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Decommissioning Challenges at the Molten Salt Reactor Experiment Site

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MSRE Aerial View

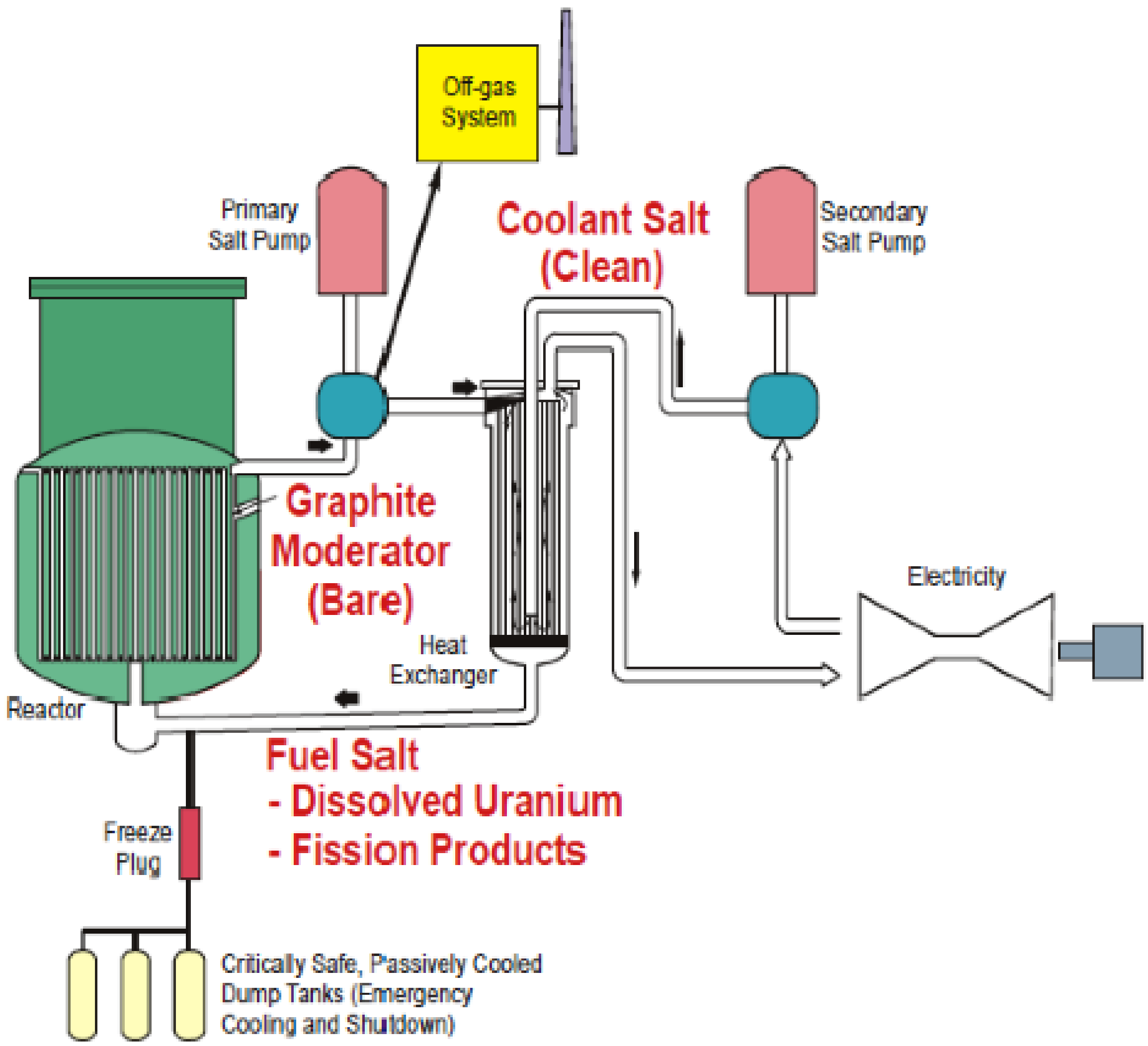
Overview of MSRE Facility

- 8 MW DOE test reactor operated from 1965 - 1969 to demonstrate molten salt breeder reactor technology
- Nuclear Category 2 facility
- MSRE originally fueled with ~218 kg of uranium, consisting of 30% U-235 and 70% U-238, to the carrier salt
- Later refueled with ~37 kg of uranium, consisting of 80% U-233 and 20% U-235—the first nuclear reactor to operate with U-233
- ^{239}PuF was used to demonstrate flexible reactor operations near the end of the U-233 fuel campaign

