Justification for an Increase in Authorized Operating Power at HFIR

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INTRODUCTION

The High Flux Isotope Reactor (HFIR), a multipurpose research reactor located at the Oak Ridge National Laboratory (ORNL), achieved a rated, operating power of 100 MW_{th} on September 9, 1966. Due to concerns about pressure vessel embrittlement, in 1990, the operating pressure was reduced from 600 psig (4.14 MPag) to 468 psig (core inlet, 3.23 MPag) and the allowed operating power was reduced to 85 MW_{th}. That value was achieved on May 18, 1990, where it remains today. The reactor physics and heat transfer methods and analyses that supported the decision to allow operation at 100 MW_{th} and subsequently at 85 MW_{th} remain the bases of the current safety analysis report (SAR). [1] The National Nuclear Security Administration is sponsoring studies of the conversion of HFIR to 20% enriched fuel. To maintain the current level of performance after conversion, the reactor power must be returned to 100 MW_{th}.

At the previous American Nuclear Society meeting (2010 winter meeting), an analysis of a recent HFIR fuel cycle (number 400) using current state-of-the-art methods was presented. [2] In this study, the results of that physics analysis are input to the 1966 HFIR thermal hydraulics methodology to determine if advances in reactor physics methods and data impact the predicted, allowable operating power.

METHODOLOGY

Prior to the initial startup of HFIR, a computer program was written to model the integral thermal hydraulic behavior of the core, simultaneously accounting for the nuclear heating, hydraulic, heat transfer, mechanical, and corrosion history of the reactor [3]. The maximum operating power was determined by iteratively solving the spatially-discretized, channel integral momentum and mass conservation equations for the reactor power level that yields the maximum value of all the local, clad-surface-temperature-to-coolant-incipient-boiling-temperature ratios equal to 1.0 (coolant would just begin to boil but only at that one spot in the reactor; here termed onset-of-incipient-boiling power). Maximum allowable operating power is then set to be the onset-of-incipient-boiling power/1.3, i.e. the limiting condition of operation for HFIR is 1.3 times the maximum allowable operating power and if the reactor were in that condition, no boiling would occur. Reactor operating parameters (pressure, inlet temperature, flow rate) are set at limiting control settings with allowances for measurement uncertainties. While originally unnamed, the code is now designated the HFIR steady state heat transfer code (HSSHTC).

The nuclear heating (reactor power distribution) is calculated with a neutronics code and provided as input to the HSSHTC. For the initial HFIR startup, this calculation was performed with a one-dimensional, diffusion theory code. [4] Then, according to [5, p. 49], "(A) set of experiments (HFIRCE-4) (was) conducted in the actual HFIR facility. Power distributions from these experiments were used to normalize the most recent calculated values for all times in the fuel cycle. … Power distributions … were obtained by adjusting the one-dimensional fuel cycle calculation results with the critical experiment data to obtain a normalized two-dimensional power distribution." These distributions are provided in [5] and replicated without change in [1]. Using these distributions along with plant data and defined safety margins, a maximum allowable nominal power of 85 MW_{th} was determined for current operating conditions and accepted by the U.S. Department of Energy [1].

Over the past few years, several studies have been conducted to validate MCNP [6] models of HFIR critical experiments and full power operation using measured data. [2, 7, 8, 9, 10] Agreement between measured and calculated physics and operating parameters, e.g. cycle length, has been excellent.

In the analyses reported here, all input parameters to the HSSHTC had the same values as those used in the current SAR safety basis analyses except that the original time-dependent power distributions [1, 5] were replaced with values from the analyses documented in [2]; these analyses were performed using VESTA [11], a code that couples MCNP (here version 5) with ORIGEN-2.2 [12]. The spatial meshes (radial and axial) for the new power profiles were somewhat more dense (about 30% more mesh points) than in the original model, but the HFIR core dimensions are unchanged between calculations.

RESULTS

The maximum allowed operating power as a function of irradiation time (cycle length is approximately 25 days) is provided in Table I. Due to power density redistribution and fuel burnup effects, the potential

operating power increases during the cycle. However, the maximum operating power is fixed and limited to the minimum of the time-dependent values, which occurs at the beginning of the cycle.

Fig. 1 shows the spatial variation in the clad-surface-temperature-to-coolant-incipient-boiling-temperature ratio. The distribution shown is for an inner element fuel plate, the top of the plate – where coolant enters the core – is to the right. The hottest water will be at the bottom of the plate (left side of drawing). Because of frictional pressure loss, the lowest coolant pressure in the core will be at the bottom of the plate (left side of drawing). The back face of the plot (gridded region) is the edge of the fuel that faces toward the center of the annular core and thus has the highest local power densities. The combination of all of these factors leads to the maximum local clad-surface-temperature-to-incipient-boiling-temperature ratio being at the inside edge on the lower face of the plate.

Table I. Estimates of operating powers based on MCNP-derived power density profiles for cycle 400

Time at full power into cycle (eff. full power days)	0 (BOC)	1	11	22	24.3 (EOC)
Onset of incipient boiling power (MW_{th})	111.1	116.1	115.6	119.4	120.2
Maximum potential operating power (MW_{th})	85.4	89.3	88.9	91.8	92.5

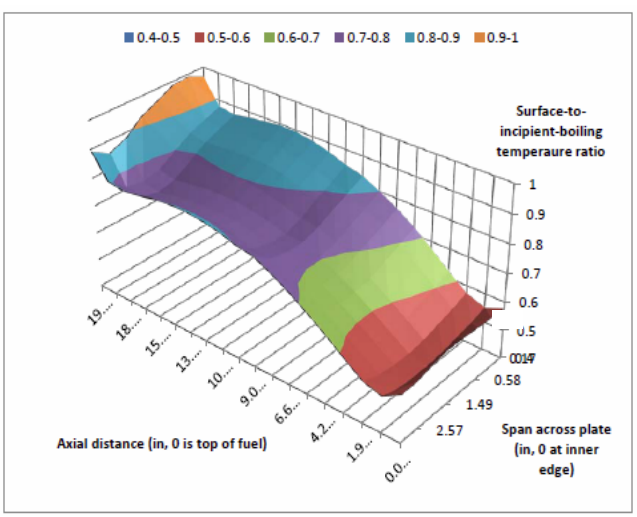

Fig. 1. Spatial dependence of clad-surface-temperature-to-incipient-boiling-temperature ratio at beginning-of-life, cycle 400

CONCLUSIONS AND COMMENTS

1) Using verified and validated reactor physics methods coupled to a currently accepted thermal hydraulic analysis methodology, onset of incipient boiling power agrees perfectly with the currently-accepted safety basis value. The MCNP-based methodology is acceptable for scoping studies of LEU fuel conversion.

2) A balance-of-plant assessment would have to be conducted to determine if the power up-rate to 100 MW_{th} could be supported for LEU fuel.

3) The level-of-agreement between analyses performed 45 years ago based on experimental measurements and today's methods supports pursuing development of extremely-fine-resolution computational models for the study of thermal hydraulic, materials, and structurally-related phenomena.

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