1130.1

December 4, 1995

The Honorable John T. Conway
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, D.C. 20004

Dear Mr. Chairman:

In an effort to keep the DNFSB informed of the status of safety activities within the DOE complex the Office of Oversight is providing copies of several technical reports reflecting our most recent oversight efforts. Enclosed you will find a copy of our oversight evaluation of the Idaho National Engineering Laboratory (INEL). This document provides conclusions regarding the safety performance at INEL as well as the background information necessary to support these conclusions. Also enclosed is a copy of our analysis of the issues relative to Suspect/Counterfeit Parts within the Department of Energy. We are aware that this subject has been of concern to the DNFSB. Additionally, a special study of Occurrence Reporting Programs within the Department of Energy and a special review of the Molten Salt Reactor Experiment at the Oak Ridge National Laboratory (ORNL) are provided for your information. Lastly, we are providing you a copy of our Emergency Management at Department of Energy Headquarters Special Study and our Increasing Fissile Inventory Assurance Within the U.S. Department of Energy Special Study report.

If you have any questions regarding the information provided please feel free to contact me.

Sincerely,

Original signed by
Glenn S. Podonsky
Glenn S. Podonsky
Deputy Assistant Secretary
Office of Oversight
Environment, Safety and Health

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6 Reports

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INDEPENDENT OVERSIGHT SPECIAL REVIEW
OF THE
MOLTEN SALT REACTOR EXPERIMENT
OAK RIDGE NATIONAL LABORATORY

October 1995

Office of Oversight
Environment, Safety and Health

U.S. Department of Energy

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INDEPENDENT OVERSIGHT SPECIAL REVIEW OF THE MOLTEN SALT REACTOR EXPERIMENT OAK RIDGE NATIONAL LABORATORY

1.0 PURPOSE

This report summarizes the status of safety concerns existing at the Molten Salt Reactor Experiment (MSRE) at Oak Ridge National Laboratory (ORNL). This review is part of an ongoing effort by the Office of Environment, Safety and Health, Office of Oversight, and its predecessor organizations. The Office of Nuclear Safety, the precursor oversight organization at the Department of Energy (DOE), had previously reviewed the status of nuclear safety issues at MSRE. A chronology of safety issues is provided in Appendix A.

The Office of Oversight examined the status of safety concerns at the Molten Salt Reactor Experiment.

2.0 BACKGROUND

2.1 INTRODUCTION

The MSRE is located at ORNL. The fuel used at the MSRE was a mixture of fluoride salts including uranium and plutonium. The MSRE was operational from 1965 to 1969. For the last operational run, the primary isotope was uranium-233 (U-233). The mass of uranium (all isotopes) was about 37 kilograms, and less than 1 kilogram of plutonium was present. The MSRE system condition is described in Appendix B. Table 1 lists the chemical and isotopic composition of the last fuel salt mixture used.

The Molten Salt Reactor Experiment is located at Oak Ridge National Laboratory.

Union Carbide, the DOE management and operating (M&O) contractor at the time, placed the MSRE in permanent shutdown in 1969 by draining the molten salt mixture to core drain tanks located in a sealed cell and by cutting and plugging the main system piping. The M&O contractor also deactivated and isolated many other systems and components no longer needed for safety in the shutdown mode. The M&O contractor maintained operational systems and components necessary to perform an annual reheat, or "annealing," of the salt mixture in the core drain tanks. This annealing does not melt the salt and is necessary to stabilize the mixture.

The reactor was shut down in 1969.

At present, there are about 30,000 curies of various radionuclides at the facility. Uranium tetrafluoride in the salt mixture slowly disassociates under radiolysis into semi-stable uranium trifluoride, thus liberating fluorine (F_2). Other constituents of the salt mixture also

The materials remaining in the reactor were expected to remain stable with regular reheating of the salt mixture.