Nature of Reactor Operation

- Reactor used liquid fuel formed by dissolving UF_4 fuel in a carrier salt composed of a mixture of LiF, BeF_2, and ZrF_4
- In reactor vessel, fuel salt was circulated through channels of graphite to provide geometry/moderation necessary to sustain a nuclear chain reaction
- Heat was transferred from fuel salt to secondary coolant salt in the primary heat exchanger (at temperatures > 600°C)
- Coolant salt similar to the fuel salt, except that it contains only LiF (66%) and BeF_2 (34%)
- Coolant salt passed from the primary heat exchanger to an air-cooled radiator, a coolant salt pump, and then returned to primary heat exchanger

Nature of Reactor Operation (continued)



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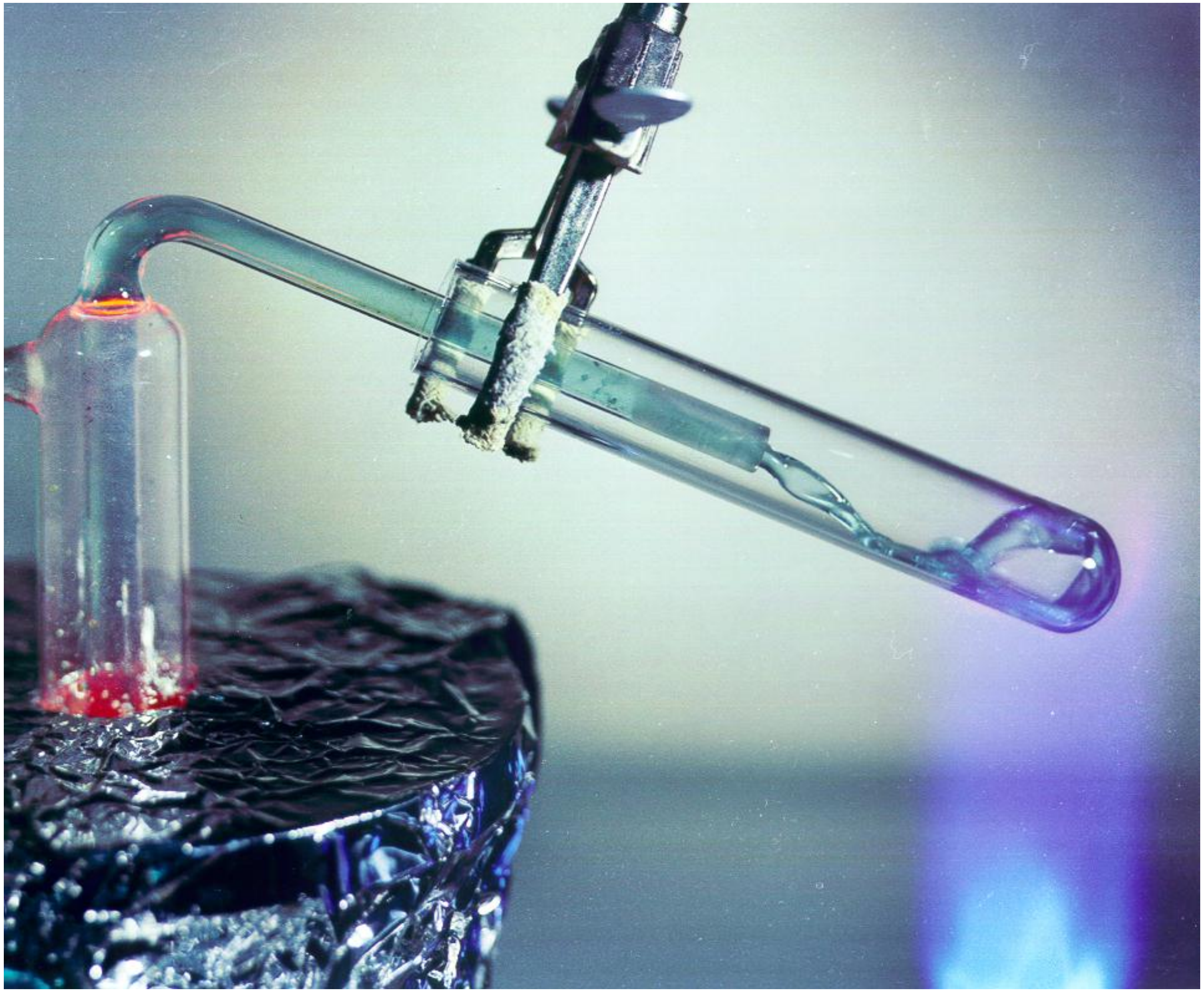

