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HANFORD'S ROLE IN SPACE POWER

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Hanford's role in early space reactor development and testing ranged from thermo-electric and thermionic power systems, SP-100 test reactor fuels testing, the design and fabrication of the SP-100 ground engineering system test, thermal propulsion testing for the Multi-MW reactor, and the proposed Jupiter Icy Moons Orbiter (JIMO) reactor materials testing.

I. Early Space Reactor Development

Table 1 lists an extensive irradiation program that was conducted in the 1950's and 1960's to develop fuel pins for space nuclear reactors (Ref. 1). That program emphasized thermal reactor fuels and materials. Also examined were refractory metal clad uranium nitride (UN) uranium carbide (UC), uranium oxide (UO_2) and metal matrix fuels (UCZr and BeO-UO2). Weaver and Scott (Ref. 2), Gluyas and Watson (Ref. 3). Mayer (Ref. 4) et al. provided summaries and experiment descriptions of the irradiation experience with UN, UC, and metal matrix fuels. The UO_2 fuel irradiation data can be found in Chubb, Storhok and Keller (Ref. 5) and Kangilaski (Ref. 6). Based on this earlier work, UN and UO_2 fuels in conjunction with refractory metal cladding showed a high potential for meeting space reactor requirements (Ref. 7, 8, 9).

These tests suffered from the non-prototypic feature of having been irradiated in thermal rather than fast neutron reactors. Thus, the effects of fast neutrons on cladding properties were not simulated, and the fission rate distribution across the fuel diameter had a marked depression in the center of the fuel. Moreover, the length of the fuel column was quite small in many of the experiments. This results in highly uncertain predicted temperatures and powers due to complicated heat transfer paths and magnified effects of power peaking at the ends of the fuel columns in thermal reactors. These early tests indicated that, because of weight and neutronics considerations, Ta alloys are most practical with a system design using UN. Based on compatibility and strength considerations, Mo alloys were expected to meet performance requirements with either UO_2 or UN fuel. Nb alloys have the lowest creep strength and require a W diffusion barrier if used with UN. The extensive fabrication experience with Nb alloys tends to favor them as cladding materials, particularly for the first generation systems. Previous irradiation testing provided guidance for the selection of fuel and cladding candidates. However, each of the fuel/cladding combinations had one or more feasibility issues with it, such as high temperature UN swelling, fuel/cladding compatibility, and fast neutron damage to cladding materials.

II. SP-100 Space Reactor Development

Westinghouse Hanford Company (WHC) was deeply involved in the development of a 100-kilowatt electric reactor for space, called SP-100, funded jointly by the National Aeronautics and Space Administration, the Department of Energy, and the Department of Defense, specifically the Strategic Defense Initiative Office. Figures 1 through 6 show various aspects of the SP-100 program. The program was initiated in 1983 for the development of a compact nuclear reactor capable of producing electrical power in the range of 10 to 1000 kilowatt electric. This was a national program with contributions by the Jet Propulsion Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, the General Electric Company, Westinghouse Hanford Company, and a number of industrial suppliers. The mission of the program was to develop technology to support construction of a flight prototype in the mid-1990's.

Hanford's SP-100 activities included fuels testing, such as the design and fabrication of the EBR-II tests SP-1, SP-2, and SP-3, materials testing in EBR-II and FFTF, contractor reviews and fuels and materials development planning, QA plan development, pump design audit, and design and fabrication of the ground engineering system.. One of WHC's role in the SP-100 program was to prepare an existing Hanford Site reactor facility to accommodate the new space reactor for ground testing in a simulated space environment. Hanford was selected as the preferred site to conduct the test program in November 1985. Environmental and safety review documents were completed showing that subsequent operation will be safe and environmentally acceptable. Unusable equipment was removed from the facility, and an array of usable components from other programs was assembled to minimize the cost of facility modifications. The design and safety analysis activities were initiated as well as several lead procurements. WHC was involved in the irradiation testing of fuels and materials for the development of the SP-100 and other advanced space reactor designs. These tests also combined the efforts of

TABLE I. Early Nuclear Reactor Development.