Table 1. Stored MSRE Salts

	Fuel Salt	Flush Salt[a]	Coolant Salt[a]
Total Mass (kg)	4650	4290	2610
Volume (ft^3 @ RT)	66.4	69.9	42.5
Composition (mole) %			
LiF	64.5	66[b]	66[b]
BeF_2	30.3	34[b]	34[b]
ZrF_4	5.0	—	—
UF_4	0.13	—	—
Uranium Content (kg)			
U-233	30.82	0.19	—
U-234	2.74	0.02	—
U-235	0.85	0.09	—
U-236	0.04	0.00	—
U-238	2.01	0.19	—
Total	36.46	0.49	
Plutonium Content (g)			
Pu-239	657	13	—
Pu-240	69	2	—
Other Pu	2	0	—
Total	728	15	
Lithium Composition (%)			
Li-6	—	0.009[c]	0.009
Li-7	—	99.991[c]	99.991

[a] Trace element analysis of 39 batches used for both salts gave 16 ppm Cr, 39 ppm Ni, and 121 ppm Fe. Twelve other analyses of the flush salt gave 38, 22, and 118 ppm, respectively. (Note: Could the Cr and Ni have been interchanged?) In another series of 22 batches, the values were 19, 25, and 166 ppm.

[b] Reported values. Analysis data for batches 116-161 gives 63% and 37%, calculated from reported values of 12.95 wt % Li, 9.75 wt % Be, and 77.1 wt % F. For batches 101-130, the calculated composition is 64.5% and 35.7%.

[c] For batches 116-142. The values are 0.0065/99.9935 for batches 143-161.

disassociate under radiolysis, liberating additional F_2. Annealing causes most of the F_2 to recombine with the salt. Even with some F_2 buildup, the rate of corrosion was expected to remain relatively low as long as moisture and other contaminants were excluded. With a low corrosion rate, the various systems and components were considered to remain intact indefinitely. However, the safety analysis did not fully explore other ways system integrity could be lost and did not anticipate later developments.

2.2 RECENT HISTORY

However, UF_6 gas was generated, migrated through the piping, and solidified in the system.

Martin Marietta Energy Systems (MMES) assumed the DOE M&O contract in 1984; however, most personnel continued in their existing positions. These personnel continued to perform the annual annealing operation under the new management without realizing that some of the F_2 had combined with UF_4 to create chemically stable UF_6 gas. The heated UF_6 gas migrated through core drain tank offgas system piping, solidified on cooler surfaces, and was preferentially adsorbed on an activated charcoal filter in the offgas system. Radioactive decay created highly radioactive U-232 daughter products, which were also deposited in proportion to the quantity of uranium at any given location (Appendix C). MMES first detected high dose rates in the North Electrical Service Area (NESA) of the MSRE in 1989 and placed a moratorium on the annealing operation pending an understanding of the cause. However, until 1994, MMES neither issued a safety basis document justifying ceasing the annual annealing operation, nor determined the cause of the high dose rates in the NESA, nor understood the full implications of the data.

2.3 1994 DISCOVERIES

The materials of concern are concentrated in a one-foot-long section of the charcoal bed filter assembly.

MMES determined in mid-1994 that masses of fissile material and other highly radioactive materials, as well as some possibly highly reactive chemicals, are located in a concrete lined pit (also known as the charcoal bed cell) outside the building housing the MSRE. These materials are presently concentrated in an approximately 6-inch diameter, 1-foot long section of the aforementioned charcoal bed filter assembly (see Appendices B and C). The filter assembly is expected to remain subcritical by a large margin as long as water is excluded. However, at the time of this discovery the entire enclosed filter assembly was under water.

The filter assembly is over 20 feet high and was constructed from straight and curved U-bend segments for a total filtered length of over 80 feet. The filter tube is relatively thin walled stainless steel and the inlet pipe enters at a right angle to the tube near its top end.

