OVERVIEW OF NUCLEAR SPACE SCIENCE

EARLY BACKGROUND:

The first instance of serious nuclear space science and technology actually began with studies as 'Project Feedback' in the U.S. just after the end of World War II. These studies proposed two types of nuclear power sources of interest: Radioisotope power sources and nuclear reactors. This was a period where the Earth's first artificial satellites weighed 184 lbs. was launched. Sputnik II including 'Laika' the first space faring dog. The Earth's 3rd artificial satellite was sent into orbit on January 31,1958 Explorer I weighed 31 pounds.
The early success of Sputnik launches caught the American public by surprise and American scientists and engineers in the aerospace community were aware of Soviet advances.

Programs and projects like Explorer and Vanguard, the ROVER nuclear rocket project at Livermore Labs and Los Alamos Labs and even plans for a moon landing these were consolidated under ARPA who's mission was to consolidate existing aerospace project however unusual they seemed like project Orion an interplanetary spaceship powered by nuclear bombs idea first proposed by Los Alamos mathematician Stanislaw Ulam. These were all studies and projects that grew out of a post war period that saw unprecedented potential in technologies that used chemical and nuclear sciences for space and aeronautical applications just a decade following World War II.

It was for a nascent U.S. space program (National Advisory Committee on Aeronautics NACA) that in 1958 launched Navy navigation satellites systems that ushered the use of space nuclear power.

IDEAS AND SPECIALIZED APPLICATIONS

SPACE NUCLEAR TECHNOLOGY (SNT) comes in different forms under the rubric 'nuclear' becomes the physics of fission and fusion. An alternate extension is antimatter. Included are ways to manipulate heavy atomic nuclei into two or more major fragments example: Uranium-235 in fission or the fusing of light nuclei elements example: hydrogen, into those of the heavier elements, example: helium in fusion. Antimatter a form of matter in which most of the attributes like electrical charge, magnetic moment, and spin of elementary particles are reversed these particles (antiparticles) can be created in particle accelerators example: antihydrogen. All of these SNT forms can be used for space propulsion and power.
Thermoelectric Generators: If two wires or rods made of different metals are joined and their connection placed at different temperatures than their opposite ends, a voltage is produced across the enjoined ends. This effect was discovered by Seebeck in 1822. Only milliamps of current at a fractions of a volt are produced by metal wires fashioned this way in thermocouples to measure and control temperatures.
Only with the discovery of semiconductors in the 1950's were materials discovered that could produce useful amounts of electrical power. The basic thermoelectric cell uses P-type and N-type semiconductors to allow electrons of different valence electrons to flow from a hot junction toward a cold junction. This flow of charge in turn produces a current through an external load attached to two cold junctions of a thermoelectric cell. To obtain useful amounts of power and reasonable voltages, several cells are connected together in series to form a thermopile. Silicon and Germanium semiconductor make for high efficiency thermoelectric converters and research to find better materials for higher efficiency thermoelectric generators
Radionuclide Thermoelectric Generators: Any high-temperature thermal energy source can be used for a thermopile. A traditional source is the decay heat from radionuclides. (Radioisotope Thermoelectric Generator) RTG's of varying designs and power capacities have been made and tested for example in SNAP (System for nuclear Auxiliary Power) many other RTG's (odd number SNAP series) have been built and used in terrestrial and space applications. These RTG's had electrical power capacities ranging from a few W(e) up to 285 W(e) and used fuels like Po210, Pu238, Sr90, Cm242 although designs for lifetimes last for 5 years or less many early deep space probes still continue to operate well over 30 years since their launch.
Reactor Thermoelectric Generators: Are the even number SNAP series of thermoelectric devices use a small nuclear reactor to heat a liquid coolant that, in turn heats hot junctions of the thermoelectric cells. Boosting thermal energy sources can provide far more energy than a 'passive' radionuclide source an example is the first nuclear reactor to power thermal energy for thermoelectric energy conversion was SNAP-10A it used a liquid metal NaK coolant used as the thermal energy source.
Thermionic Electrical Generators: A thermionic generator converts thermal energy directly into electrical energy by placing two closely spaced metal plates. One plate (emitter) is heated to a high temperature to boil electrons from its surface into the gap between the plates the second plate the (collector) cooled to a lower temperature collects the electrons. This potential difference is developed between the two plates which; in turn produces current through an external electrical load. As electrons boil into the gap a negative space charge is created which inhibits the flow of electrons forcing some back to the emitter to make this system more efficient a gas like cesium vapor is injected which readily ionizes to form plasma is placed between the electrodes. The positive ions of the inter electrode gas counteract the negative electrical field of the electrons.
Any source of heat can be used in thermionic generators for low power applications. The decay from radioisotope can be used while a higher power application such as heated coolant from a compact nuclear reactor can be used. A thermionic generator is a heat engine thermal Q_e added to emitter and thermal energy Q_c is rejected at the collector Thermal conversion efficiency $\eta=(Q_e- Q_c)/Q_e$ in order for efficient thermal conversion emitter temperature need to be typically in excess of 1400K.
Radionuclide Thermionic Generators: Use decay heat of radioisotope (isomite battery) operate at relatively low emitter temperature (700K to 1400K) cesium is used to improve the work function of emitter and collector surface. 147Pm or 238Pu is used as thermal heat source between 0.3 and 3.5W. Output voltage between 0.1 and 0.15V to

yield power outputs of between 1 and 20 mW(e).
Multi-Mission Radionuclide Thermoelectric Generators (MMRTG): As part of NASA's Mars Exploration Program (MEP) the purpose of which is to conduct comprehensive science on the surface of Mars and demonstrate technological advancements in the exploration of Mars. The overall scientific goal of the proposed MSL (Mars Science Lab.) scheduled for Mars landing in 2010 is to access the biological potential of at least one selected site on Mars. Characterize the geology and geochemistry of the landing region at all appropriate spatial scales. Investigate planetary processes of relevance to past habitability. Characterize the broad spectrum of the Martian surface radiation environment.
This type to RTG is the first of a class of RTG technology since use in Apollo, Galileo and Cassini missions. MMRTG are designed for rugged surface use on Mars. The DOE has designed the MMRTG to provide containment of PuO2 fuel to the extent feasible during all mission phases including ground handling, launch and unplanned events such as reentry , impact, and post-impact situations.

SPACE REACTORS: For long lunar, planetary and deep-space missions, space vehicles need more electrical power than can be provided by the Radioisotope electric generators. or solar cells. Nuclear reactors can provide both thermal energy and duration for missions. The United States and the former USSR began programs that developed small light-weight nuclear reactors whose heat could be converted into electrical energy.
A U.S. nuclear rocket program Project Rover/NERVA officially spanned the years 1955-1973 which saw core reactor designs with hydrogen and oxygen gas pumped through the hot cores designs in an effort to test the viability of configurations best suited for a range of final designs. Presently with better materials the basic concept can again prove to be valuable in positioning spacecraft for shorter transit periods to mission human and robotics combined with nuclear electric propulsion (NEP) the Nuclear thermal Rocket (NTR) both can provide the reusable capability to service a wide scale range of missions types from the smallest robotics to a full human crew toward a Mars endeavor. (more...)