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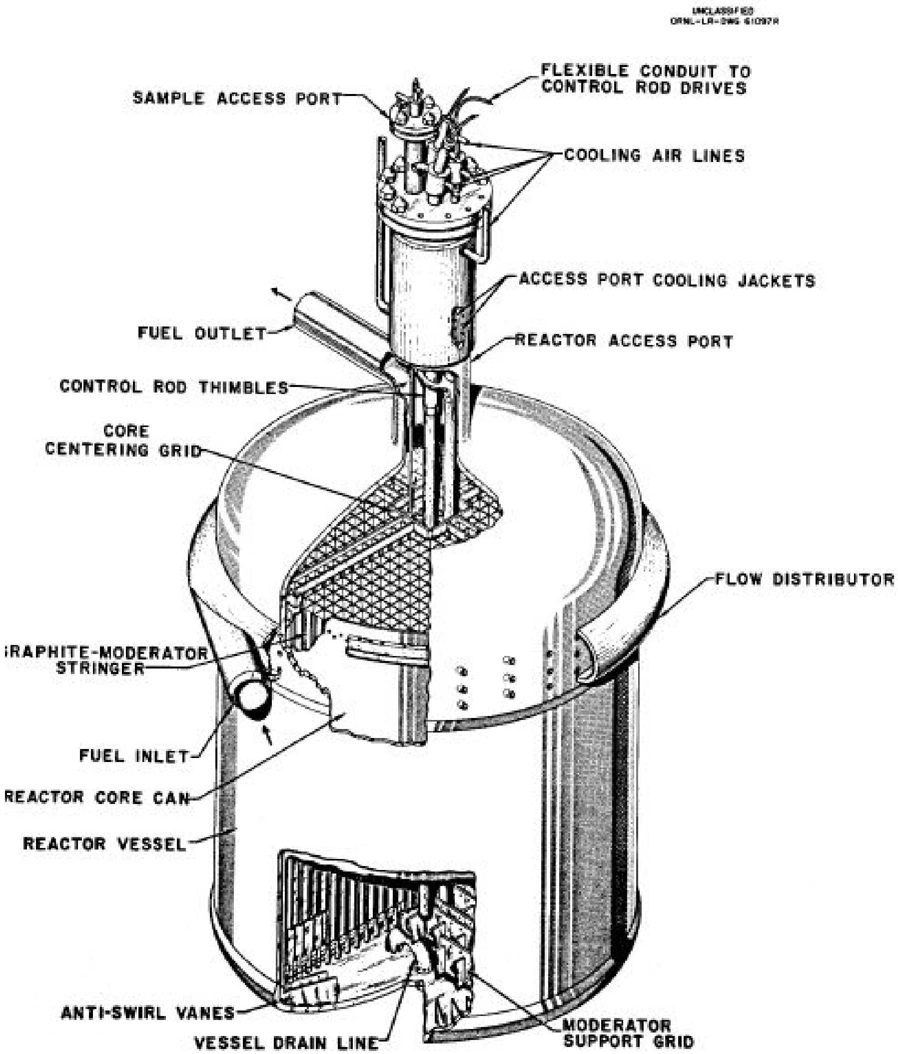
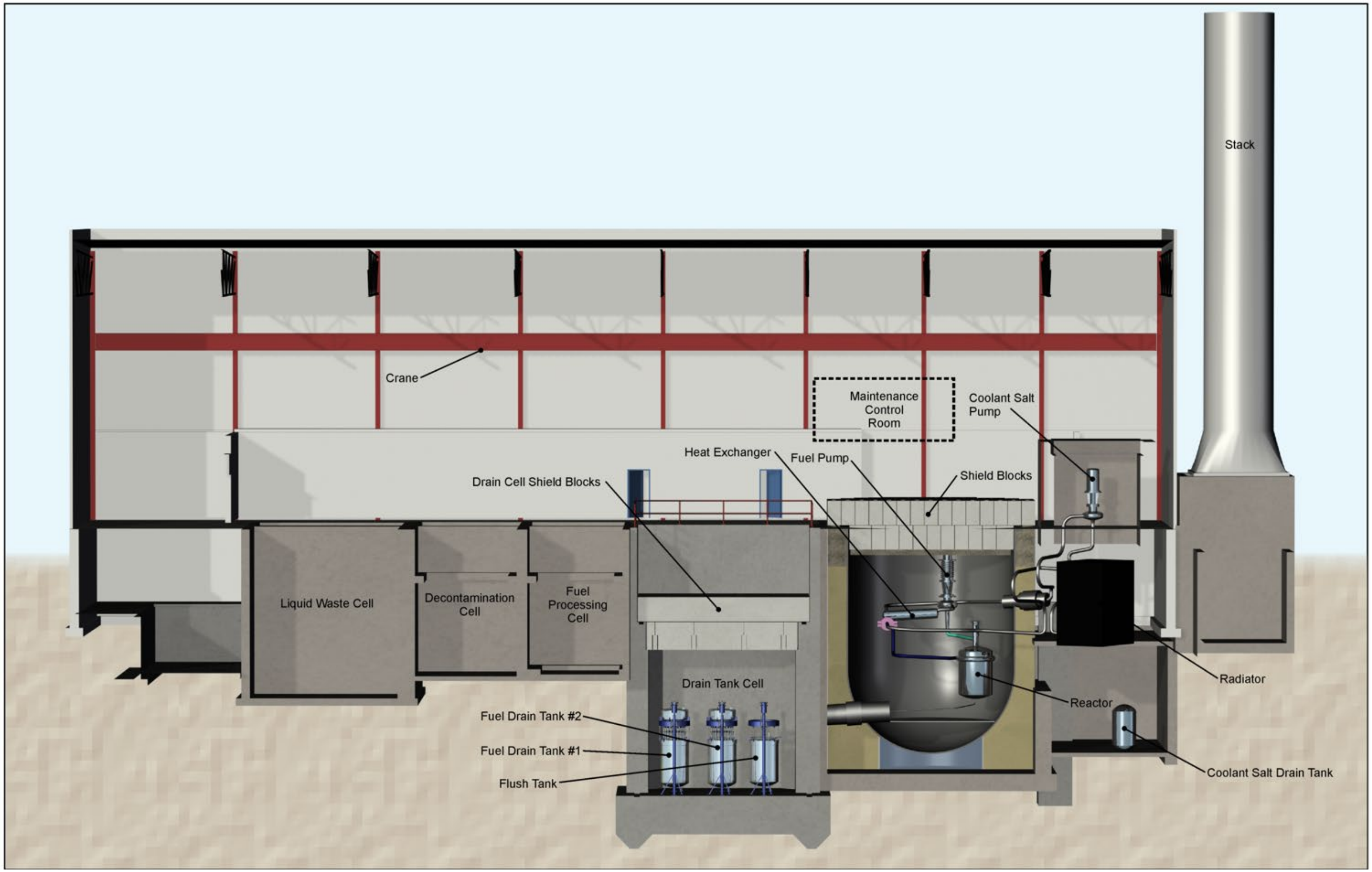


