HTGR History Lesson

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NRC/DOE MHTGR Technology Course

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ML-1

- Mobile-Low power, Unit 1, the first gas turbine reactor; funded by US Army. Its mission? To supply energy near the battle field (e.g. a field hospital).

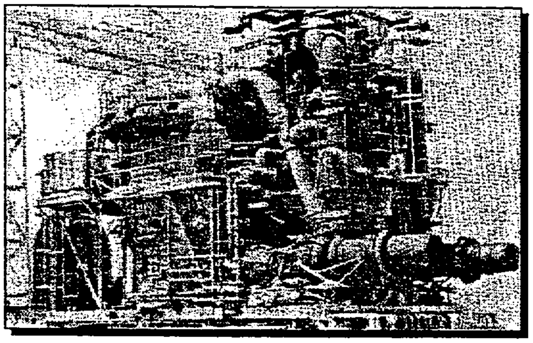
- Desired electrical output was 330 kW, delivered 650°C nitrogen at 20 atm. to a small turbine. Used a water moderator; refractory metals for cladding of $U0_2$ and BeO pellets.

  1. Design initiated 1957, ML-1 built at NRTS (Idaho), shut down in 1963, never produced a net power output.

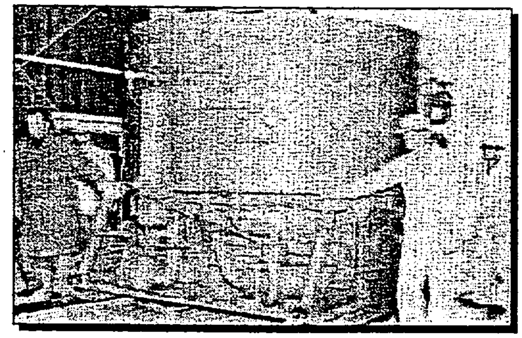
Rt/Rc = 1 -S(DP/P) ~ 0.9

D-33

GAS TURBINES OPERATED WITH NUCLEAR HEAT SOURCE



Open Cycle Gas Turbine
Test Facility For Aircraft
Nuclear Propulsion (1958-61)



Mobile Closed-cycle Nuclear
Gas Turbine Power Plant (1961-65)

J-290(2)
11-22-94

LESSONS LEARNED

1. Gas temperature and pressure must be sufficiently high to overcome the inevitable mechanical loss and flow inefficiencies degrading the ideal Brayton cycle.

2. Refractory metals insufficient to protect fuel and deliver high temperature gas. What seems best today is a graphite moderator and ceramic fuel.

3. Both the turbine and compressor must be sufficiently large that by-pass flows due to rotor clearance can be minimized in proportion to total flow.

4. Parasitic pressure drops in ducts, heat exchangers, plenums, diffusers, and anywhere else must be minimized.

Gas Turbine Background

- ML-1 operated unsuccessfully 1962-1963.
- In February 1970, S.B. Hosegood and others published a paper entitled "Dragon Project Engineering Studies on the Direct Cycle HTR." This study identified problem areas and assessed the effects of heat exchanger performance, pressure drops, design configurations, and gas temperature limits.
- A helium turbine plant in Oberhausen, Germany (1976), was fossil fuel fired and had an inlet temperature of 750°C. Turbine size and other major components were appropriate to an HTGR-GT plant. For successful operation redesign and replacement of the bearing system and the rotor were necessary, but system pressure losses were higher than estimated resulting in power output less than the rated 50MW(e).

Gas Turbine Background, cont'd.

- In the late 1970's at Julich, Germany, the High-Temperature Helium Facility (HHV) was operated to an helium outlet temperature of up to 1000°C to test ducts, heat exchangers, valves, and insulation. The turbine was sized to represent an output power of 300MW(e). An oil ingress while in cold condition penetrated duct insulation. Removal proved difficult.
- In the early 1980's General Atomic considered a helium turbine power conversion system for its large HTGR design but chose to remain with steam because a clear economic advantage was not indicated.
- In the mid-1980's Professor Larry Lidsky of MIT explored the combination of a small HTGR with helium turbogenerator and, working with the German pebble bed version of the MHTGR, directed a thesis on this subject (Staudt and Lidsky).

