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NUCLEAR REGULATORY COMMISSION
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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

SUPPORTING AMENDMENT NO. 31 TO

AMENDED FACILITY OPERATING LICENSE NO. R-37

THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DOCKET NO. 50-20

1.0 INTRODUCTION

By letter dated October 3, 1997, as supplemented on January 14, June 24, July 29, October 20, and November 12, 1999, the Massachusetts Institute of Technology (MIT or the licensee) submitted a request for amendment of Appendix A, "Technical Specifications for the MIT Research Reactor," to Amended Facility Operating License No. R-37 for the MIT Research Reactor (MITR). The amendment would allow operation of a subcritical fission converter and associated medical therapy room at the MITR. The requested amendment would not allow the irradiation of humans. The authorization to use the fission converter facility for irradiation of humans is the subject of a separate request for license amendment by the licensee.

2.0 EVALUATION

2.1 Introduction

The licensee has requested an amendment to their reactor license to permit the operation of a subcritical fission converter facility. The purpose of the facility will be to provide a new epithermal neutron beam for the boron neutron capture therapy (BNCT) program. The licensee has conducted BNCT using a NRC-approved beam and medical therapy room since 1993. This new beam will have several advantages over the existing beam including shorter patient irradiation times. The licensee has applied for a second amendment to allow the fission converter facility to be used for the irradiation of humans similar to the existing BNCT facility.

The staff's review encompassed the fission converter design including neutronic design, thermal hydraulic design, fuel handling, safety analysis, instrumentation and control system, emergency power, pre-operational tests and initial operation. The staff also reviewed the control shutters and medical therapy room designs and proposed modifications to the technical specifications (TSs).

The fission converter facility is a complex experimental facility used for irradiations. It is a subcritical array of fuel and cannot maintain a self-supporting chain reaction like a reactor. In addition, the fission converter cannot perform its irradiation function without the MITR operating. Because it contains fuel, the approach used by the licensee in their safety analysis is similar to that for a reactor in some respects. For example, the licensee has proposed using in the fission converter TSs terms such as safety limits and limiting safety system settings that are normally found in reactor TSs. These terms are used because the concept of protecting fission product barriers as applied to the fission converter is similar to that in the reactor. However, the use of these concepts does not mean that the regulatory requirements for a reactor apply directly to the fission converter.

The conclusions of the NRC staff are based on acceptance criteria that are stated in several documents, such as NUREG 1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors," and American National Standard ANSI/ANS-15.1-1990, "The Development of Technical Specifications for Research Reactors" (ANS-15.1) as applied to experiments.

2.2 Facility Description

The MITR is a multi-purpose research reactor located in Cambridge, Massachusetts. A major research effort at the reactor is developing BNCT for human patients. BNCT is a form of cancer therapy that has the potential to kill cancer cells selectively while sparing normal tissue. For this work, an existing neutron beam has been used which emerges into a therapy room below the reactor. When using this beam, approximately 2.5 hours are required to deliver an appropriate dose to the tumor. A new facility with a higher intensity beam with an improved energy spectrum is necessary for advanced clinical trials and routine therapy. With the proposed fission converter facility it will be possible to treat a patient in just a few minutes.

The new beam design is based on a fission converter driven by neutrons from the MITR. Thermal neutrons from the reactor are "converted" to neutrons with a fission spectrum by the fission converter. This subcritical multiplication of the reactor neutron flux results from fissioning of the uranium loaded into the fission converter. A filter/moderator is used to tailor the neutron beam by eliminating unwanted fast neutrons and photons without significantly decreasing the useful, epithermal neutrons. The fission converter consists of MITR fuel elements placed on a grid and enclosed in a fission converter tank. A collimator and a system of shutters are used to deliver the beam to a patient located in the shielded medical therapy room. A converter control shutter (CCS) is used to control the flow of the thermal reactor neutrons to the fission converter. When the CCS is open, thermalized reactor neutrons can reach the converter. The converter is cooled by natural or forced convection of water or heavy water in the tank.

Figure 1 is an isometric drawing of the MITR that shows the major components before the installation of the proposed fission converter facility. Of special interest are the spaces between the graphite reactor reflector and the fast spectrum facility including the hohlraum (cavity room). It is in these locations that the proposed fission converter facility will be installed.

Figure 2 is an isometric drawing of the proposed fission converter and the medical therapy room, which shows the major components of the fission converter facility and their relationship to one another and the reactor. Further details of the proposed facility are shown in Figures 3 and 4, which are top and side cross-section views of the proposed facility respectively.