Fig. 2.2. Reactor Vessel.

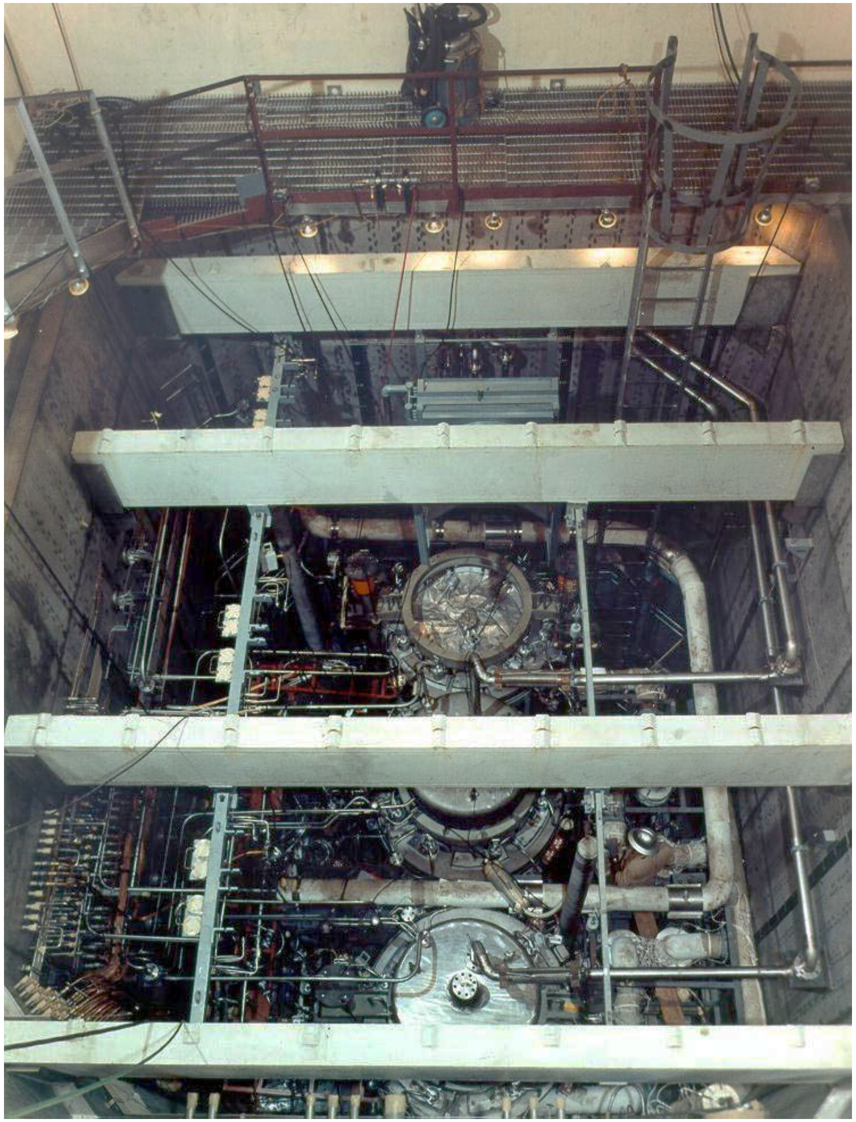
Current Conditions of Fuel Salt

- Salts cooled and solidified into a monolithic mass; radiolysis from beta/gamma radiation constantly generates fluorine gas
- Residual fuel salt remains stored in 2 fuel drain tanks (each 80 ft^3)
  - Uranium present at <2.5 kg U per tank
  - Fission/activation product radioactivity predominantly (98%) from Cs-137 and Sr-90; volatile fission products treated via off-gas system (not retained in fuel)
  - Actinide radionuclide inventories by U-232 (via impurity) and U-233 decay chains; Tl-208 and its 2.6 MeV gamma (100% intensity), exposure rates ~37 R/h per gram of salt
- Flush salt (similar composition to coolant salt) contains less than 2% of uranium and fission products; drained into fuel flush tank

MSRE Cross-Section View



Fuel Drain Tanks/Fuel Flush Tank in Drain Tank Cell



Decommissioning Options*

- Once a facility has reached the end of its operational life a decision must be made regarding its future
- MSRE decommissioning options have been considered and evaluated for decades
- Decommissioning options include:
  - DECON
  - SAFSTOR
  - ENTOMB (also called in situ D&D)

* These decommissioning options are commonly used for commercial nuclear reactors; recognizing MSRE was a DOE test reactor

DECON

- Generally, DECON most popular option because it settles the decommissioning issue once and for all
- Facility is decontaminated and/or dismantled to levels that permit release; contaminated equipment is either decontaminated or removed as radioactive waste
- Key issue – Does salt waste have a disposal option?

