentrations. Fission products or transuranic isotopes had not been detected in the primary coolant during operations and were not considered during deactivation. Phase I of the All Hazards Assessment identified five primary radiological areas of concern (7). The areas are the refueling room, reactor access compartment, containment vessel, spent fuel tank, and hull bottom tanks (Figure 3).

Refueling Room – During the deactivation the refueling room was used as the primary work area for operations. Several pieces of equipment remain from the reactor operations and include the crane hoist used for reactor refueling operations, upper section of the refueling shield tank, new fuel rod storage cask, spent fuel storage cask, and the spent fuel transfer cask.

Table I– Activation/Corrosion Products

			Total Activity, TBq (3)						
Radionuclide	Half-Life (1)	Shutdown (2)	10 Years	20 Years	30 Years	40 Years	50 Years	60 Years
^{57}Co	270.9 d	60	-----	-----	-----	-----	-----	-----
^{58}Co	70.8 d	547	-----	-----	-----	-----	-----	-----
^{60}Co	5.271 y	4657	1250	336	90	24	6	2
^{51}Cr	27.704 d	35710	-----	-----	-----	-----	-----	-----
^{55}Fe	2.7 y	15881	1219	94	7	1	-----	-----
^{59}Fe	44.63 d	589	-----	-----	-----	-----	-----	-----
^{54}Mn	312.7 d	220	-----	-----	-----	-----	-----	-----
^{63}Ni	100.1 y	422	394	368	343	320	299	279
^{59}Ni	75,000 y	3	3	3	3	3	3	3
TOTAL		58,089	2,866	800	444	348	309	284
Ratio of 55Fe/60Co		3.41	0.97	0.28	0.08	0.02	0.01	< 0.01
Ratio of 63Ni/60Co		0.09	0.32	1.10	3.81	13.23	45.99	159.83
Ratio of 59Ni/60Co		< 0.01	< 0.01	0.01	0.04	0.14	0.52	1.95

(1) Activation/corrosion product half-life adopted from Microshield Software, Version 5.03.
(2) Activity at shutdown is assumed to be correct as reported in the "Calculation of Activity in Irradiated MH-1A Reactor Structures After Shutdown", U.S. Army, FESA, Fort Belvoir, VA.
(3) Activities after shutdown were estimated using Microshield runs does not include any potential residual radioactivity from activation products of impurities.