2.3 Fission Converter Neutronic Design

The fission converter consists of an array of up to 11 MITR fuel elements (proposed TS 6.6.4-3) arranged on a fuel grid plate located in the fission converter tank. To minimize bypass flow around the fuel elements, the small clearances between fuel elements and the tank wall are partially blocked by the grid plate. The maximum allowable bypass flow is the subject of proposed TS 6.6.2.1-2.

Figures 5 and 6 present an isometric and cross-sectional view, respectively, of the fission converter tank and the fuel location. It is possible to insert an aluminum block (that displaces the coolant/moderator near the fuel in order to improve the epithermal neutron beam) between the fuel and the converter tank wall. Proposed TS 6.6.4-5 requires the aluminum block to be installed unless calculations have been performed to show compliance with certain important design criteria with the block removed. Unless otherwise stated, the NRC staff's analyses and conclusions assume that the aluminum block is in place.

2.3.1 Fission Converter Effective Multiplication Factor

An important aspect of operation of the fission convertor is assuring that it will be subcritical and not capable of achieving a self-sustaining chain reaction. Using the Monte Carlo N-Particle (MCNP) code, the effective multiplication factor (k_{eff}) for 11 fresh or partially spent MITR fuel assemblies with either light water (H_2O) or heavy water (D_2O) coolant has been calculated by the licensee. MCNP is an acceptable code for the calculation of reactor physics parameters at non-power reactors. Without the aluminum block and with all conditions of coolant and fuel mass, k_{eff} is never more than 0.670 (for a critical reactor, k_{eff} is 1.0). If the aluminum block is placed as shown in the drawings, the maximum k_{eff} is 0.589 for all conditions of coolant and fuel mass. In all cases, the k_{eff} is low enough to preclude a criticality accident in the converter and is well below the limit already established in the TSs of the MITR for fuel storage racks (k_{eff} less than 0.90). Proposed TS 6.6.2.1-6 states that the maximum allowed value of k_{eff} for the fueled region of the converter will not exceed 0.90. The staff has reviewed the methods that the licensee used to determine the k_{eff} of the fission converter for all configurations of fuel elements and coolant. MCNP is a well established code and its use for this analysis is acceptable to the staff. In addition, it will be verified during initial start up testing that the k_{eff} is less than 1.0. Based on its review of the licensee's application, the staff concludes that the calculations, proposed start up testing and proposed TS are acceptable.

Because of its location in relation to the reactor and its material content, the converter will have a reactivity effect on the MITR. Using similar techniques to those used to calculate the effective multiplication factor of the converter, the k_{eff} values of the MITR core coupled with the fission converter were calculated by the licensee. These calculations were performed with the CCS open and closed, 11 fresh or spent fuel assemblies, and either H_2O or D_2O coolant. The highest calculated value of reactivity associated with opening the CCS and placing the converter into operation is 0.00125 $\Delta k/k$. This calculated reactivity is well within the TS limit already established for the MITR for a movable experimental (current TS 6.1.1 with a limit of 0.002 $\Delta k/k$). The movable experiment TS limit is appropriate for limiting the worth change occurring while opening the CCS. Reactor control manipulations can be used to compensate for the reactivity change resulting from the opening of the CCS. The reactivity worth of the CCS will be limited by proposed TS 6.6.2.2-2 to the existing movable experiment reactivity and verified with testing required by proposed TS 6.6.2.2-1 at initial start up and then annually. This annual surveillance interval is similar to that given in ANS 15.1 and is supported by the NRC staff for reactivity worth measurements. Because the worth of the CCS will be controlled by existing TS requirements and surveillance of the reactivity worth will be performed at acceptable intervals, proposed TS 6.6.2.2 is acceptable to the NRC staff. The staff reviewed the methods that the licensee used to calculate the reactivity effects of the fully loaded fission converter coupled to the MITR core with the CCS going from full closed to full open. This calculated value, which will be experimentally verified, is less than the movable experiment limit in the licensee's current TSs (TS 6.1.1). The staff concludes that this reactivity effect is small and within the TS limit and is therefore acceptable.