SAFSTOR

- SAFSTOR involves maintaining the facility in a safe condition over a number of years, by performing surveillance and maintenance (S&M) activities—eventually followed by D&D
- SAFSTOR is considered deferred dismantlement, while DECON is prompt dismantlement
- To prepare facility for SAFSTOR, used fuel is removed from the reactor vessel and radioactive liquids are drained from systems and components—leaving the facility in a stable condition
- Surveillance and maintenance activities continue to be performed at MSRE

ENTOMB

- ENTOMB involves encasing contaminated portions of the facility in a structurally long-lived material, e.g., grout
- ENTOMB concept is to isolate the contamination from the environment, mainly by keeping water out of the containment
- Most likely source of potential exposure is due to inadvertent leakage of contamination from an entombed structure
- Residual radioactivity levels must be acceptable for release following an entombment period (e.g., 60 y, 100 y, 300 y)
- In situ D&D (ISD) has many similar attributes to ENTOMB

Drivers to Take Decommissioning Action

- MSRE is an aging facility—while S&M provides a measure of risk mitigation, ultimately DOE and stakeholders desire more permanent and lasting decommissioning outcome
- Remove/mitigate risk to ongoing ORNL operations/mission; e.g., environmental releases to groundwater
- Fuel drain tanks and associated components are protected from groundwater due to sump pumps that must remove groundwater (FDTs are below the natural water table elevation)
- Physical barriers including concrete cell walls and stainless steel liner must be maintained to ensure integrity of tanks and piping

Major D&D Activities Performed To-Date

Timeframe	Notable Activities
1971-1989	Routine maintenance and "salt annealing" (to prevent F_2 accumulation in drain tank cell)
1994	Positive confirmation of "uranium migration" Failed off-gas valve resulted in notable uranium deposits in off-gas charcoal bed
1995-2000	Uranium denaturing and removal, install Reactive Gas Removal System
2001-2008	Restoring salt chemistry, defueling, attempt salt transfer
2008-present	Reactive gas management operations, surveillance & maintenance

Uranium Fuel Recovery—Auxiliary Charcoal Bed

- Due to radiolysis process in fuel salt, high concentrations of fluorine (F_2) and uranium hexafluoride (UF_6) gases were present in the off-gas system piping
- Estimated 2 to 3 kg UF_6 migrated to auxiliary charcoal bed (ACB), and another 1 kg migrated to other 4 charcoal beds via MSRE off-gas system
- Majority of the uranium-laden charcoal material residing within the ACB has been safely removed using uranium deposit removal system, remote equipment, and long-handled tools
- Estimated 4 kg of uranium stored in charcoal canister within a concrete shielded cask; awaiting processing and disposal

Uranium Fuel Recovery—Fuel Salt

- U fuel recovery tasks were completed from 2004 to 2008:
  - salts were melted and chemically treated,
  - molten salts were fluorinated to remove uranium,
  - uranium was condensed into cold traps and transferred to chemical (NaF) traps, and
  - NaF traps loaded with the uranium were transferred to an ORNL building for storage
- Fuel salt in two fuel drain tanks and flush salt in flush tank melted for removal using a process known as "pool melt" using a heated probe to melt the salt
- Hydrofluorination process conducted by sparging the melted salt with mixture of hydrogen fluoride, hydrogen and helium to restore chemical balance in the salt; ensuring uranium is in the form of UF_4

MSRE-Specific S&M Activities

- Routine maintenance activities are required to ensure the proper functioning of:
  - Facility ventilation systems
  - Radiological monitoring equipment
  - Facility systems such as heating and air conditioning units
  - Overhead cranes
- Maintaining Reactive Gas Removal System (RGRS), which has been in operation since 1996 to remove reactive gases containing uranium material (UF_6) and other reactive gases (F_2, MoF_6, HF, etc.); capturing effluent on NaF/alumina traps