MMES took immediate and near-term corrective actions, which included pumping practically all of the water out of the pit in stages. MMES also made a precautionary evacuation of personnel who routinely work in the facility and only admitted personnel necessary to perform the activities. Near the pit, MMES installed a criticality accident alarm system and devices to detect hydrofluoric acid fumes. MMES erected a lean-to over the pit to keep out rainwater, constructed a fence around the facility, locked the gates, and posted warnings.

Water has been pumped out of the area to minimize criticality and safety concerns.

MMES also discovered that the V-561 valve isolating the activated charcoal filter from the reactor core drain tanks cannot be closed; the reach rod handle turns freely. The annealing procedure requires opening this valve during annealing operations and closing it afterwards. MMES has determined through research, radiographs of this valve, and nondestructive and destructive examination of other components that the threads on this valve are stripped, the spring is holding it open, and the cause is not due to loss of offgas system integrity. The threads on this and similar valves at the MSRE are aluminum and are easily stripped. MMES is preparing to close alternate valves to isolate and partition the offgas system and is designing a clamping device to close this valve. High dose rates require that this work be done remotely and progress has been slow. It will be necessary to isolate the offgas system prior to removing the deposit from the filter.

The valve intended to isolate this portion of the system cannot be closed.

2.4 PIT CONDITIONS

Also in 1994, MMES inserted a special camera and videotaped the interior of the pit, determining that the carbon steel supports for the filter tubing are heavily corroded due to exceeding their service life in a wet environment. The first stage of water removal was to lower the water level to just below the filter inlet; MMES accomplished this quickly to significantly lower the risk of accidental criticality both in the pit and in the core drain tanks. MMES then studied the status quo at some length and tentatively concluded that much of the UF_6 deposited near the filter inlet has combined chemically with the carbon of the charcoal bed filter, possibly creating a number of carbon-fluorine compounds; the stability of some of these compounds is not certain. Traces of radioactive contamination, MSRE salt mixture, or related chemicals were not observed in the water, and the exterior of the stainless steel filter appears unscathed. However, because of the radiation field associated with the uranium deposit, very reactive F^- radicals are constantly being created; the condition of the interior wall of the filter is unknown.

The condition of the interior wall of the filter and the exact chemical conditions inside the filter are not known.

MMES did not immediately remove all the water from the pit because of the possibility that the water surrounding the filter was cooling ongoing chemical reactions and that removing it might cause a runaway exothermic reaction that might breach the filter tube. Eventually, engineering studies alleviated this concern and MMES then pumped the pit out. A second benefit of removing the water from the pit is that there is no longer a credible way for water to drain into the reactor fuel drain tanks and thus no potential for a criticality accident in that location. Short-term criticality safety depends on not raising the water level in the pit and LMES[1] continues to monitor for the water intrusion.

3.0 STATUS OF CORRECTIVE ACTIONS

Immediate corrective actions have been completed.

LMES has completed immediate corrective actions and has begun reoccupying the building. LMES is periodically monitoring residual moisture (puddles) in the pit via video camera. LMES concluded that the pit walls and bottom are intact, which may be inferred from the fact that the pit held over 20 feet of water without apparent outleakage, and inleakage has not been observed. Because LMES has not performed annealing in over five years, the partial pressure of F_2 is approaching half an atmosphere. During the past five years, other gaseous constituents raised the total pressure in the offgas system such that it was only a few inches of water negative. The pressure fluctuates with seasonal warming and cooling. However, during mid-1994, the pressure went positive and is anticipated to peak this year at about 2 pounds per square inch. If it follows previous trends, it will decline this winter but may remain positive. LMES speculated that this change in the previous negative values is due to the estimated five-year latency for F_2 to evolve in quantity from the salt mixture. However, dose rates in the NESA are nearly stable, and there is no indication of significant migration of UF_6 to other areas. LMES concludes that the UF_6 is in equilibrium or saturated in the vapor phase.