Power Plant	Purpose	Power (MWt)	Operating temp. (K)	Period	Type	Converter	Development level
Rover	Propulsion	365-5000	2450	1955-73	Epithermal		Twenty rectors tested
Fluidized bed reactors	Propulsion	1000	3000	1956-73	UC		Demonstrated all components of flight engine 2 hours; ready for flight engine development
Gaseous core reactors	**Propulsion** electricity	4600	3000	1959-78	Thermal	Brayton	Cold flow, bed dynamics experiments successful
SNAP-2	electricity	3 kWe	920	1957-63	UC and ZrC	Mercury Rankine	Successful critical assembly of uranium fluoride
SNAP-8	electricity	0.5 kWe	810	1960-66	Uranium plasma	Thermo-electric	Development level; tested two reactors; longest test reactor operated 10,500 hours; precursor to SNAP-8 and SNAP-10A
SNAP-10A	electricity	30-60 kWe	975	1960-70	Thermal, uranium zirconium hydride	Mercury Rankine	Flight tested reactor 43 days; tested rector with thermo-electrics in 417 day ground test
Advanced Hydride Reactors	electricity	5 kWe	920	1970-73	Thermal, uranium zirconium hydride	Thermo-electric and Brayton	Tested two reactors; demonstrated 1 year operation; non-nuclear components operated 10,000 hours and breadboard 8700 hours

the national laboratories and industrial suppliers to supply the fuels and material irradiation data for reactor components. These tests supported the national space reactor programs including the SP-100 reactor and the development of direct electrical conversion thermionic fuel elements for advanced reactors. Not only did these tests provide data that eliminated lifetime and performance concerns; they also provided a conclusive demonstration that the national laboratories and industrial participants can effectively cooperate to solve the engineering challenges of space nuclear power. The best resources of Los Alamos, Oak Ridge, Idaho National Engineering Laboratory, Hanford Site, and industry were involved in preparing the specimens for the tests and analyzing the data. Irradiation testing results showed that the selection of a sound fuel and material system for further development for space reactors had every expectation of success. The feasibility issues were addressed by irradiation tests, SP-1, SP-2, and SP-3, designed and constructed by Hanford Engineering Development Laboratory (HEDL) and irradiated in EBR-II. The FSP-1 and FSP-1R tests were designed and fabricated by WHC for the Hanford Engineering Development Laboratory and irradiated in the FFTF. These tests were designed to provide irradiation data on UN fuel pins for the SP-100 space reactor program. These achievements were the basis of plans to continue and expand Hanford's role in space power fuels and materials testing with the Fast Flux Test Facility as the center of national testing capability (Ref. 11).