Upgrades for Long-Term S&M

- Planned general facility upgrades include:
  - Sump pump systems
  - Electrical distribution system
  - Fire detection and suppression
  - Process monitoring systems
  - Roof and drainage
- Continuous Purge System (CPS) replacing RGRS
  - Continuous gas sweeping design using nitrogen to dilute and purge fluorine from each of the tanks, then further dilutes the gas mixture with a fan, prior to discharge external to the MSRE high bay
  - More automated operations; lower risk to facility workers

Decommissioning Challenges

- Aging facility/equipment
- Challenging working environment due to radiological/hazardous conditions—requires personal protective equipment (PPE), special tools, portable maintenance shield (PMS)
- Salt waste form—Is there an ultimate disposition pathway/home for waste, like WIPP?

Aging Facility and Equipment

- Potential breach of drain tanks is considered to be highest risk at MSRE
  - Would result in F_2/HF release, difficult to isolate
  - Evaluate need for tank integrity measurements
  - Assess extent of tank corrosion on thinning of the tank walls and heat exchanger thimbles
- Relying on ventilation system that is original to the facility for safety significant functions
- Piping and tubing containing holdup infrequently monitored

Aging Facility and Equipment (continued)

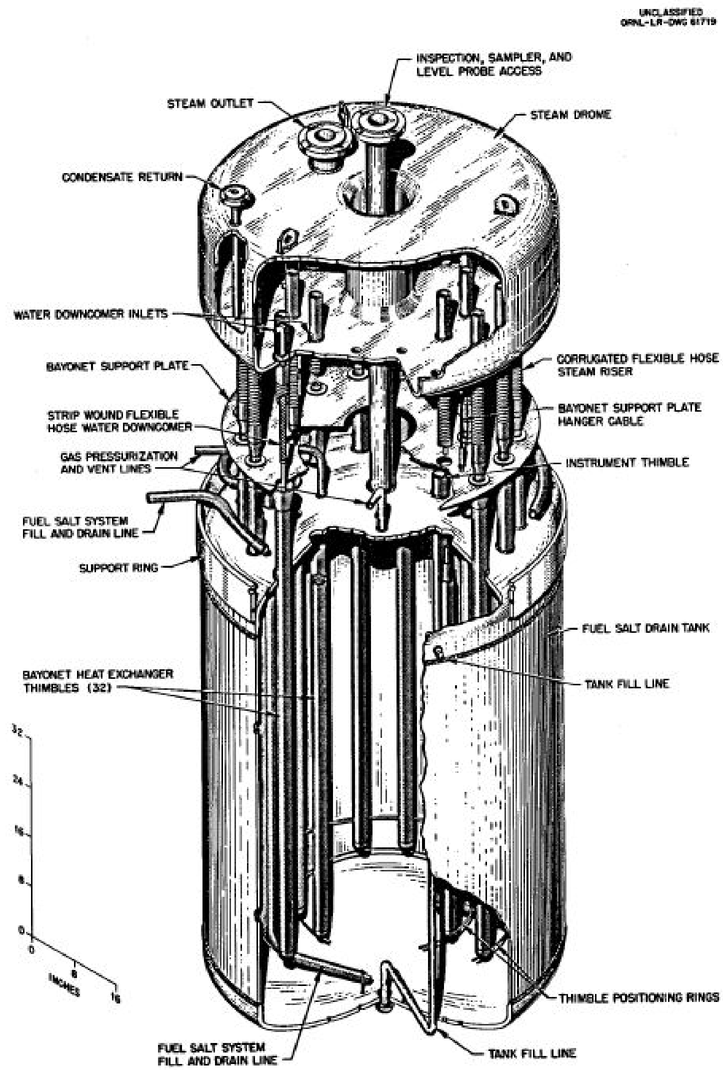
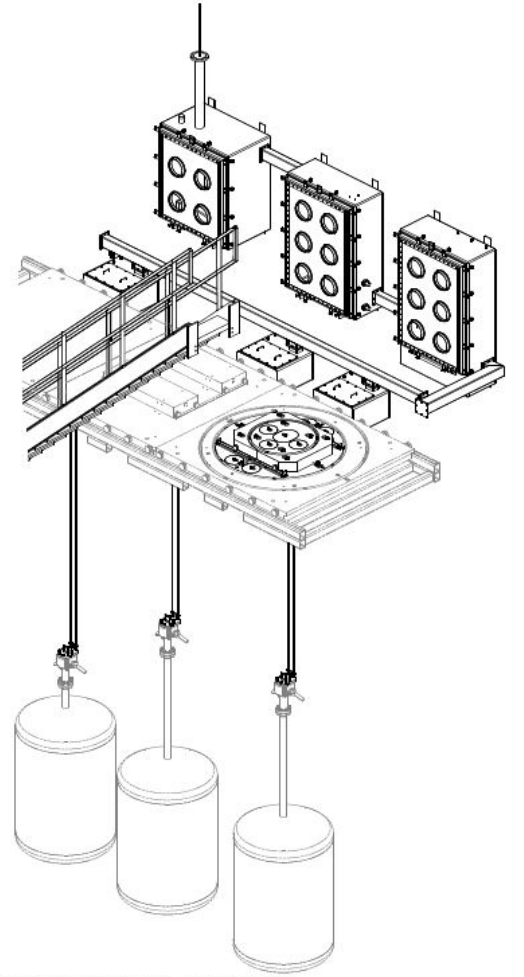


