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Preliminary Evaluation of Convective Heat Transfer in a Water Shield for a Surface Power Reactor

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INTRODUCTION

As part of the Vision for Space Exploration, the end of the next decade will bring man back to the surface of the moon. A crucial issue for the establishment of human presence on the moon will be the availability of compact power sources. This presence could require greater than 10's of kWt's in follow on years. Nuclear reactors are well suited to meet the needs for power generation on the lunar or Martian surface.

Radiation shielding is a key component of any surface power reactor system. Several competing concepts exist for lightweight, safe, robust shielding systems such as a water shield, lithium hydride (LiH), and boron carbide. Water offers several potential advantages, including reduced cost, reduced technical risk, and reduced mass. Water has not typically been considered for space reactor applications because of the need for gravity to fix the location of any vapor that could form radiation streaming paths. The water shield concept relies on the predictions of passive circulation of the shield water by natural convection to adequately cool the shield. This prediction needs to be experimentally evaluated, especially for shields with complex geometries. NASA Marshall Space Flight Center has developed the experience and facilities necessary to do this evaluation in its Early Flight Fission - Test Facility (EFF-TF).

EXPERIMENT DESCRIPTION

The test bed consists of a core simulator that simulates the reactor vessel and everything inside (core, reflector, control drums, coolant manifolds, etc.), and the outer tank that forms the outer boundary of the water shield. For initial evaluation, the test bed is not pressurized, and has a simple 2.5" thick foam lid located at the top of the outer tank, to prevent evaporative cooling. Both the core simulator and lid can be moved vertically relative to the outer tank to accommodate different shield configurations (Figure 1). The testbed is

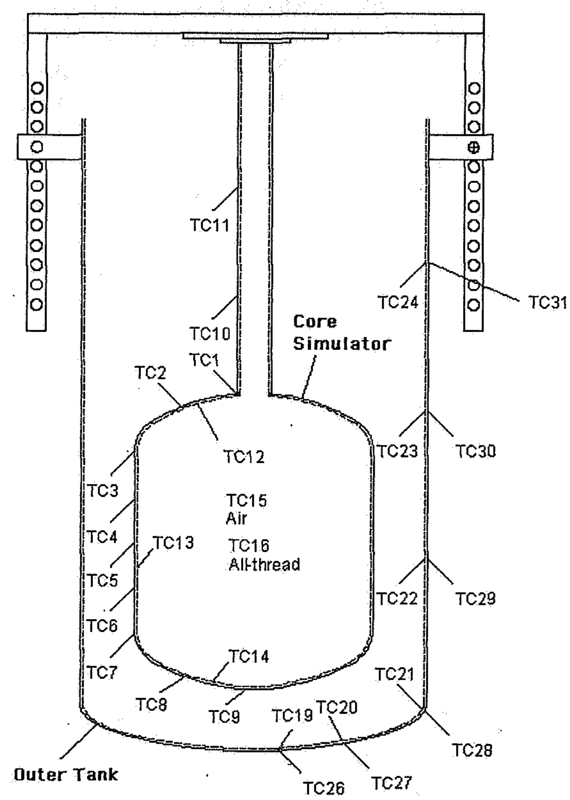

Fig. 1. Schematic of the test bed with thermocouple placement and numbering. The outer tank inner diameter is 35", and the core simulator outer diameter is 24".

The thermal load on the water shield is supplied by heaters on the inner surface of the core simulator in three 'zones' (top dome, barrel section and bottom dome) with a maximum total power of 18.8 kW. This thermal load represents thermal heat from the reactor vessel, and neutron heating in the water. It is assumed that the majority of the neutron heating in the water occurs close enough to the reactor vessel to make the simulator relevant. This assumption is conservative because one of the major questions to be answered is whether the natural convection of water between the reactor vessel and the outer tank is strong enough to handle the thermal load.

Heat removal from the outer tank is accomplished by natural convection to still air at room temperature. This was sufficient for the initial run of tests, with a thermal load in the core simulator of 2 kW. Coupling to the ultimate heat sink in future tests will incorporate forced convection and/or heat pipes to accomodate larger thermal loads and maintain positive temperature control of the boundary.

RESULTS

Three cases have been tested and evaluated with this apparatus. The nominal case is based on a SNAP derivative reactor, with a predicted thermal load in the water shield of 2 kW. Another case was run at 1.0 kW, and the third case was run with 0.33 kW to match the Rayleigh number for the nominal thermal load in lunar gravity. The results are presented in Figure 2.

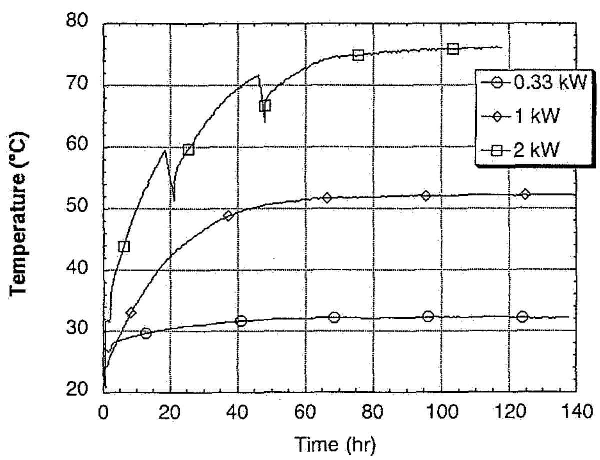

Fig. 2. Representative data from three cases (TC4). ?

Note the two temporary power failures in the nominal case. In all cases the time to reach steady state was approximately 80 hours. These results demonstrate the effectiveness of natural convection in removing heat from the core simulator to the outer tank. Higher fidelity tests are being planned, with more prototypic heat removal from the shield. Further work is also being done to determine other relevant similarity parameters that could allow the test bed data to be extrapolated to lunar conditions.