2.3.2 Fission Converter Power Level

Because the fission converter is a subcritical system, the power level of the fission converter is directly related to the power level of the MITR. The MCNP code was used by the licensee to determine the fission converter power level. For various combinations of fuel loading and coolant type, the highest calculated fission converter power level with the MITR operating at 10 MW(t) is 251 kW(t) with the aluminum block in place and 316 kW(t) without the aluminum block in place for forced convection operation of the converter. Although the MITR is currently licensed to operate at 5 MW(t), the licensee has performed the analysis for the fission converter assuming a reactor operating power level of 10 MW(t). Therefore, unless otherwise stated, all analysis and proposed TSs are associated with a 10-MW(t) reactor power level driving the converter. The power level of the converter for a given combination of reactor power level, coolant type, and uranium-235 content of the fission converter fuel will be estimated prior to initial use and confirmed during initial use (proposed TS 6.6.4-8). The staff examined the technique that the licensee used to calculate the fission converter power level relative to the reactor power and finds the technique acceptable. On the bases of our review of the licensee's determination of fission converter power and because fission converter power level will be verified during start up tests, the staff concludes that the licensee's calculation of fission converter power level is acceptable.

2.3.3 Power Distribution

In addition to the above neutronic calculations, the radial and axial power distributions from fission induced in the converter were determined by the licensee for various combinations of coolant and fresh fuel in the fission converter with the MITR at 5 and 10 MW(t). The power distributions, the hot channel factors, fuel loading, and k_{eff} of the fueled section of the fission converter were calculated using MCNP. These are the subject of some of the provisions of proposed TS 6.6.2.1 and are the basis of the thermal hydraulic calculations used to determine the safety limits and the limiting safety system settings. Proposed TS 6.6.2.1-1 requires that the fraction of the total power deposited in the fuel region multiplied by the ratio of the maximum power deposited in the hottest fuel plate to the average power per fuel plate (nuclear hot channel factor) not exceed 1.53. The purpose of this proposed TS is to ensure that the converter is operated within the bounds of the licensee's safety analysis which calculated a maximum nuclear hot channel factor (for fresh fuel cooled by heavy water) of 1.53. The licensee assumed that all power is deposited in the fuel region. Proposed TS 6.6.2.1-3 requires that after a fuel loading change that might increase the hot channel factor, an evaluation, approved by two senior reactor operators, must be made to ensure that TS 6.6.2.1-1 continues to be met. It was determined by the licensee that the orientation of the fuel element plates was important to ensure that the axial power profile was not excessively peaked. The allowable orientation is with the edge of the plates toward the reactor core. Restriction of the orientation of the fuel elements to plate edge-on is the subject of proposed TS 6.6.2.1-7. These proposed TSs are acceptable to the staff because they help ensure that the fission converter will be operated within its design limits. The staff has reviewed the method and the application of MCNP that the licensee used to calculate the power distribution and hot channel factors and finds them to be acceptable. Therefore, the staff concludes that the licensee has properly determined the power distribution of the fission converter and will control the power distribution to acceptable limits.

2.3.4 Conclusions

Based on our technical review of the information presented by the licensee in their application for license amendment, the staff concludes that the design and the analyses of the fission converter neutronic design, important aspects of which are to be verified with start up testing, provide assurance that operation of the fission converter facility within the proposed TSs will not pose a threat to the health and safety of the MITR staff, the public and the environment.

2.4 Fission Converter Thermal Hydraulic Design

2.4.1 Fission Converter Coolant and Cleanup Systems

Figure 5 presents an isometric view of the fission converter tank, which illustrates the flow pattern during forced convection cooling of the converter. Proposed TS 6.6.4-1 states that the fission converter primary coolant system can utilize either light or heavy water as a coolant. By removing the inlet cooling pipes, a natural convection circuit can be established and the fission converter can operate at low power levels. Natural convection operation at low power levels with the tank lid removed will facilitate activities such as neutron flux measurements in the fueled region. Administrative procedures and as low as reasonably achievable techniques will be used to limit personnel dose when operating in the natural convection mode.

Figure 7 is a schematic drawing of the heat removal system of the fission converter. Also shown on this drawing are the ion exchange water clean up system and the makeup water system. Proposed TS 6.6.4-6 concerning design features of the cooling system requires that pumps and other components of the fission converter's primary cooling system be located to prevent uncovering of the fission converter fuel elements as a result of siphoning. Because it will help to ensure that the fuel elements remain covered with coolant, this TS is acceptable to the staff. The staff finds that the design of the cooling system meets this requirement.

The coolant system incorporates two primary coolant pumps, either one of which can provide the required flow. This redundancy is provided to decrease the probability of a complete system shutdown due to a loss of flow.

An auxiliary pump (clean up pump) is used to maintain a small flow through the cleanup loop. This pump may also be used to remove decay heat from the fission converter after shut down.