Some other problems in the area will have to be addressed before the salt mixture can be removed.

There are some other minor, unrelated problems at MSRE for which corrective actions are necessary to permit abating the existing safety hazards. Polychlorinated biphenyls are leaking from a crane that will eventually be needed to support removing the salt mixture from the core drain tanks. Also, hundreds of barrels of contaminated dirt, as well as some contaminated equipment, are stored in the facility. LMES will need to remove most of these items from the MSRE building to create a laydown area and allow access to the core drain tanks.

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[1] Recently, due to a merger, the M&O contractor name changed to Lockheed Martin Energy Systems (LMES). Essential personnel involved with MSRE were affected by this merger.

4.0 ISSUES OF CONCERN

4.1 PRESENT SAFETY ISSUES

While criticality safety had been identified as a concern based on previous oversight reviews, it is not a concern under present conditions. However, significant radiological and chemical hazards remain. Draining the pit has effectively eliminated the concern of accidental criticality in both the pit and in the core drain tanks. LMES is planning to install another pump and a CO_2 recirculation system that will further dry the environment in the pit. This will assure criticality safety because the mass of U-233 in the pit is insufficient for criticality in the absence of water.

Although criticality is no longer a concern, significant radiological and chemical hazards remain.

The extensive corrosion of the filter tube supports in the pit raises radiological and chemical safety concerns. Failure of these supports could result in excessive stresses on the filter tube, especially at the inlet. A breach of the system would release radionuclides and toxic chemicals. LMES indicated that F_2 would react exothermically with moisture either in the pit or absorbed from a leaking structure to create hydrogen fluoride (HF). The heat generated from this reaction could possibly cause other highly exothermic, even explosive reactions involving existing intermediate carbon-fluorine compounds in the charcoal of the filter. LMES has designed and installed a seal and a hold-down device over the pit to prevent the shield plug from blowing off in the event of rapid pressure buildup. Until these tanks are isolated, there is no way to positively prevent an ongoing series of reactions and release of radionuclides at least into the pit.

Failure of filter tube supports and explosive pressure buildup are the primary concerns.

4.2 FUTURE SAFETY ISSUES

Removing the salt mixture and uranium deposits in the absence of water will preclude the formation of toxic chemicals, and should help prevent an explosion or rapid deflagration that could enhance the release of radionuclides or toxic chemicals. LMES estimated that the present uranium deposit in the filter would still not be critical if optimally moderated and fully reflected. There is uncertainty as to the exact amount of U-233 in the filter, and the amount present is probably slowly increasing. However, it will remain substantially subcritical (estimated $k_{eff} < 0.4$; criticality requires $k_{eff} \geq 1.0$) if kept dry and minimally reflected, even allowing for a modest increase in mass of the deposit due to migration of UF_6 gas. LMES personnel indicated that laboratory tests show that the UF_6 gas is reduced to UF_4 by the charcoal. Because UF_4 is insoluble in water, accidental criticality is less likely than if the uranium compounds are soluble for any given geometry and mass of uranium. This is because the large density difference between solid particles of uranium and water normally precludes optimum moderation. Nevertheless, it is difficult to take any criticality safety credit for the fact that the UF_4 is insoluble because it may be suspended in the charcoal matrix in a near optimum fashion, and the charcoal matrix may become agitated during exothermic chemical reactions.

It will be important to exclude water from the area when the salt mixture and uranium deposits are finally removed.

5.0 PATH FORWARD

5.1 PLANNING AND BUDGET ALLOCATIONS TO SUPPORT NEAR-TERM ACTIVITIES

Near-term recovery activities are funded and generally on schedule.