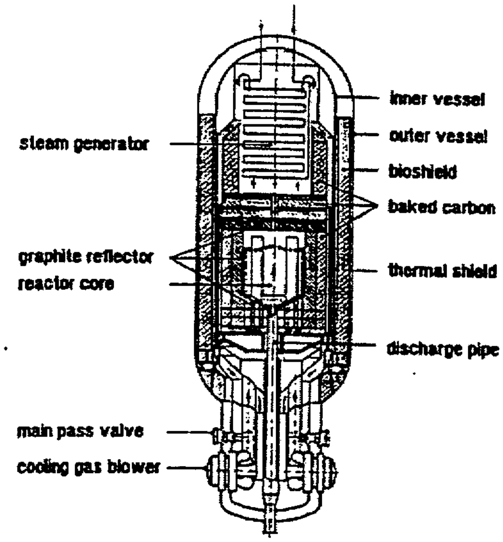
AVR PEBBLE BED REACTOR

The attractive concept of a reactor core in the form of a helium-cooled pebble bed was first demonstrated at Julich, Germany, when the 15MW(e) AVR went critical in August 1966. Initial power operation was reached in 1968 with a helium outlet temperature of 750°C. It was raised to 950°C in 1974.

The AVR operated successfully for 22 years, during which time it recovered from a large ingress of water from a leaking steam generator during a shut down, demonstrated very low maintenance doses, and successful ATWS test response.

The pebble bed concept was also studied by Sanderson and Porter in the US in the 1959 to the 1962 time period but was terminated by the AEC in favor of the Peach Bottom program.

LAYOUT OF THE AVR



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LESSONS LEARNED

1. Over its lifetime of 22 years, the information gained from the AVR has supported the development of the modular concept for HTGRs, both for pebble bed and prismatic fuel.

2. Information and demonstrations in reactor operations, (including transient and accident response), materials, (including fuel, graphite, ceramics, and metals), and reactor design, (including control, pebble bed fuel manufacture and handling, vessel and auxiliary systems) has been immense and supports the rekindled interest in gas-cooled nuclear power.

THTR
(Thorium High Temperature Reactor)

Design Power 300 MW(e), operated from June 1987 to October 1989 when shut down for inspection. Resolution of safety issues achieved, but a decision to decommission was made because of "institutional" issues.

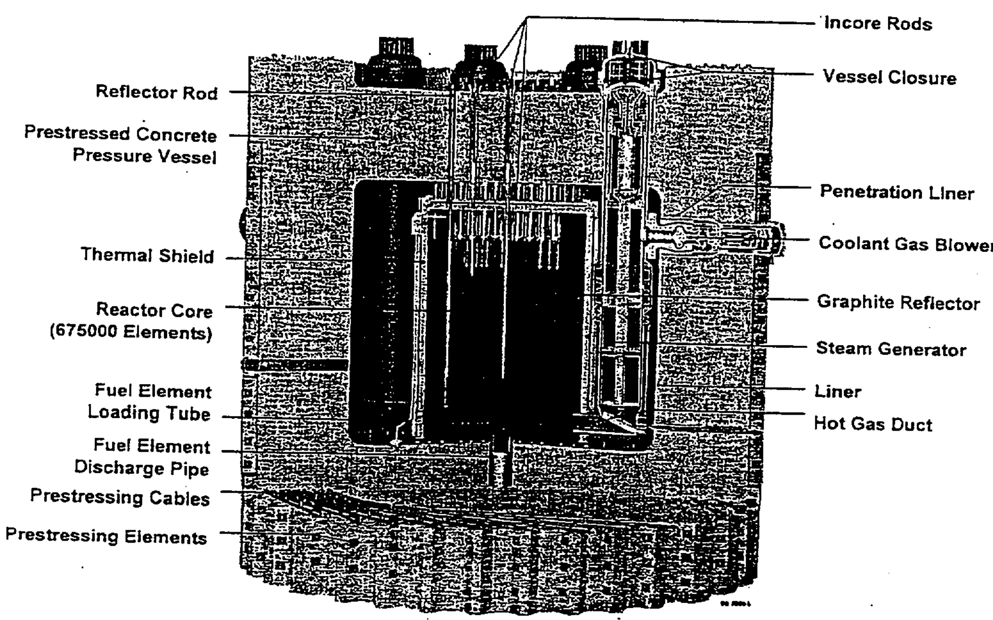
Used an integral cooling circuit within the PCRV with downward flow, with core supported by structural graphite. Emergency removal of decay heat by two independent auxiliary circulators.