The licensee has proposed TS 6.6.2.6 on primary coolant quality requirements to control corrosion of the fission converter fuel and components, and to control activation products in the fission converter coolant. The proposed TS 6.6.2.6 reads as follows:

1. The pH of the fission converter primary coolant shall be kept between 5.5 and 7.5, except as noted in provision (4) below.

2. The conductivity of the fission converter primary coolant shall be kept less than 5 μmho/cm at 20°C, except as noted in provision (4) below.

3. Any gross β-γ sample activity that exceeds the average of the previous monthly values (normalized by power) by a factor of three or more shall be investigated to determine the cause.

4. Operation of the fission converter with the pH or conductivity outside the limits given in (1) and (2) above is permitted provided:

    a. the pH is between 5.0 and 8.0,

    b. any increase in conductivity is not the result of a chloride ion concentration in excess of 5 ppm,

    c. sampling of the fission converter coolant is done at least once every eight hours, and

    d. the pH band specified in provision (1) is re-established within 48 hours.

Otherwise, the fission converter shall not be operated.

The licensee has also proposed an associated surveillance interval in TS 6.6.3-4 that reads as follows:

4. The pH and gross β-γ activity of the fission converter primary coolant shall be determined at least monthly. The conductivity of the fission converter primary coolant shall be determined either by a continuous on-line instrument or a monthly sample. The tritium content of the coolant shall be determined quarterly if D_2O is used as the fission converter primary coolant.

The pH and conductivity values proposed by the licensee are standard for systems that contain aluminum alloys and stainless steel and have been found acceptable in the past by the staff. The short period of time that the licensee is allowed to operate the converter at higher pH levels with limits on chloride ion concentration is acceptable to the staff because pH is still controlled and the amount of time that the condition exists is limited. The gross activity samples will provide a timely indication of fuel cladding failure and is acceptable to the staff. The tritium content of heavy water is determined for health physics reasons and is acceptable to the staff.

The proposed surveillance intervals are acceptable to the staff based on the low power level of the fission converter and the fact that out of specification coolant chemistry in the MITR is very unusual.

Secondary cooling is provided by the existing MITR secondary cooling system that is designed for a total of 6 MW(t). This is sufficient to handle the combined MITR heat load and the 125 kW(t) predicted heat load of the fission converter if the reactor is operated at 5 MW(t). If reactor power level is raised, coolant temperature limits would determine operating time of the reactor and fission converter if additional heat removal capacity is not added to the secondary cooling system.

The staff has reviewed the licensee's analysis and concludes that the existing MITR secondary cooling system is adequate to remove the combined heat loads of the MITR and the 125 kW(t) predicted heat load of the fission converter if the reactor is operated at 5 MW(t).

2.4.2 Fission Converter Cover Gas System

Figure 8 presents a schematic drawing of the helium cover gas system for the fission converter. The cover gas system has several important functions. These include maintaining the quality of the D_2O (if used), inhibiting the production of nitrous oxide, minimizing Argon-41 production, and providing a means to monitor for fission gases that would indicate a fuel element clad failure. An additional function is to provide an inert atmosphere for the circulation of radiolytic decomposition products through a recombiner. The conditions of operation of this recombiner are specified in proposed TS 6.6.2.4. This TS limits D_2 and H_2 concentration in the helium blanket to not exceed six volume percent, requires the recombiner to be operated for a minimum of five hours per month in any month that the converter was operated, and contains a requirement that if the recombiner is not operable, fission converter operation may continue as long as samples of the helium blanket are taken weekly and the D_2 or H_2 concentration in the helium blanket does not exceed two volume percent. The licensee has based operation and operating limits of the cover gas system on the similar system for the MITR which has been in use for many years without incident. The cover gas system is protected against over pressure with a relief valve and a rupture disk. The nominal relief setting of the valve and the nominal rupture pressure of the disk will be 4 psig and 5 psig respectively. The licensee states that the fission converter tank will be tested to 10 psig.

The staff reviewed the description of the cover gas system that the licensee is proposing. The design is based on the considerable incident free experience with a similar system used with the MITR. The pressure testing of the system and the use of the proposed over pressure protection is additional conservatism in the design. For these reasons the design as proposed by the licensee is acceptable to the staff.

2.4.3 Materials

All materials used in the fabrication of the converter system are compatible with each other and with the H_2O or D_2O coolant. These materials are primarily aluminum alloys and stainless steel. Proposed TS 6.6.4-2 concerning fission converter design features states:

2. All materials that are in contact with primary coolant, including those of the converter tank, shall be aluminum alloys, stainless steel, or other materials that are chemically compatible with H_2O and D_2O coolant, except for small non-corrosive components such as gaskets, filters, and valve diaphragms.