LMES is planning several additional recovery activities for the near future. Among the first is to vent and purge the gases from the offgas system. LMES is designing a system to remove F_2, UF_6, and other gases from the offgas piping and intends to recover solid fissile material and radionuclides that remain in the filter tube. LMES plans to isolate the offgas system by closing alternate valves; however, it is uncertain whether these alternate offgas system isolation valves can be closed. LMES has allocated $2M to alleviating the gas buildup problem and has made some progress. A recent document noted that gas processing would begin in fiscal year (FY) 1995. However, this did not occur. The EH-22 review of plans and progress on this and other items determined that other near term items are adequately funded and on schedule.

5.2 NEAR-TERM PLANNED RISK REDUCTION ACTIVITIES

Four risk reduction activities are under way.

In addition to numerous existing controls established to prevent accidental criticality, LMES has begun four other near-term programmatic activities to further reduce the risk of accidental criticality, reduce other risks, and better characterize the spread of radionuclides within and around MSRE.

5.2.1 Comprehensive Nondestructive Assay

The probable location of the materials of interest is known.

LMES has completed the first phase of this work, a gamma scan of the MSRE and the immediate vicinity, mainly using sodium iodide crystal detectors. This survey detected no appreciable buildup of uranium at any unanalyzed location. MSRE plans to perform more detailed gamma scans to assure that kilograms of uranium have not accumulated in any unfavorable geometry location; however, it is likely that this scenario is incredible. LMES calculated that it would take more than six kilograms of U-233 in the reactor to become critical because the graphite moderator present is not as effective as materials containing hydrogen. LMES estimated, based on analyzing gas samples, that approximately 2.1 kilograms of U-233 are in the reactor drain tank offgas system as UF_6, some as gas and some deposited in lines and components. Three times the mass of U-233 currently believed to be in the drain tank offgas system would have to vaporize, leak through a closed valve into the reactor, and deposit as a solid for criticality to be possible. There is no credible mechanism to cause such a large deposit of solid UF_6 in the reactor.

5.2.2 Moderator Identification, Removal, and Configuration Control

Potential moderator materials are being removed or controlled.

LMES has begun reviewing all locations where multi-liter quantities of water or other effective moderators such as oil are located and where it is credible that, without controls, they could intermix with kilogram quantities of U-233. LMES plans to remove moderators from these areas and replace them with nonmoderators (e.g., sand) wherever it is necessary (e.g., for shielding) and practical to do so. LMES will maintain control over remaining moderating materials.

Some of these activities include confirming the configuration of various systems and components when the reactor was shut down about 25 years ago. For example, this includes ensuring that water lines thought to be cut and capped at that time in fact were. Moderator control also involves making additional modifications, such as cutting and capping other lines leading to potential sources of water. LMES has completed draining and isolating almost all sources of moderator.

5.2.3 Install Purge and Vent System

A system for safely venting the generated gases is planned.

LMES is planning to install a purge and vent system together with a glovebox to handle any leaks during offgas system modification and venting operations. Positive system pressure is a significant departure from conditions existing during the last four years and changes various accident scenarios. LMES personnel indicated that at the present pressure, about 10 percent of the 2.1 kilograms of U-233 estimated to be in the gas phase could be expelled during a system breach. However, there is some uncertainty with respect to these estimates, and F_2 and UF_6 continue to evolve. Therefore, in the interim, a breach of the offgas system anywhere would result in a significant radiological and toxic chemical release to the environment. LMES plans to install a glovebox-type enclosure and ventilation at the tie-in point for the purge and vent system prior to connecting to the offgas system to protect workers.

5.2.4 Isolate Offgas System

Plans for safely isolating the offgas system include criticality considerations.