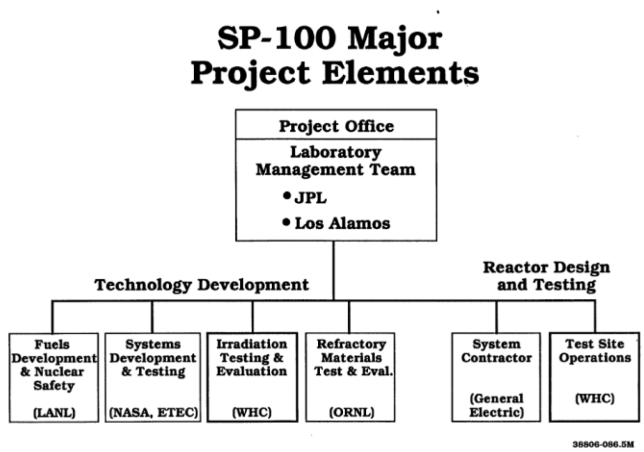

Fig. 1. SP-100 Major Elements

Fig. 2. SP-100 Potential Missions

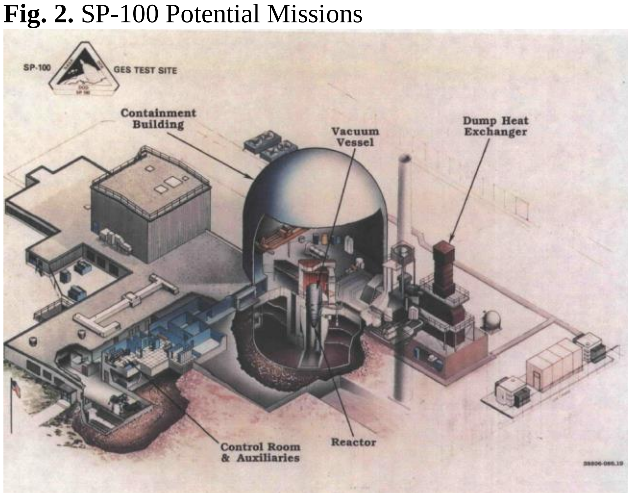

Fig. 3. SP-100 Ground Engineering Station at Hanford

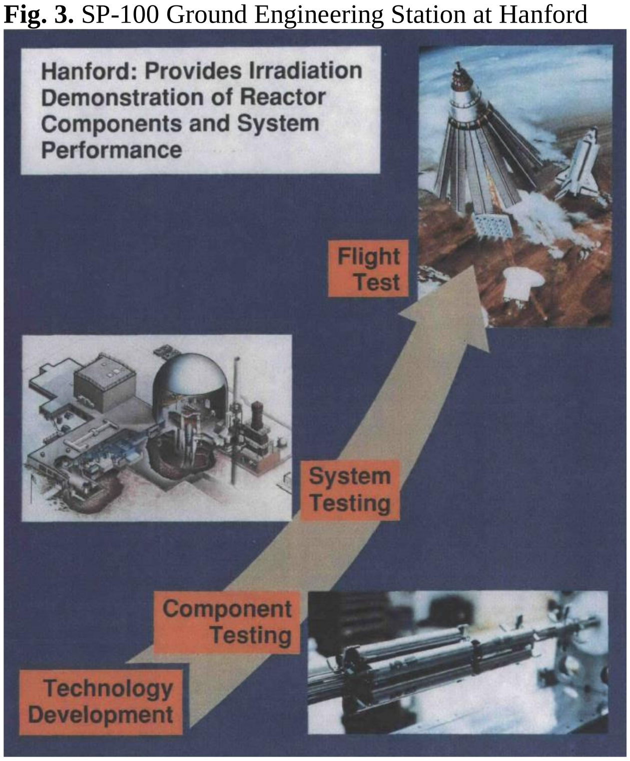

Fig. 4. Hanford's Role in SP-100

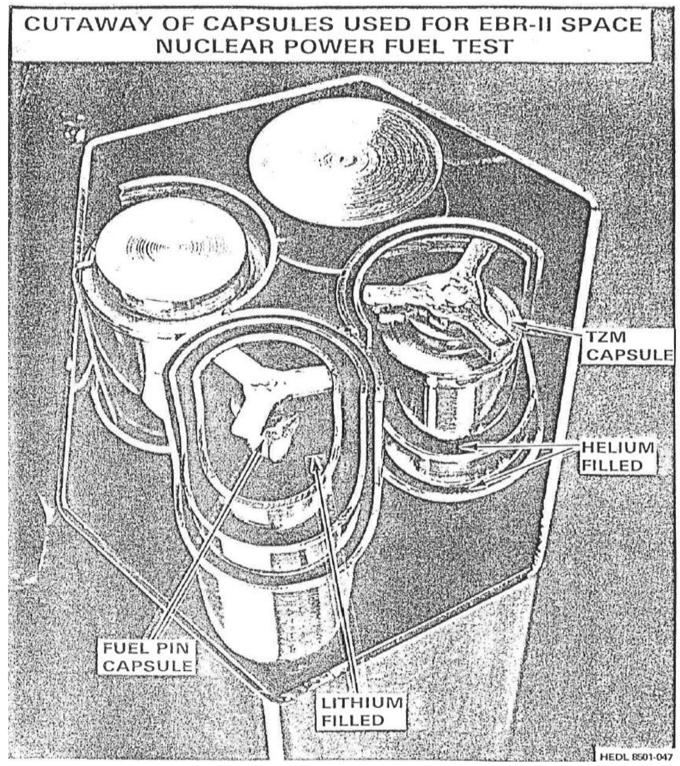

Fig. 5. SP-1 and SP-2 Tests in EBR-II

III. MMW Space Reactor Development

As development of the SP-100 electric space reactor power system progressed, space-based weapon and sensor designs continued to evolve under SDI, needing more power. Development of Multi-MW space nuclear power systems was directed out of a joint initiative between SDIO and DOE, which began in 1985. The objective was to establish the technical feasibility of at least one space reactor system concept that could meet performance requirements. PNNL had lead for reactor fuel development for the MMW program (Ref. 12). The MMW program was terminated in 1990.