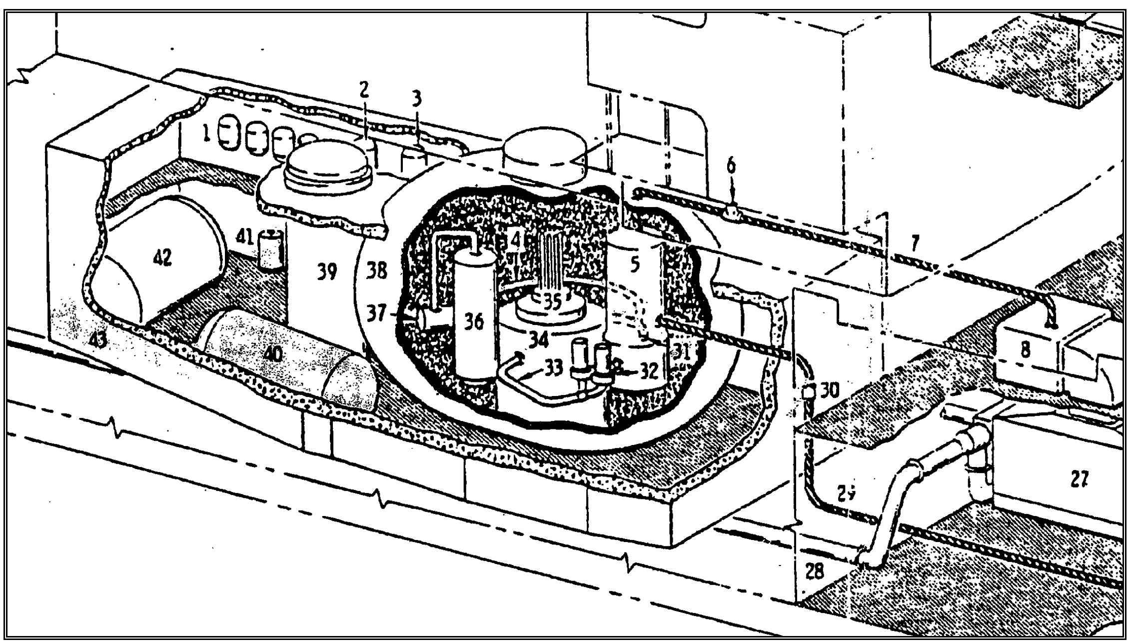

Fig. 3. Diagram of the MH-1A Reactor Access Compartment, Spent Fuel Tank and Containment Vessel.

Reactor Access Compartment – During the deactivation all piping connections were welded closed and the reactor access compartment was secured. The historical assessment indicated that several of the radioactive waste disposal tanks remained as well as significant piping for numerous systems associated with reactor operations. The reactor access compartment is also the point of entry for several of the hull bottom tanks, identified in the historical assessment, as potentially containing residual radioactive contamination (Figure 4).

Fig. 4. Refueling Room showing Spent Fuel Tank Lid and Access Plug. (Corps Photo)

Containment Vessel – During the deactivation all piping connections were welded closed and the vessel was sealed/secured. The historical assessment indicated that much of the equipment associated with the reactor was still in place. The major components remaining are the reactor pressure vessel, steam generator, pressurizer, primary loop pumps, and lower section of the refueling shield tank.

Spent Fuel Tank – During the deactivation all piping connections were welded closed and a steel cover was put in place over the tank prior to sealing/securing the tank. The historical assessment identified numerous contaminated components that were placed into the interior of the tank during the deactivation. The documentation for the material placed within the spent fuel tank, as well as the condition of the spent fuel tank, was sufficient for future decommissioning activities. Therefore, the decision was made not to open the tank for inspection.

Hull Bottom Tanks – There are several hull bottom tanks that run the length of the vessel. Several of these tanks were identified during the deactivation as containing residual radioactivity. The historical assessment indicated that all remaining liquids were removed and identified significant decontamination efforts with several of these tanks. All tanks were sealed upon completion of the deactivation.

The historical assessment identified the potential for chemical hazards as; PCB's in electrical wiring, paints, equipment, and gaskets; asbestos in insulation, gaskets, and floor/ceiling tiles; lead shielding; metals in paints (i.e. barium, cadmium, chromium, and lead); mercury in fluorescent lights and monometers; chromium in chrome-plated fasteners; residual diesel in fuel tanks; and organo-tin antifouling agent of hull paint.

The historical assessment also identified significant logistical challenges involved with the mobilization of equipment, daily site access, and environmental conditions that would be encountered during field activities.

Phase II - Characterization Activities

The objectives for the Phase II characterization survey completed in 2001 were to:

- Quantify the inventory and distribution of radionuclides present in impacted areas of the *Sturgis* as required for decommissioning alternative assessment and waste management planning.

- Quantify the radiation fields and removable contamination from accessible surfaces, equipment and structures in impacted areas of the *Sturgis* as required for decommissioning worker dose projections and waste management planning.

- Confirm the presence of hazardous or toxic substances that have the potential to significantly affect the decommissioning alternative assessment and waste management planning.

To accomplish the objectives identified above, the radiological characterization activities included in-situ gamma spectroscopy, direct beta measurements, dose rate measurements, removable contamination wipe analysis, and volumetric sampling of sediments, liquids and concrete where available. For hazardous materials the characterization activities focused on sampling suspected liquids, gaskets, paint, and electrical equipment for PCB's; insulation, gaskets, floor and ceiling tiles for asbestos; and paint for metals (8).