LMES plans to isolate and reconfigure portions of the reactor drain tank offgas system (e.g., closing the offgas system building isolation valve mentioned above). In addition to assuring that releases would be minimized or eliminated, this also assures that the moderator will not accumulate in the reactor drain tanks by water or condensate flowing back by gravity to them. These tanks are approximately 50 inches in diameter and are at a low point in the system, and it is strongly suspected that several kilograms of UF_6 are present in these tanks. LMES personnel indicated that UF_6 is at saturation, some in the gas phase and some solid. However, in the presence of water, it would react to form solid UO_2F_2 and HF. Each mole of water would produce two moles of HF; each mole of UF_6 would produce four moles of HF. These chemical reactions are highly exothermic, and an excess of water would result in a heated, highly corrosive solution containing many curies of radionuclides, as well as quantities of U-233 that would raise criticality concerns. It is conceivable that sufficient heat would exist to form steam and force much of this heated solution and gases in the system into an unanalyzed location. LMES understands the importance of excluding water and is working vigorously to preclude water entry by all practical means.

5.3 PLANNING FOR LONG-TERM ACTIVITIES

A number of additional activities will be necessary before decontamination and decommissioning can proceed.

LMES is planning longer term activities to recover from the existing situation and abate the aforementioned hazards. These include removing the deposit of uranium from the pit and removing the fuel salt from the reactor drain tanks as well as residual UF_6 in lines, valves, and other components. Downstream plans for recovery and removal operations that include liquefying the fuel salt and removing it from the building are less firm than those for addressing the buildup of gases in the offgas system. A full recovery may take years and by itself does not address decontamination and decommissioning (D&D), for which there is no committed funding. Other events can occur elsewhere in the facility if D&D is delayed indefinitely because radiolysis, corrosion, and aging continue in addition to loss of corporate memory. Due to the contractor merger to form LMES, most personnel associated with the MSRE when it was operational have since retired or are otherwise unavailable. Many of the personnel who were involved in later years are similarly unavailable, and required records from both periods are not well organized, or are incomplete. Much of the existing equipment, instrumentation, and controls associated with operating the reactor or maintaining the MSRE in standby are not suitable for a controlled reheat and removal of the salt mixture.

5.4 REMOVAL AND STABILIZATION ACTIVITIES

Material removal and stabilization will require design of some containers and equipment.

Apart from requalifying existing equipment or replacing it, prior to removing the salt mixture from the core drain tanks or the uranium deposit from the filter, LMES must design and construct special "geometrically favorable" containers. These will preclude criticality and keep moisture out of the stored material. It may not be possible to use the same design for both applications. LMES must also design or adapt a cask to transport the containers of salt mixture and deposit material, and must also devise additional equipment needed to perform or support safely liquefying and removing the salt mixture.

There is a different salt mixture in a flush tank adjacent to the two drain tanks. Because of its much lower fuel and radionuclide content, liquefying and removing the contents of the flush tank has a lower priority; however, it will be necessary to empty that tank before commencing D&D. Moreover, the salt mixture and possibly the uranium deposit will continue to evolve F_2 and generate UF_6 in the new containers, so it will be necessary to further process the contents to a more stable form. LMES indicated that conceptual design to stabilize the material at another facility has low priority.

5.5 POST REMOVAL CONDITIONS

After the material is removed and relocated to another facility, the MSRE will still represent a significant source of radionuclides. The removed material will pose criticality, radiological, and chemical hazards until it is completely stabilized and encapsulated.

Removing the material alone will not eliminate hazards.

5.6 RISK IMPLICATIONS

Failure to effectively recognize risk and fully understand existing conditions and reactions is at the core of the present situation. DOE cautioned its M&O contractors to check all ventilation and offgas systems where it was credible that deposits could occur. LMES personnel indicated that they knew of no reason that this phenomenon would occur at MSRE; they indicated that they did not suspect the mode of transport that occurred because it was caused by "new chemistry." However, LMES did not check MSRE at the time to determine whether the annual annealing operation had transported small crystals of MSRE fuel salt to the offgas system.

Facility operators must continue to be aware of changing conditions within their facilities.