Because the licensee proposes the use of standard materials that have been successfully used in non-power reactors, the materials used in the fission converter design and proposed TS 6.6.4-2 are acceptable to the staff.

2.4.4 Calculations for the Forced Convection Cooling Mode

The thermal hydraulic calculations have been performed by the licensee for the highest power level configuration with the aluminum block, D_2O coolant, and fresh fuel elements present. In this configuration, the maximum fission converter power with the MITR operating at a power level of 10 MW(t) is 251 kW(t). The forced convection cooling system has therefore been designed to remove 300 kW(t).

The licensee has proposed a TS requirement on the flow through the fuel elements for both forced and natural convection flow. Proposed TS 6.6.2.1-2 requires that the fueled region coolant flow factor (F_f) multiplied by the channel flow disparity factor (d_f) be greater than or equal to 0.80. The purpose of this TS is to help ensure that the design of the fission converter fueled region is covered by the licensee's analysis. The values of the fueled region coolant flow factor and channel flow disparity factor are based on measurements and experiments with fuel elements and the MITR. The staff has reviewed these design requirements in the licensee's analysis and finds them acceptable. Because the purpose of this TS is to ensure that the licensee's analyses are applicable to the fission converter, this proposed TS is acceptable to the staff.

Onset of significant voiding has been selected as the criterion for the derivation of safety limits. Onset of nucleate boiling has been selected as the criterion for the establishment of limiting safety system settings. In addition, thermal hydraulic calculations show only small differences between a 10 and 11-element loading of the converter during forced convection mode. Proposed TS 6.6.2.1-4 requires that all positions in the fueled region of the converter be filled with either a fuel element or another approved unit. If the converter will be operated with other than 10 or 11 elements in forced convection flow or other than 11 elements for natural convection flow, proposed TS 6.6.2.1-4 requires that the safety limits, limiting safety system settings and other important TS parameters be reevaluated. The reason for these limits is that calculations by the licensee show significant changes in the safety limit and limiting safety system setting curves if the number of fuel elements drops below the TS limit. Therefore, operation under those conditions must be carefully evaluated.

A computer code, MULCH-FC, was written by the licensee to model the primary and secondary coolant systems of the fission converter. It is based on the MULCH-II code, that was developed at the MIT Nuclear Reactor Laboratory for the safety analysis of the MITR reactor. The code was benchmarked using steady state and transient experimental data for the MITR. The licensee determined that the code calculations of onset of flow instability compared satisfactorily with correlations derived from experimental data. The licensee modified the

MULCH-II code for the fission converter to evaluate the thermal hydraulic design options. This modified code was called MULCH-FC. It was modified by adding six special features to enhance its usefulness. The licensee has described the code and its application in detail. This computer program was used to calculate steady state operating conditions, safety limits and limiting safety system settings for the converter.

The staff reviewed the description of the code, its history and the licensee's use for the design of the fission converter facility. The fact that the parent code, MULCH-II, was properly applied for the safety analysis of the MITR, and successfully benchmarked using experimental and operational data from the MITR is indication that the code is well written and was correctly applied by the licensee. This also demonstrates that the licensee is qualified to modify the MULCH-II code to create MULCH-FC and use it correctly for the thermal hydraulic design of the fission converter facility. The staff finds the licensee's development, verification, and application of MULCH-FC acceptable for this analysis.

Using the MULCH-FC code the licensee determined the safety limits for the fission converter facility. The safety limits were chosen such that onset of significant voiding was not reached. It has been observed experimentally that onset of significant voiding occurs before onset of flow instability and can be more accurately predicted. In turn, the licensee has found that safety limits based on onset of flow instability are more conservative than those based on applicable critical heat flux correlations. Therefore the use of onset of significant voiding as a criterion for the safety limits provides additional conservatism. Figure 9 shows the results of the fission converter safety limit calculations for forced convection. Points to the left of the curves represent operating conditions at which onset of significant voiding will not occur as long as the operating limits are satisfied. The basis of the safety limits is that as long as onset of significant voiding is not reached the fuel will be adequately cooled and the fuel and cladding integrity will be maintained. The staff has reviewed the licensee's basis for the determination of the safety limits for the fission converter and finds that the use of onset of significant voiding is conservative and acceptable. The staff concludes that the conditions specified in proposed TS 6.6.1.1-1 for the safety limits of the fission converter facility in the forced convection mode give reasonable assurance that the fuel and cladding integrity will not be lost as long as those limits are not violated.

