NUCLEAR REACTOR LABORATORY

AN INTERDEPARTMENTAL CENTER OF
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

50-20

O. K. HARLING
Director

138 Albany Street, Cambridge, Mass. 02139-4296
Telefax No. (617) 253-7300
Telex No. 92-1473-MIT-CAM
Tel. No. (617) 253-4202

J. A. BERNARD, JR.
Director of Reactor Operations

April 26, 1995

U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
Attn: Document Control Desk

Subject: Item of Information Concerning Use of a Fission Converter for the Generation of an Epithermal Neutron Beam

Gentlemen:

The Massachusetts Institute of Technology is in the process of designing a fission converter for the purpose of generating an epithermal neutron beam. Enclosed is a brief description of the design and an enumeration of its major safety features. This is provided to you as an item of information. Detailed technical information will be provided upon completion of the design studies later this year.

Sincerely,

John A. Bernard

John A. Bernard, Ph.D.
Director of Reactor Operations
MIT Research Reactor

JAB/CRM

cc: USNRC - Senior Project Manager, NRR/ONDD

USNRC - Region I - Project Scientist, Effluents Radiation Protection Section (ERPS) FRSSB/DRSS

Epithermal Neutron Beam Using A Fission Converter

Prepared by Professor Otto K. Harling, Project Director
July 27, 1995

Introduction

Recently the pace of R&D in neutron capture therapy (NCT) for cancer has been accelerating [Ref. 1]. Clinical trials have been initiated at the MIT Reactor (MITR-II) and at the Brookhaven Medical Reactor. An European collaborative effort is poised to begin trials in the near future, and Japanese researchers are continuing their clinical trials using several reactors [Refs. 2,3,4,5]. The advantages of using epithermal rather than thermal neutron beams for deep seated tumors have been clearly demonstrated [Refs. 6,7].

An improved epithermal beam at the MITR-II would be very useful in the current near term clinical trials and is essential for future Phase III clinical trials and for routine application of NCT should this treatment become an accepted approach to cancer therapy. An improved epithermal neutron beam for NCT has been designed at the MIT Nuclear Reactor Laboratory. This beam uses a fission converter as a source of neutrons. The converter, can be composed of any suitable fissionable fuel. We have based most of our studies upon the use of standard MITR-II fuel elements, both fresh fuel and fuel which has been discharged from the MITR-II. In the following sections an overview of the preliminary design for this facility is presented and safety features are outlined. This overview of the current design is provided to the NRC as an item of information. It is hoped that by doing this the formal and detailed request for the necessary approvals, which we expect to prepare in the future, will require a shorter review because the request will have addressed all NRC concerns. We would therefore appreciate any comments and/or guidance that NRC can provide on our preliminary design.

Overview of Design

The fission converter based epithermal neutron treatment facility is shown schematically in Fig. 1. This figure is taken from Ref. 8, which provides the neutronic design of the facility. A copy of Ref. 8 is attached. The neutron source for the converter-based beam is created by the MITR-II

fuel, which is located in a water-filled tank . The fueled tank is located near the core side of the reactor's thermal column, where the unperturbed thermal neutron flux is 1-2x EXP 12. Monte Carlo calculations show that a converter, using 12 MITR-II fuel elements will generate 90-210 kW at a reactor power of 5 MW. The power depends on whether spent or fresh fuel is used and whether the water cooling is achieved with light or heavy water.

The converter operates with a k-effective which is much less than one. Typically this important parameter is in the range of 0.4-0.6 with D_2O/H_2O coolant for the configurations of interest. The fission neutrons from the converter are moderated and filtered to a beam of the desired energy with a low background of undesired thermal and fast neutrons and of gamma rays. After collimation the epithermal beam is incident upon the target, which might typically be a human head/brain for the treatment of virulent brain tumors. We have carried out extensive neutronic calculations using the MCNP Monte Carlo program. These calculations show that our converter-based beam will have a high intensity of desired neutrons in the 1 eV-10 keV range and negligible components of fast neutrons and gammas in the treatment beam.