Logistical Challenges

The *Sturgis* is currently moored in the James River Reserve Fleet, Newport News, VA. This posed significant logistical challenges that would be encountered during the characterization activities. Some of the challenges of performing the characterization on a vessel floating several hundred yards from shore were; coordinating one morning and one evening trip for characterization crew to get to and from the site, coordination of a crane barge to mobilize/demobilize equipment necessary to perform the field activities, communication (computer and personnel) with support staff on shore, on board communication with staff, and environmental conditions of the vessel.

SURVEY RESULTS

Residual Radioactivity

Dose Rates – Elevated dose rates were measured throughout the Reactor Access Compartment and the Containment Vessel. The highest readings, 20 µSv/hr (2,000 µR/hr), were recorded in the Containment Vessel, near the Reactor Pressure Vessel and the Steam Generator.

Fixed Measurements – The direct alpha and beta surveys were conducted with two instruments/detectors. The first, a gas proportional detector capable of detecting both gross alpha and gross beta. The second, a windowless gas proportional detector used specifically for the detection of low energy beta radiation.

Removable Contamination – Wipes indicated that there were small levels of removable contamination within the Reactor Access Compartment and the Containment Vessel. All but a few of these measurements were below the release guidance identified within Army Regulation 11-9. Several wipes were taken from inside tanks/pipes and the results indicated levels well above the release guidance.

Table II - Summary Table by Areas of Concern

Area	Dose Rates (µSv/hr)	Total Beta (Bq/m^2)	Removable Beta (Bq/m^2)
Refueling Room	0.03 – 0.75	0 – 5,513	0 – 917
Reactor Access Compartment	0.2 – 6	0 – 176,667	1,667 –26,405
Containment Vessel	3 – 20	0 – 367,501(3)	0 – 10,000
Spent Fuel Tank 1		0 – 1,333	
Hull Bottom Tanks	0.03 – 1.50	0 – 22,167	0 – 5,667
Other Small Components 2		0 – 472,329	0 – 373,334

1 – Internals of the spent fuel tank were not accessed during All Hazards Assessment. Dose Rates and Removable Concentrations are included in the Reactor Access Compartment.
2 – Other small components include accessible tanks and/or pipes. Dose rates are included within the other areas. Elevated total/removable readings specific to a component were placed within this category, not within the larger area. +
3 – The total beta readings recorded may be overestimating surface activity by including the elevated gamma radiation shine emanating from the internal surfaces.

In-Situ Gamma Spectroscopy – A total of fourteen measurements with the high purity germanium in-situ gamma spectroscopy system were performed on components that could not be easily accessed by the field crew. The only isotope detected was Co-60. The gamma spectroscopy system proved to be difficult to maneuver on board the ship with limited access and entry to specific areas and separate levels.

Volumetric Samples – A total of 40 samples were sent for offsite analysis. The media included concrete, steel, rust, water, sludge, paint, insulation, and wipe composites. Initial indication shows trace amounts of contamination within the steel and concrete outside of the containment vessel. The supported the historical information by identifying the primary contaminants as Co-60 and Ni-63.

Chemical Hazards

Asbestos – A total of 22 groups of like material was identified and 12 of those groups were identified as asbestos containing material and will require controls for removal and disposal. The 12 groups were identified as ceiling tiles, two groups of wall tiles, four groups of floor tiles, two groups of gaskets, and three groups of thermal system insulation.

Resource Conservation Recovery Act – Painted materials were evaluated and samples collected throughout machinery, occupational, and outdoor spaces on the ship. Samples of paint and the underlying substrate did not exceed the RCRA regulatory limits. Samples of paint only did exceed the RCRA regulatory limits and may require disposal at a permitted facility if the material is not recycled.

Polychlorinated Biphenyl's (PCB) – Samples of remaining transformer liquid as well as paint were sent for analysis. Both sample sets indicated small quantities of PCB's, however none were above the Toxic Substance Control Act levels.

DECOMMISSIONING CHALLENGES

Complete decommissioning of the *Sturgis* offers many unique challenges not encountered in the typical power reactor decommissioning process.