2.4.5 <u>Calculations for the Natural Circulation Cooling Mode</u>

For natural circulation operation, the pressure drop equation was solved by the licensee to obtain the flow rate through the fuel region. The temperatures in the average and hot channels were then calculated by the licensee based on the natural circulation flow rate. The thermal hydraulic calculations were performed with the aluminum block, D_2O coolant, and fresh fuel elements present. The calculations show significant differences in safety and operating limits between a 10 and a 11-element converter. Therefore, as discussed above, the TSs only allow 11 fuel elements in the converter when it is used in the natural convection mode.

Similar to forced convection mode, using the MULCH-FC code the licensee determined the safety limits for the fission converter facility during natural convection mode. The safety limits were chosen such that onset of significant voiding was not reached. The basis of the safety limits is that as long as onset of significant voiding is not reached the fuel will be adequately cooled and the fuel and cladding integrity will be maintained. Figure 10 shows the result of the safety limit calculations of the fission converter in natural circulation mode. Points to the left of the curve represent the operating conditions at which onset of significant voiding will not occur as long as the operating limits are satisfied. The safety limit in proposed TS 6.6.1.1-2 for the natural convection mode of operation is based on these results. The staff has reviewed the licensee's basis for the determination of the safety limits for the fission converter and finds that the use of onset of significant voiding is conservative and acceptable. The staff concludes that the conditions specified in proposed TS 6.6.1.1-2 for the safety limits of the fission converter facility in the natural convection mode give reasonable assurance that the fuel and cladding integrity will not be lost as long as the safety limits are not violated.

The licensee proposed TS 6.6.2.1-8 which requires that the fission converter tank lid be in place and sealed for operation at fission converter power levels greater than 20 kW(t). The licensee's calculations show that radiation levels at the top of the tank would be at acceptable levels (about 450 mr/hr) at the coolant surface with a coolant height of 2.4 meters. This would allow access to the fission converter during operation. Existing administrative controls would be used to limit radiation exposure to persons. The staff finds that operation of the fission converter up to 20 kW(t) with the tank top off is acceptable because radiation exposures will be controlled. Therefore, this proposed TS is acceptable to the staff.

2.4.6 Determination of Limiting Safety System Settings for Forced Convection Cooling Mode

For the fission converter, limiting safety system settings are those limiting values for settings of the safety channels by which point protective action must be initiated to prevent safety limits from being exceeded during abnormal situations. The calculation of limiting safety system settings includes the process uncertainty, the overall measurement uncertainty and transient phenomena of the process instrumentation. The limiting safety system settings have been determined by the licensee for the highest power level configuration of forced convection with the aluminum block present, D_2O coolant, and either 10 or 11 fresh fuel elements. The results are presented in Figure 11. The licensee picked preventing onset of nucleate boiling as the basis of the limiting safety system settings. Onset of nucleate boiling occurs before onset of significant voiding giving additional conservatism and therefore additional safety margin. Points to the left of the curve represent the operating conditions at which onset of nucleate boiling will not occur as long as the operating limits are satisfied. The licensee also considered process and measurement uncertainty and instrumentation response in their determination of the limiting safety system settings. The following limiting safety system settings (proposed TS 6.6.1.2-1) are proposed by the licensee for operation with forced convection:

Parameter	**Limiting Safety System Setting**
Fission Converter Power (P)	300 kW (max)
Primary Flow W_p	45 gpm (min)
Ave. Primary Outlet Temperature (T_{out})	60^0 C (max)
Fission Converter Tank Level (above top of fuel element) (H)	2.1 m (min)

The staff has reviewed the licensee's analysis and has determined that the methods used are appropriate for application to the proposed fission converter facility and are very conservative. Based on these considerations the staff concludes that the conditions specified in proposed TS 6.6.1.2-1 for the limiting safety system settings of the fission converter facility in the forced convection mode give reasonable assurance that the fuel and cladding integrity will not be lost during abnormal situations when the fission converter facility is operated at licensed power levels and within the proposed limits.