6.0 SUMMARY

There are many unknowns and uncertainties associated with near-term and longer-term activities, unstable components and systems, credible events, and consequences of various accidents. By the year 2003, LMES plans to remove all but a few hundred grams of the nuclear material present. This is a long time to be in a recovery mode, considering the unknowns and uncertainties associated with this project. Many things can go wrong in addition to what has already happened, and line management should review the schedule to determine how it can be safely accelerated. Reevaluations of hazards should continue to be an important aspect of MSRE project activities. Removing, stabilizing, and repackaging the bulk of the radioactive and toxic materials present is essential to ensuring the safety of MSRE and the prevention of additional unexpected chemical phenomena and hazards.

Hazards should continue to be evaluated throughout the process of removing material from the Molten Salt Reactor Experiment.

This combination of unknowns and uncertainties, coupled with past history, relatively slow progress, and underfunding, requires that the risk associated with MSRE be constantly reevaluated to ensure that workers, the public, and the environment are adequately protected. Line management should safely accelerate the planning and implementation of the removal of reactive gases, uranium deposits, and fuel salts. Until DOE/Oak Ridge and LMES have demonstrated and verified that the activities to support the risk reduction strategy for MSRE are successful, the Office of Oversight will continue to monitor progress and safety performance at MSRE until the major hazards are abated.

Consistent with safety, opportunities for accelerating the removal of material should be explored.

APPENDIX A

CHRONOLOGY OF MOLTEN SALT REACTOR EXPERIMENT SAFETY ISSUES

APPENDIX A

CHRONOLOGY OF MOLTEN SALT REACTOR EXPERIMENT SAFETY ISSUES

1965 - 1969	Molten Salt Reactor Experiment (MSRE) operates first with a core using uranium highly enriched in uranium-235 (U-235), then with a core using U-233 and plutonium.
1969	Fuel salt of second core is drained to reactor core drain tanks; core is flushed and flush salt drained to flush salt drain tank.
1970	Piping and components modified and sealed to isolate stored fuel salt from "undesired outside influences (principally water)."
1971	Annual annealing begins to recombine radiolysis products; procedure requires opening reactor core drain tank isolation valve during annealing and closing it afterwards.
1972 - 1989	Annual annealing continues; surveillances and engineering evaluations uncover no significant safety issues at MSRE. Personnel identified that the offgas system isolation valve was inoperable. Insufficient radiation surveys conducted to find elevated radiation readings.
1985	During offgas system breach for maintenance, puff of white vapor noted.
1989	Elevated radiation readings discovered in North Electrical Service Area (NESA) (a basement area adjacent to the reactor core drain tank offgas system). Annual annealing discontinued without documented safety basis for this change.
1990	The Department of Energy (DOE) informs other management and operating contractors about multiple critical masses of plutonium in ventilation ductwork at Rocky Flats; requests sites to check for accumulations of uranium and plutonium as applicable in ventilation, offgas systems.
1990 - 1993	Occasional venting of reactor core drain tank offgas system to avoid pressure going positive.
December 1992	Safety analysis report update program report issued; does not address observed increase in dose rates in NESA and resultant decision to cease annual annealing or potential for fuel salt crystals to migrate via any mechanism besides earthquake.
1993	Campaign to sample offgas system lines begins.
October 1993	EH performs spent fuel vulnerability assessment for MSRE; report lists "Radioactive Material Migration within the Molten Salt Reactor Storage Tanks" as the first of six such

vulnerabilities at Oak Ridge National Laboratory. EH did not discover that the offgas isolation valve is open or that there is a large deposit of uranium outside the MSRE building.