The converter fuel elements are located in a double-walled aluminum tank which will have a leak detector in the air space between the tank walls. Level and temperature measurements are also provided for the cooling water in the tank. Figure 2 provides a schematic of the fuel tank and cooling system. The cooling circuit for the converter uses a separate heat exchanger to transfer heat to the secondary system of the reactor. A circulating pump is used to force the coolant, either light or heavy water, through the heat exchanger. The fuel in the fuel tank has its heat removed to the water by natural convection. This assures that a coolant pump failure will not cause rapid changes in fuel temperature since the entire heat capacity of the ~ 246 gallon fuel tank is available as a thermal buffer. The normal operating temperature of the fuel clad is 70 C, i.e. well below the onset of nucleate boiling on the surfaces of the fuel plates. The time dependence of the fuel temperature in the event of cooling pump failure has been calculated and is shown in Fig. 3. A considerable time, ≥100 minutes, is available after pump or cooling pipe failure before any actions are needed to prevent potential fuel damage. Lowering the cadmium curtain in front of the converter reduces the converter power by two orders of magnitude, requires only ~10 sec, and is independent of the continued operation of the reactor. Reactor shutdown provides the ultimate backup to reducing converter power if the cadmium shutter failed to operate.

The converter fuel is loaded and unloaded in a manner which is very similar to the way these functions are handled for the MITR-II. A fuel transfer cask is positioned above the fuel tank and irradiated fuel is transferred through the water into or out of the shielded transfer cask. The fuel in the fuel tank is positioned in a grid. A linear array of up to 12 fuel elements can be loaded.

Patient safety is assured by observing carefully developed written procedures and hardware systems to help assure precise dose control. These procedures will be comparable to those which have been developed for use with the existing medical beam at MITR-II. The hardware systems used for patient dose control will include a fast-acting shutter placed directly in front of the patient position and a cadmium shutter directly in front of the converter fuel. The possibility of rapid reactor shutdown provides the ultimate backup for turning off the treatment beam. Beam monitors and readout systems currently used at the MITR-II medical irradiation facility will be adapted for use at the fission converter based epithermal treatment beam and will help assure that the patients receive the prescribed dose.

Reactor and medical staff will be protected against unnecessary radiation exposure by the shield walls of the medical irradiation room. Only the patient will be in this room when the beam is allowed into the room. This is exactly the same approach which is used with the current medical beam and is similar to that which is used at conventional radiotherapy facilities.

Summary of Safety Features

Water cooled fuel in a double walled tank
Convection cooling of fuel
Long time periods before temperature can reach boiling if the heat removal system for the fuel tank fails
MITR-II fuel elements capable of much higher power densities will be used
The k-effective will be much less than 1, typically less than 0.6
Fuel will be handled similarly to fuel at MITR-II
The treatment beam is controlled by two shutters and is backed up by the reactor shutdown options
Radiation dose will be monitored by a currently used and proven system
Radiations will take place in a shielded room

References

1. D. E, Wazer, R. G. Zamenhof, O. K. Harling, and H. Madoc-Jones, "Boron Neutron Capture Therapy," Chapter 7 in: Radiation Oncology Technology and Biology, P. M. Mauch & J. S. Loeffler, eds., W. B. Saunders, Company, Philadelphia, 1994, pp. 167-192.

2. R. L. Moss, " On the Progress Towards Clinical Trials at Petten (Post-Sydney)" in: Advances in Neutron Capture Therapy, A. H. Soloway, R. F. Barth, and D. E. Carpenter, eds., Plenum Press, New York, 1993, pp. 739-743.

3. Y. Nakagawa, T. Kageji, H. Hatanaka, K. Mukai, K. Kitamura, F. Tsuji, K. Kanda, and T. Kobayashi, "Thermal Neutron Capture Therapy for Brain Steam and Skull Base Tumors: Heavy Water and Multiportal Neutron Delivery," in: Advances in Neutron Capture Therapy, A. H. Soloway, R. F. Barth, and D. E. Carpenter, eds., Plenum Press, New York, 1993, pp. 671-675.

4. Y. Oda, M. Takagaki, Z. H. Zhang, H. Kikuchi, T. Kobayashi, and K. Kanda, "Clinical Experience with BNCT for Malignant Brain Tumors," in: Advances in Neutron Capture Therapy, A. H. Soloway, R. F. Barth, and D. E. Carpenter, eds., Plenum Press, New York, 1993, pp. 689-693.

5. H. Hatanaka, J. H. Goodman, and M. E. Miner, "Current Standard Boron Neutron Capture Therapy with Shionogi's Mercaptoundecahydrododecarborate for Malignant Glioma," in: Advances in Neutron Capture Therapy, A. H. Soloway, R. F. Barth, and D. E. Carpenter, eds., Plenum Press, New York, 1993, pp. 695-698.