2.4.7 Determination of Limiting Safety System Settings for Natural Circulation Cooling Mode

During natural convection cooling, the licensee's analysis showed that the prediction of onset of nucleate boiling coincides with that of onset of significant voiding because of the low coolant flow rates. Therefore, the limiting safety system settings for natural circulation are established by adding a 5 °C margin to the calculated values for the natural convection safety limit (Figure 10). The licensee has calculated that this allows sufficient margin for process uncertainty, overall measurement uncertainty and transient phenomena of the process instrumentation instrument response. The configuration is with the aluminum block present, D_2O coolant, and 11 fresh fuel elements. The result is presented in Figure 12. The following limiting safety system settings (proposed TS 6.6.1.2-2) are proposed by the licensee for operation in the natural circulation mode:

Parameter	**Limiting Safety System Setting**
Fission Converter Power (P)	20 kW (max)
Fission Converter Tank Mixing Temperature (T_{mix})	60^0 C (max)
Fission Converter Tank Level (above top of fuel element) (H)	2.5 m (min)

The staff has reviewed the MITR analysis and has determined that the methods used are appropriate for application to the proposed fission converter facility operation during natural convection mode and are very conservative. Based on these considerations the staff concludes that the conditions specified in proposed TS 6.6.1.2-2 for the limiting safety system settings of the fission converter facility in the natural convection mode give reasonable assurance that the fuel and cladding integrity will not be lost during abnormal situations when the fission converter facility is operated at licensed power levels and within the proposed limits.

2.4.8 Conclusions

Based on the information presented above, the staff concludes that the thermal hydraulic design and analyses of the fission converter facility are adequate. Operation within the proposed TSs provides reasonable assurance that operation of this facility in either the forced or natural circulation mode is safe.

2.5 Fission Converter Shutters and Medical Therapy Room Design

The design of the shutter system and medical therapy room associated with the fission converter is based on the safety considerations established during the review and licensing of the existing medical therapy beam. There are three shutters associated with the fission converter. The CCS controls the neutrons reaching the fission converter from the reactor and thus controls the power and radiation generated by the fission converter. The water shutter and mechanical shutter provide shielding to ensure the safety of personnel working in the medical therapy room and are used to control radiation doses to patients. Upon loss of electrical power, only the water shutter will close as water flows by gravity into the shutter. The mechanical shutter can be closed manually in a short period of time.

2.5.1 Converter Control Shutter

The location and the arrangement of the shutters are shown in Figures 3 and 4.

The CCS is located between the reactor core and the fission converter tank. Its purpose is to control the thermal neutron flux from the reactor core to the converter thus controlling the fission converter power. When in the down position, the CCS absorbs more than 99 percent of the incident reactor thermal neutrons.

The shutter is constructed of aluminum followed by cadmium and either Boralyn or Boral. A frame welded to the converter tank only allows vertical movement of the CCS. The CCS movement is controlled by a motor using two cables attached to its top corners. Drive-in and drive-out limit switches are used to stop the motor and to provide the fully open and fully closed indication. Because the licensee uses materials that are used successfully in non-power reactors for similar applications, the materials used in the CCS are acceptable to the staff.

Calculations have been performed by the licensee to determine the fission converter power, the epithermal neutron flux, and fast neutron dose rate at the patient position as a function of CCS position. In addition, as discussed above, the reactivity worth of the CCS has been estimated to be less than 0.002 $\Delta k/k$, which is the MITR TS limit for a movable experiment (TS 6.1.1). The CCS reactivity worth will be verified during the start up testing. Proposed TS 6.6.2.2 contains limiting conditions for operation for the CCS that specify the start up worth measurement and limits the reactivity worth of the CCS to the TS 6.1.1 limit. The staff concludes that the reactivity effect of moving the CCS is small and within existing TS limits and is therefore acceptable.

The licensee has calculated that, with a reactor power level of 10 MW(t), the equilibrium temperature of the CCS when fully closed is 232 °C. This is well below the melting point of any of the materials used in construction of the CCS. To help verify the calculations, a thermocouple will be installed on the CCS during the initial start up testing. The results will also be used to verify, by extrapolation, the maximum equilibrium temperature for 10 MW(t) MITR operation. The licensee's calculations and proposal to measure the CCS temperature during the initial start up testing are acceptable to the staff.

The CCS takes about 60 seconds to go from fully open to fully closed. In the licensee's safety analysis (discussed below in Section 2.7.4), it was shown that with this closure time there is no fission converter fuel damage from overheating even if the reactor fails to scram on loss of primary flow in the converter. There is additional conservatism in the analysis in that the proposed failure scenario requires the unlikely failure of two redundant systems. The staff has reviewed the licensee's analysis and finds their conclusions acceptable.