Waste Disposal Options

There are several potential waste types that will be associated with the decommissioning of the *Sturgis*. These types include Class A and B radioactive waste, as classified using 10 CFR 61.55, hazardous waste, and radioactive and hazardous waste combined. Availability of commercial disposal sites for specific waste streams may pose significant challenges due to the prohibition of non-Atlantic Compact waste disposal at the Chem-Nuclear Systems facility in Barnwell County, South Carolina after 2008. Accessing Department of Energy (DOE) disposal facilities for the radioactive waste streams is being investigated because the Army Nuclear Power Program association with the Atomic Energy Commission, the DOE predecessor agency. The waste challenges may be compounded with the selection of the decommissioning site and impacts to the sites compact affiliation.

Location for Decommissioning Activities

Selecting a location for the decommissioning activities may prove to be a challenging task. Typical reactor decommissioning takes place in a community familiar with the reactor operations and environmental groups are typically enthused to see the plant decommissioned. There are usually issues with the cleanup levels and transportation of wastes. However, the *Sturgis* decommissioning will involve taking the barge under tow to a facility capable of conducting these activities. This will require significant public relations and educational programs. This also means that there may be different regulatory requirements for each potential decommissioning location. The activities associated with the decommissioning may allow for a portion of the process to take place dockside utilizing cranes to remove large components for transportation to waste facilities. A complete structural review will be required prior to the disassembly to ensure the hull can handle the significant changes.

Ship Breaking Activities

Upon completion of the reactor decommissioning activities the remaining vessel will require complete dismantlement, recycling, and/or disposal. This will require significant data to ensure that there is no residual radioactive material on board that would have the potential to expose workers or enter the market through a recycling process.

CONCLUSIONS

In the 1970's the original decommissioning strategy that was developed included placing the *Sturgis* in a safe storage mode for approximately 50 years. In 1998, after review of preliminary information, indications suggested that it may not be the most cost effective strategy to maintain the *Sturgis* in a safe storage condition. The All Hazards Assessment was designed to gain a better understanding of the residual radioactivity remaining, the potential waste streams and volumes, feasibility of completing decommissioning, identifying potential changes to the industry that may cause significant impact to the decommissioning process, and to gather enough information to develop a more accurate cost estimate for the decommissioning.

The All Hazards Assessment data supports the historical information from the reactor deactivation. The primary radiological constituents of concern are Co-60 and Ni-63. The All Hazards Assessment gathered data to support hazardous and mixed waste issues for decommissioning. The most significant use of the information gathered will be to support the health and safety of workers and planning for any future decommissioning.

The Corps is currently reviewing the radiological data to determine if there will be any benefit to allowing the radioactive material to decay for an additional time period. The Corps will also attempt to identify future changes in industry and cost escalations that will impact the decommissioning. By comparing the reduction in waste from radioactive decay to the cost and industry changes time table, the Corps hopes to determine the most efficient time period to decommission the *Sturgis*.

REFERENCES

1. Section 42 U.S.C. 2011 et seq.
2. Army Regulation 50-7, "Army Reactor Program," August 1996.
3. U.S. Army Corps of Engineers, "Management Plan for the U.S. Army Deactivated Reactor Program," December 1999.
4. Wright, R., "Corps has responsibility for three old atomic reactors," Engineer Update, Vol. 25 No.4, April 2001.
5. Federal Register, July 1977, Department of Defense, Department of the Army, "Decommissioning of the *Sturgis* [MH-1A] Nuclear Power Plant at Fort Belvoir, VA"
6. U.S. Army Nuclear and Chemical Agency, "United States Army Reactor Disposition Study," January 1998.
7. U.S. Army Corps of Engineers, "Methods and Sources of Disposal of the Nuclear Barge *Sturgis*," February 2000.
8. U.S. Army Corps of Engineers, "Sampling and Analysis Plan, Decommissioning of the Nuclear Barge *Sturgis*, James River Reserve Fleet, Ft. Eustis, Virginia, " July 2001.