Quarterly Report

Period of September 1 – November 30, 1999[1]

Novel, Integrated Reactor/Power Conversion System

NERI Award No. 99-0198

Westinghouse Electric Company and University of New Mexico

Task 0. Definition of Objectives and Key Parameters

This task is completed on schedule. Desired design objectives and operation parameters were determined and system characteristics to be investigated were identified together with critical issues. Specific tasks were outlined and communicated to the performing personnel.

The target/desired system parameters are as follows:

- Electric power from 50 MWe to 100 MWe. The minimum power that would make a system attractive for utilities is about 50 MWe assuming a large number of units can be build;
- Core life of 10 to 15 years;
- Working fluid in the order of preference: sodium and potassium;
- Coupling schemes in the order of preference: a) evaporation outside of the core; b) capillary pumping and evaporation at the fuel elements surface ("gas core"); c) boiling in the core; and d) fully liquid, insulated loops. The options a) and b) imply the working fluid condensation inside the AMTEC cells, thus providing liquid, isothermal anode (vapor fed, liquid anode AMTEC);
- Core exit temperature: as low as possible; ideally, the reactor core would be operating at a pressure slightly below atmospheric (~1150 K core exit temperature for a sodium-cooled reactor);
- Economics: target capital cost comparable to that of state-of-the-art LMR plants ($1500-$1800/kWe). Target cost of electricity $0.02-0.03/kWhr;
- Safety and reliability: Redundancy will be emphasized in the power system design, and its impact on both reliability and economics will be evaluated;
- Proliferation resistance is to be achieved through the use of a long life core, infrequent or no refueling, and in-vessel fuel disposal. Since no proliferation-proof system can be developed and desired level of proliferation resistance might vary from country to country, a concept of inherent proliferation resistance should be introduced where it is achieved as a result of basic design solutions (long life core in this case) rather than special design measures which have a detrimental economic effect;
- Disposal strategy and associated costs have to be considered and taken into account from the very beginning. At this time the reference disposal method is in-vessel disposal;
- In factory fabricability and transportation: the goal is to transport a fully assembled system, or major pieces of a larger system by railroad/barge with minimum assembly work required on site to minimize construction costs and expertise required from the host country;
- economics and transportation requirements limit size and weight.

Subtask 1a. Neutronics

The first phase of this task was devoted to defining criteria for the long life core design, reviewing previous core design that had similar objectives, and establishing/benchmarking computational capabilities.

[1] Due to the delay in putting this award into effect, UNM started work on this contract on November 1st, 1999.

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Core characteristics that will be used to evaluate different designs are:

- initial enrichment needed for 15 years, or attainable lifetime for a given enrichment;
- core reactivity over the lifetime and excess reactivity at beginning-of-life (BOL);
- power density distribution (including profile change over the lifetime);
- depletion, i.e. isotopic composition change over the lifetime;
- reactivity feedback;
- control requirements (over lifetime).

Both deterministic and Monte Carlo calculation methods will be used, combining Westinghouse in-house codes as well as codes available through the RSICC center. Use of the ORIGEN 2.1 code is planed for depletion calculations, and initial testing of fast reactor libraries was performed.

A range of options may be considered when trying to achieve desired core characteristics, i.e., the decision space is very large. This includes different types of fuel (metal-oxide-carbide-nitride), lattice arrangement and pitch, core aspect ratio, etc... To make the selection task manageable, the following set of starting assumptions was formulated (based on analysis of characteristics of previous liquid metal reactors and long cycle cores): metallic (10%Zr) fuel, oxide fuel, nitride or carbide fuel, triangular pitch, <20% "enrichment" (fissile U+Pu over total heavy metal), pancake core, and fission gas plenum at the core bottom.

Subtask 1c. Cladding Evaluation

Materials issues that should be considered for estimating core lifetime are: resistance to corrosion in air; alkali-metal corrosion in the presence of dissolved oxygen; strength and creep at operating temperature; contaminants and chemical reactions; and radiation damage. From the lifetime point of view, it is preferable to keep the core exit temperature as low as possible. A database of mechanical and corrosion properties is being assembled for candidate and reference cladding materials including super-steel alloys, Hastelloys, Haynes-25, and advanced refractory materials such as D-66 alloy (45%Ni-12%Cr-34%Fe), Nb-1%Zr, PWC-11 and W-Re alloys, as well as for structural materials used in state-of-the-art LMRs.

Subtask 1f: Reactor / energy conversion interface

The literature was reviewed on the design of high power AMTEC systems, and on the different heat source/AMTEC/heat sink coupling concepts. The initial work effort will focus on investigating the feasibility of a LMR/AMTEC direct cycle (attractive concept, simplicity, etc.) which uses sodium working fluid.

Subtask 2a: AMTEC working fluid selection

The thermophysical and radiological properties of liquid metals (sodium, potassium) working fluids, as well as those of Na-BASE and K-BASE, are being reviewed and a database is being compiled. Both sodium and potassium working fluids will be considered for the AMTEC cycle. The properties of lithium working fluid and Li-BASE will be compiled at a later time.

Subtask 2c. Energy conversion modules

A design model is being developed to evaluate and compare the performance of sodium and potassium AMTEC converters. This model will be used later to evaluate the effect of different parameters on the electrical and thermal performance of both liquid-anode and vapor-anode converters. Design parameters of interest are the BASE membrane thickness; the electrodes' temperature-independent charge-exchange current; and the contact resistance between electrode and current collector. Operating parameters of interest include evaporator temperature, BASE temperature and condenser temperature. The model will be used to identify the operating conditions for optimal conversion efficiency and maximum electrical power, and the load-following characteristics of the converter's electrical output.

A preliminary literature search was performed to identify future, potential AMTEC electrode candidates. Desirable properties of interest include: good electrical conductivity; strong physical bond with BASE membrane; thermal expansion coefficient close to that of BASE; high permeability to sodium vapor; high corrosion resistance to sodium vapor; low material loss rate by chemical reaction or sublimation; and slow grain growth and material migration. Refractory electrode materials such as TiB_2, TiC and NbN have many of these desirable properties. Molybdenum electrodes have also some attractive characteristics for use in sodium- and potassium-AMTECs, particularly the enhanced ionic and electronic conduction of the molybdate compound.

A literature review is being performed to compile the properties necessary to evaluate the possibility of an electrical discharge in sodium and potassium vapor between the BASE electrodes, when operating the AMTEC modules at high voltage (> 100 V d.c.). The maximum number of BASE electrodes that could be connected in series in an AMTEC converter module, as well as the number of modules connected in series, will be limited by the breakdown voltage. A discharge model will be developed to evaluate these design limitations. Also, the impact of the numbers of modules connected in parallel and series on performance, cost and redundancy will be evaluated.

Subtask 2d. Materials selection and research in AMTEC

Some of the materials issues that should be considered for estimating lifetime of AMTEC converters are: resistance to corrosion in air; alkali-metal corrosion in the presence of oxygen; strength and creep at operating temperature; contaminants and chemical reactions. The literature on structural materials for use in sodium-LMR systems (EBR2, Phoenix, Super-Phoenix,...) is being reviewed, and a database on their thermophysical and compatibility properties is being compiled. During this compilation process, data pertaining to potassium working fluid are also being collected for future use and documentation. Most of the information pertaining to potassium corrosion and materials compatibility originated from the research and development programs of Potassium-Rankine cycles.