Source term for accident analysis was unmitigated rupture of largest tube carrying helium (65 mm) outside the PCRV. A rectangular reactor building was capable of 1.6 bar overpressure to provide third barrier protection with controlled ventilation to a stack, with smaller releases being filtered first.

LESSONS LEARNED

- Very low maintenance doses
- Control rod drive into pebbles eventually not a problem
- Reliability of on line refueling and pebble discharge
- Mal flow distribution in large diameter bed
- Problem with thermal barrier attachment in cross ducts
- Costly delays by major redesigns to meet licensing requirements

LAYOUT OF THE THTR



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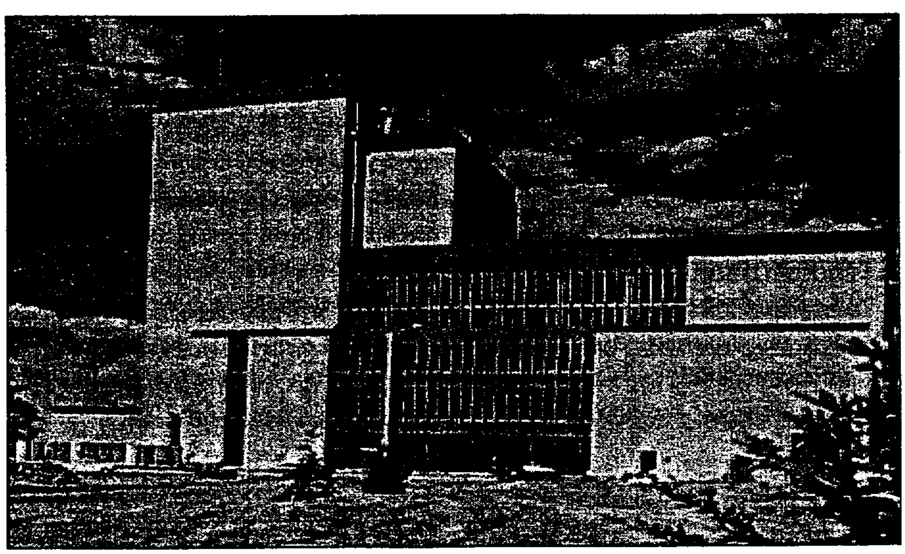
Fort St. Vrain History

General Atomic entered into a contract with the Public Service Company of Colorado in 1965 for a 330MW(e) HTGR nuclear generating station for which a construction permit was issued in September 1968. Although the project was part of the AEC's power demonstration program, only $40 million was made available, thus the principle research and development costs as well as certain unpredicted commissioning costs were the burden of General Atomic. An Operating License (No. DPR-34) was issued by the AEC on December 21, 1973, but restricted power to 40% of rated. On October 1978, Amendment 18 to the operating license was issued permitting a rise to 70%. Although testing at 100% was performed in November 1981, the facility was closed permanently in 1989 due to multiple causes and never sustained an annual availability of greater than 30% during its ten years of commercial operation. O&M costs were exceeding its revenue.