IV. Project Prometheus

In 2004, PNNL was tasked with designing and fabricating materials tests in the JOYO reactor in Japan for Naval Reactors, which was developing the JIMO reactor, part of the Prometheus Project at NASA. The structure of the Prometheus Project is shown in Figure 7. The exploration objectives of the Prometheus Project were to enable a new era of space exploration through increased spaceship maneuverability and unprecedented amounts of on-board electrical energy. This was to be accomplished by developing a Deep Space Vehicle for outer solar system robotic exploration that combined a safe, reliable, space nuclear reactor with electric propulsion. Significantly improved capability for scientific measurements, mission design, and telecommunications would have been provided. The Jupiter Icy Moons Orbiter (JIMO) was a proposed NASA spacecraft designed to explore the icy moons of Jupiter. The main target was Europa, where an ocean of liquid water may harbor alien life. Ganymede and Callisto, which are now thought to have liquid, salty oceans beneath their icy surfaces, were also targets of interest for the probe. JIMO was to have a large number of revolutionary features. Throughout its main voyage to the Jupiter moons, it was to be propelled by an ion propulsion system via either the High Power Electric Propulsion or NEXIS engine, and powered by a small fission reactor. A Brayton power conversion system would convert reactor heat into electricity. The reactor power level was 200 kWe and was expected to open up opportunities like flying a full scale ice-penetrating radar system and providing a strong, high-bandwidth data transmitter. Using electric propulsion would make it possible to go into and leave orbits around the moons of Jupiter, creating more thorough observation and mapping windows than exist for current spacecraft, which must make short fly-by maneuvers because of limited fuel for maneuvering. The design called for the reactor to be positioned in the tip of the spacecraft behind a strong radiation shield protecting sensitive spacecraft equipment. The reactor would only be powered up once the probe was well out of Earth orbit, so that the amount of radionuclides that must be launched into orbit is minimized. The Europa Lander Mission proposed to include on JIMO a small nuclear-powered Europa lander. It would travel with the orbiter, which would also function as a communication relay to Earth. It would investigate Europa's habitability and assess its astrobiological potential by confirming the existence and determining the characteristics of water within and below Europa's icy shell. It was to be the first proposed mission of NASA's Project Prometheus, a program for developing nuclear fission into a means of spacecraft propulsion. Due to a shift in priorities at NASA that favored manned space missions, the project lost funding in 2005, effectively cancelling the JIMO mission (Ref. 12).

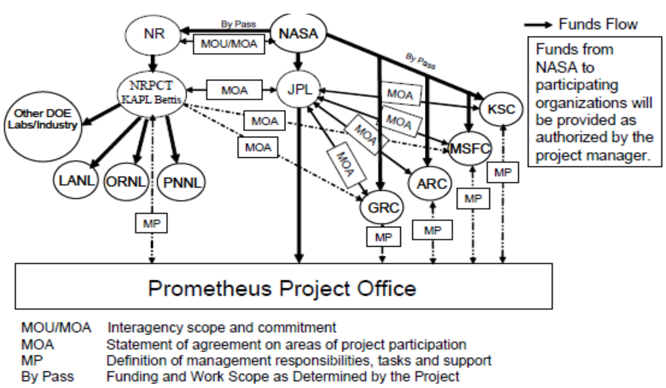

Fig. 6. Project Prometheus Structure

V. CONCLUSIONS

Hanford played a key role in early space reactor development and testing that ranged from thermo-electric and thermionic power systems, SP-100 test reactor fuels testing, the design and fabrication of the SP-100 ground engineering system test, thermal propulsion testing for the Multi-MW reactor, and the proposed Jupiter Icy Moons Orbiter (JIMO) reactor materials testing.

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