Fig. 2.6. Fuel-Salt Drain Tank.

Challenging Working Conditions

- Performing D&D with portable maintenance shield
  - Need adequate ventilation flow rate when the PMS openings are increased to permit access to drain tank pit
  - PPE due to fluorine gas hazard and rad contamination
- High radiation areas—largely due to Cs-137, and many other rad constituents fission products and U-232 progeny (Tl-208)
  - FDT#1 has 35 ft^3 salt - 6800 Ci (3000 Ci of Cs-137)
  - FDT#2 has 31 ft^3 salt - 5700 Ci (2500 Ci of Cs-137)
  - FFT has 68 ft^3 salt - 200 Ci (2500 Ci of Cs-137)
  - Exposure rates from FDT#1 and #2 very high (>1000 R/h)—requires use of remote tools and significant shielding

Portable Maintenance Shield



Salt Waste Form/Uranium Disposition

- Major waste streams to be generated by the MSRE D&D project:
  - Fuel salt, and salt-contaminated components
  - Uranium-laden charcoal
    - Collection canister
    - Remaining uranium in the charcoal beds
  - Asbestos, lead, and PCB-contaminated equipment
- How to disposition the uranium-laden charcoal?
- What salt waste form will be accepted at WIPP?
  - Fissile material content limit
  - Passive fluorine management

WIPP Disposal

- Preliminary analysis shows that MSRE salt waste meets WIPP waste acceptance criteria

Regulation	RH Waste Limit	FDT#1 Salt	FDT#2 Salt	FFT Salt
LWA Sec 7(a)(2)	Specific Activity <23 Ci/L	9.43 Ci/L	9.57 Ci/L	0.167 Ci/L
LWA Sec 2(18)	TRU Activity Density >100 nCi/g	13,696 nCi/g	13,711 nCi/g	275 nCi/g

- “As-received,” waste container gas generation*
  - — Waste containers required to be vented
  - — MSRE salt F_2 generation management needs to be addressed
    - Passive getters, accept F_2 release, entrained getters

*Flammability and explosiveness are not anticipated to be technical issues of concern for MSRE salt waste

Conclusions/Recommendations

- SAFSTOR approach is working
  - Facility in safe, stable condition
  - Spending $$$ while delaying decision on salt waste disposal
- ENTOMB optimizes SAFSTOR condition for next 50 years
  - Reduces potential for environmental releases
  - Land use controls required to maintain protectiveness
  - Best alternative if salt waste not approved for WIPP
- DECON addresses salt disposition and eliminates future liability
  - Technical challenges exist for salt removal and WIPP disposal
  - Ultimate solution for addressing environmental risk at ORNL via long-term salt disposal at dedicated facility