1

FORT ST. VRAIN
GAS-COOLED NUCLEAR REACTOR
330 MW(e)CAPACITY



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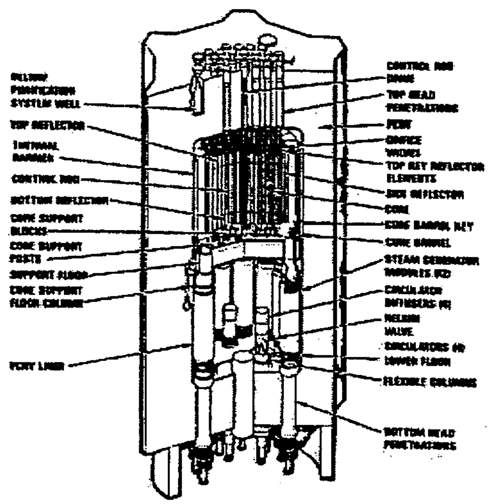
FORT ST. VRAIN PCRV, CORE AND PRIMARY SYSTEM



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Design Basis Accidents

Two design basis accidents were considered. The first was a rapid depressurization through a 100 square inch area, arbitrarily analogous to a large pipe break in a light water reactor. The second was a failure of all forced circulation resulting in core heat up, mitigated by manual vessel depressurization to protect its integrity from convective heating and by heat removal by the PCRV liner cooling system. In both cases, accident progression, siting parameters and emergency planning considered the delay in fission product release demonstrated for HTGR particle fuel. For example, the two-hour iodine dose criteria for water reactors was not relevant.

Reactor Building

The reactor did not have an independent, pressure retaining containment building following the practice of water reactors. Rather, a low-pressure confinement building in combination with the PCRV was licensed as sufficient mitigation for the design basis accidents. Early pressure pulse was vented through building louvers, while smaller and later flows, with more fission products flows were filtered through charcoal.

Licensing Criteria

Licensing criteria used for water reactors during this time period was adapted for HTGR including the General Design Criteria, Regulatory Guides, and applicable industry codes and standards.

Temperature Fluctuations

In late 1977, core outlet temperature fluctuations were observed during the plant's rise to power. Its cause was due to shifting nonuniformities in pressures and temperatures in gaps between fuel and reflector columns and was solved by devices that restrained the upper end of the columns from lateral motion.

Water Bearings for Helium Circulators

In a unique design selection all four helium circulators used water as a bearing lubricant. Water was chosen instead of oil in a misguided and unnecessary effort to avoid carbon dust. A highly complicated system was installed to assure bearing integrity, but often malfunctioned with the consequence that substantial amounts of water were injected into the hot core. The graphite and fuel materials successfully withstood these challenges, but their possible degradation remained of concern. Replacement of the bearing lubricant with oil was explored but found to be too costly.

Graphite Fire Analysis

The disaster at Chernobyl in April 1986 caused a special concern about the potential for a graphite fire in graphite moderated reactors. The NRC staff and the ACRS jointly addressed this concern and concluded that the potential for fire, if any, would require a large supply and rapid flow of air through the core which could be imagined only if with the occurrence of large failures at the bottom and top of the PCRV. These would in effect cause a chimney. Both the staff and the ACRS found acceptable the proposal of the licensee that water could be used to flood the bottom region of the reactor building, thus providing a seal for the lower entry of air into the PCRV.

Steam Generator Problems

Near the end of its operational lifetime a leak occurred in a steam generator tube and small cracks were found in a header to one of the steam generators. This, in combination with the mentioned low availability and costly estimated repair to the circulator bearing system, precipitated the decision to terminate operation.

Other Problems

- Water emergency pump cavitation: one year delay
- Reserve shutdown system malfunction
- Hot helium bypass on control rods drives
- Environmental qualification
- Hot spot on core support floor

LESSONS LEARNED
Favorable

1. Far lower than expected fission product release from fuel to the primary system

2. Reactor physics and transient behavior agreed with predictions

3. Computer controlled fuel handling system

3. Helium purification system

4. Lateral core motion could be fixed by simple mechanical restraint devices at core top

LESSONS LEARNED, cont'd.
Favorable with Certain Qualifications

1. Both control rod and emergency shutdown systems performed as designed
2. Prestressed Concrete Reactor Vessel
3. Instrumentation and control systems
4. Steam generators
5. Steam generator dump system
6. Helium circulators
7. Accident analysis assumptions

LESSONS LEARNED, cont'd.
Unfavorable

1. Helium circulator bearing water supply system

2. Failure to perform adequate post irradiation examination of fuel