April 1994	Off-normal Occurrence Reporting and Processing System (ORPS) report indicates finding "reactive gases (UF_6 and F_2)...(in) concentrations higher than suspected."
April 1994	During EH visit to K-25 about criticality safety of deposits of uranium, a DOE/Oak Ridge criticality safety engineer indicates problems exist at MSRE. However, he focuses on aging of facility; e.g., heaters used to melt fuel salt may fail. Neither he nor EH raises the issue of potential criticality at MSRE due to significant migration of fuel.
April 1994	In an internal note, a DOE/EH criticality safety engineer raises the possibility of criticality in the reactor core drain tanks due to water. However, he considers this potential low because he is unaware that there is a source of water that can flood these tanks via a single pipe break in the reactor core drain tank offgas system. (Explained in next chronological item.)
May 1994	Contractor investigation discovers significant deposit of uranium in the auxiliary charcoal bed cell (a water filled pit outside the MSRE building). The deposit is in a charcoal bed filter, part of the reactor core drain tank offgas system. Further investigation reveals that the isolation valve cannot be closed. The level of water in the pit is high enough that a pipe break at the inlet to the filter would provide an insoluble drain path to the reactor core drain tanks and more than sufficient water for criticality.
July 1994	Deposit in pit characterized by radiation readings and back-calculations to exceed three minimum critical masses. Office of Nuclear Safety Site Representatives learn of criticality concern, tour facility, and raise concern that more than 50 people are permanently housed in the MSRE building which did not even contain a criticality alarm system. Site Representatives recommend evacuation of personnel from MSRE until criticality concerns are resolved.
July 1994	DOE/Oak Ridge orders evacuation of all personnel from MSRE building, water level is lowered to below filter inlet, criticality alarms are installed, and toxic gas monitors are installed. Unreviewed safety question determination is issued.
July 1994	EH team visits site; reviews status of immediate corrective actions. Progress is slow; e.g., pit water level is still just below filter inlet because evaluations of the negative effects of removing the water which is acting as a heat sink from around the deposit of uranium are incomplete. (Heat sink may be preventing autocatalytic chemical reactions between F_2, C, C-F compounds, etc.)
August 1994	ORPS report updated to reflect new information; event still categorized as Off-Normal.
September 1994	Chemical reaction evaluations completed; potential for a runaway reaction is unlikely. Water level in pit is lowered to below that of the deposit, thereby eliminating the reflector from the region of the deposit and thus the potential for criticality.
November 1994	Practically all water pumped out of pit.

November 1994	MSRE Uranium Migration Mitigation Review Panel issues report. Recommendations "address improvements in the efforts related to fuel salt character, chemical investigations, criticality protection, project organization, and long-term disposal."
January 1995	Defense Nuclear Facilities Safety Board (DNFSB) and DOE hold teleconference on MSRE safety issues.
February 1995	DNFSB issues report on MSRE safety issues. Report indicates that key programmatic issues are "funding for this initiative beyond fiscal year 1995 and the lack of urgency with respect to elimination of water sources."
May 1995	Gas pressure in reactor drain tank offgas system goes positive; contractor decides not to vent excess.
August 1995	EH-22 team visits site to determine progress of corrective actions, near-term remediation, and plans for longer term activities. Progress is slow. For example, reactor drain tank offgas system isolation valve has not been closed and alternate valves to partition and isolate this system have not been closed.
September 1995	Gas pressure reaches seasonal maximum, about 1.5 psi above atmospheric. Feeling is that as the weather cools, this pressure will begin to decrease as it has in past years.

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APPENDIX B

MOLTEN SALT REACTOR EXPERIMENT SYSTEM CONDITION

APPENDIX B

MOLTEN SALT REACTOR EXPERIMENT SYSTEM CONDITION

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APPENDIX C

URANIUM DISTRIBUTION IN MSRE

APPENDIX C

URANIUM DISTRIBUTION IN MSRE

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APPENDIX D

TEAM COMPOSITION

APPENDIX D

TEAM COMPOSITION

Deputy Assistant Secretary, Oversight:	Glenn S. Podonsky
Associate Deputy Assistant Secretary:	Neal Goldenberg
Director, Office of Environment, Safety, and Health Evaluations:	S. David Stadler
Review Team Members:	Ivon E. Fergus, Jr. Patricia R. Worthington Bruce A. Breslau

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