6. S. D. Clement, J. R. Choi, R. G. Zamenhof, J. C. Yanch, and O. K. Harling, "Monte Carlo Methods of Neutron Beam Design for Neutron Capture Therapy at the MIT Research Reactor (MITR-II)," in: Neutron Beam Design, Development, and Performance for Neutron Capture Therapy, O. K. Harling, J. A. Bernard, and R. G. Zamenhof, eds., Basic Life Sciences, Vol. 54, Plenum Press, New York, 1990, pp. 51-69.

7. J. C. Yanch and O. K. Harling, "A Comparison of Epithermal Neutron Beams for NCT: Effect of Beam Collimation on Therapy

Parameters," in: Advances in Neutron Capture Therapy, A. H. Soloway, R. F. Barth, and D. E. Carpenter, eds., Plenum Press, New York, 1993, pp. 67-70.

8. O. K. Harling and W. S. Kiger III, "High-Intensity Fission-Converter-Based Epithermal Neutron Beam for Neutron Capture Therapy," Proceedings of the 6th International Symposium on Neutron Capture Therapy for Cancer (ISNCT), October-November 1994, Kobe, Japan, to be published in Cancer Neutron Capture Therapy.

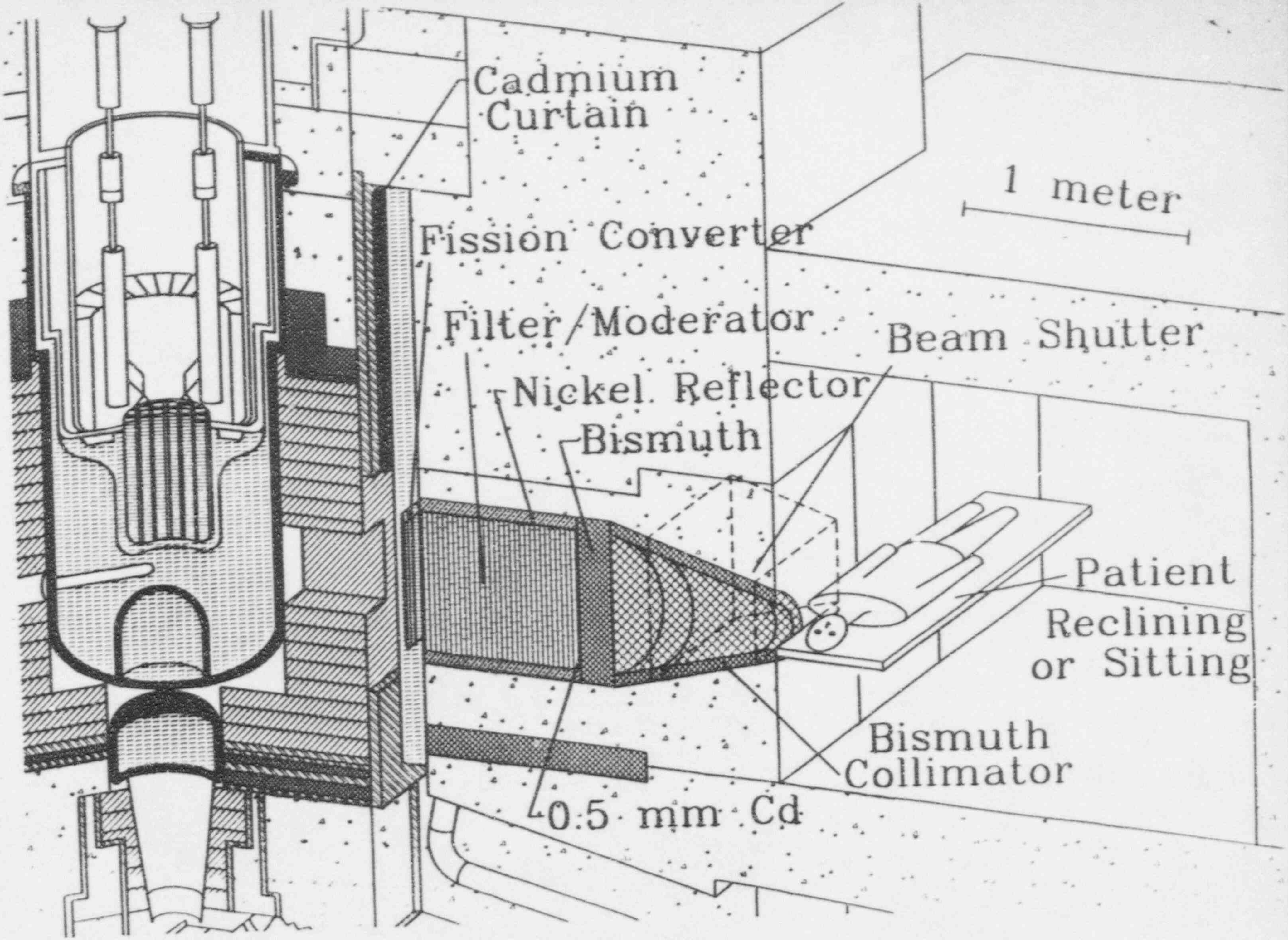
Cadmium Curtain
1 meter
Fission Converter
Filter/Moderator
Beam Shutter
Nickel Reflector
Bismuth
Patient
Reclining or Sitting
Bismuth Collimator
0.5 mm Cd

Figure 1

ISOMETRIC VIEW OF FISSION CONVERTER

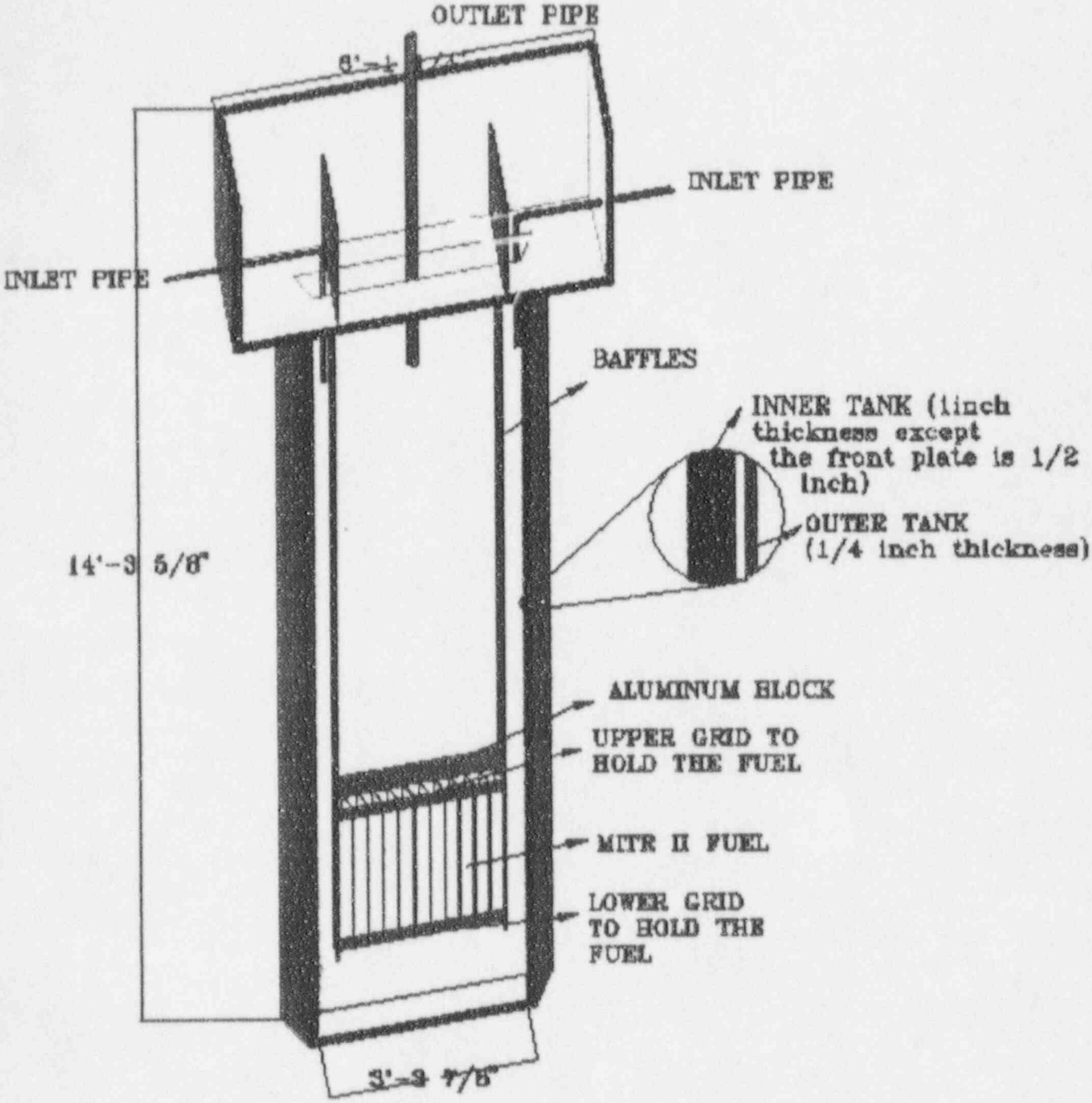

Figure 2

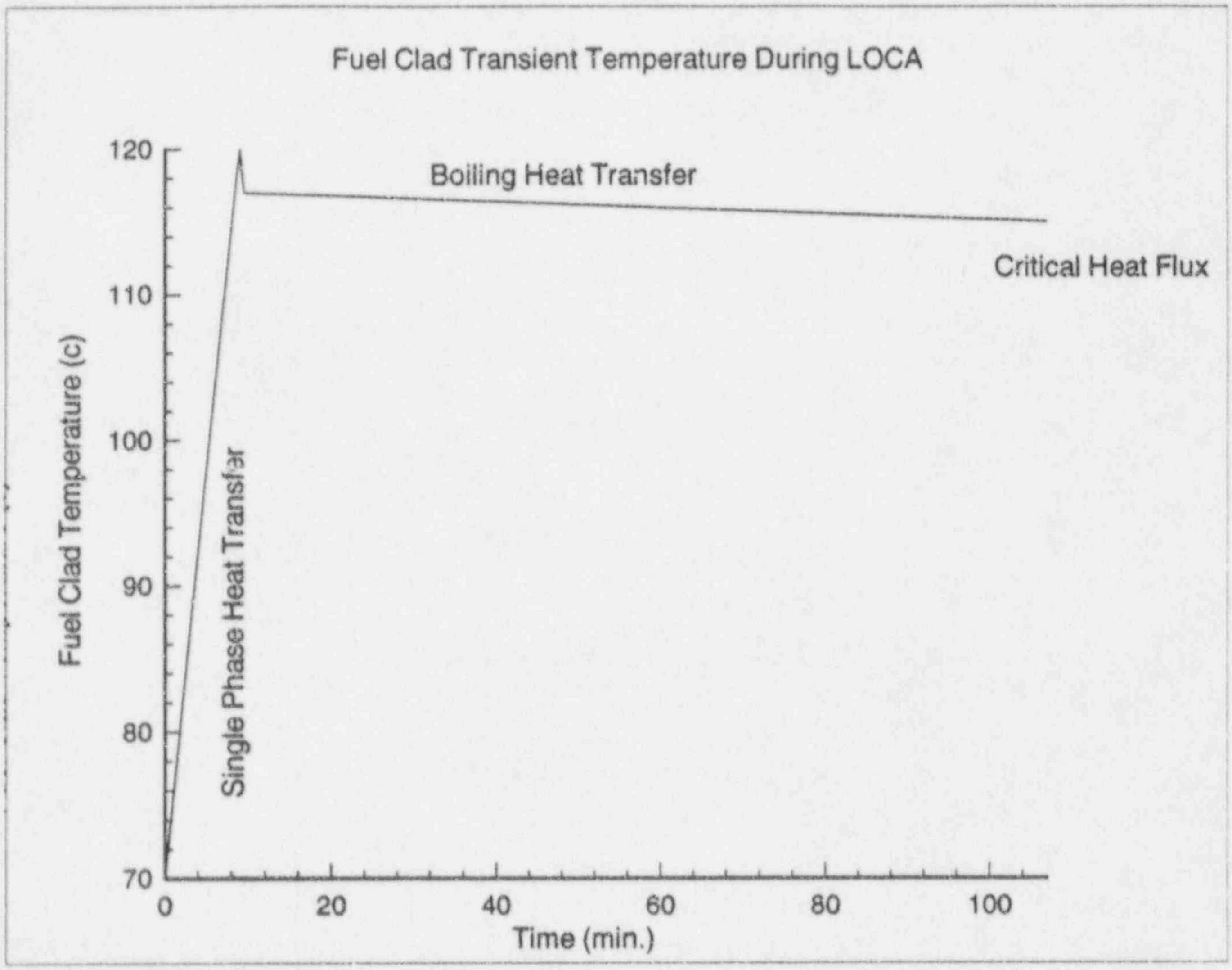
Fuel Clad Transient Temperature During LOCA
Boiling Heat Transfer
Critical Heat Flux
Single Phase Heat Transfer
Fuel Clad Temperature (c)
120
110
100
90
80
70
0
20
40
60
80
100
Time (min.)

Figure 3