Because it is an addition of reactivity to the reactor, opening of the CCS is under the control of a licensed reactor operator. The control will be with an OPEN button in the reactor control room. There will be a CCS OPEN button (operable only with the Remote Open Permission key switch ON, see below) on the Fission Converter Medical Room Control Panel (MRCP), which is located near the medical therapy room. Permission may be given by the licensed reactor operator to a trained, non-licensed individual to open the CCS from the MRCP. In this case, the licensed reactor operator must turn the CCS Remote Open Permission Key Switch in the control room to energize the CCS OPEN button at the MRCP. In all cases the licensed reactor operator retains overall control of the CCS opening. The staff concludes that the operation of the CCS is acceptable because licensed reactor operators will oversee opening of the CCS (see Section 2.9 below).

The CCS can be closed from the control room, the MRCP, or the Medical Room Emergency Control Panel (MRECP) located inside the medical therapy room.

The licensee has had considerable experience with similar controls on their existing licensed BNCT facility. That facility has been operated safely for several years. Based on the discussion above, the staff finds the proposed controls for the fission converter facility CCS adequate.

2.5.2 Water Shutter

The water shutter is located in the collimator and provides neutron and gamma ray attenuation. Figure 13 presents a schematic of the water shutter control system.

The shutter water may contain a small amount of boron-10 to increase its shielding effectiveness. The licensee has calculated that the reactivity effects on the reactor or converter because of the use of boron-10 (~1 percent by weight) in this shutter are insignificant.

The normal non-energized position of the controls creates a closed (full) shutter. To open the shutter, a valve must be closed and water pumped from the shutter to the storage tank. The shutter refills by gravity. Opening or closing the shutter will take less than 120 seconds. That time was chosen for operational efficiency only and not for safety considerations. Interlocks are provided to ensure that the shutter closes automatically when the medical therapy room door is opened or the MCRP Key Switch is turned to the OFF position. The full open or full closed positions are indicated on the MCRP.

The water shutter is one of three redundant shutters that "stop" the beam. This shutter closes (floods) by gravity with loss of off site power. The staff concludes that the water shutter is not reactor safety significant and will not have a significant reactivity effect on the reactor. The staff finds that the proposed water shutter design is acceptable.

2.5.3 Mechanical Shutter

The fast acting mechanical shutter is composed of lead and hydrogenous material (e.g., polyethylene). It will be operated by an electric motor. Manual operation is also possible using a hand crank attached to a shaft that penetrates the shield wall.

The opening and closing time of this shutter for the purpose of cutting off the beam in the medical therapy room, when operated electrically, will be less than a few seconds. This is desirable for ending patient treatment and it also will provide rapid closure for abnormal circumstances.

The mechanical shutter is one of three redundant shutters that "stop" the beam. This shutter can be closed manually upon loss of electrical power. The staff concludes that the mechanical shutter is not reactor safety significant and will not have a significant effect on reactivity of the reactor. The staff finds that the proposed mechanical shutter design is acceptable.

2.5.4 Shutter Controls

Shutter controls and displays will be located in the reactor control room, on the MRCP outside the medical therapy room and on the MRECP located inside the medical therapy room. Emergency manual shutter controls will also be provided. These controls and displays are summarized in Table 1 along with interlocks provided.

The licensee has had considerable experience with similar controls on their existing licensed BNCT facility. That facility has been operated safely for several years. The staff finds the proposed controls for the fission converter facility shutters adequate.

2.5.5 Medical Therapy Room Design

The shutters have been designed so that with all shutters closed, the dose rate in the medical therapy room will not exceed 5 mrem/hr with the reactor operating at a power level of 10 MW(t). All personnel, except the patient, will clear the room before any shutter is opened.

The medical room shielding is designed to reduce the radiation levels on the outside of the room to less than or equal to 1 mrem/hr with the reactor operating at a power level of 10 MW(t) and shutters open.

Medical staff may observe the patient by television and through a shielded viewing window. This redundant viewing capability meets the requirements of existing TS 6.5-10. Wall activation in the medical room will be minimized by the use of boron or lithium containing substances applied to the surfaces. A permanent radiation monitoring system will provide information at the MRCP about ambient radiation levels in the room.

The licensee has based their proposed design on their existing BNCT facility. The radiation levels they have estimated will be checked during initial start up. Because radiation levels will be controlled both inside and outside the medical therapy room and radiation levels in the room will be monitored, the staff finds that the proposed design is acceptable for operation of the fission converter. The use of the medical therapy room for use in medical therapy will be the subject of a separate license amendment request.

2.5.6 Medical Therapy Room Door

Access to the medical therapy room will be provided through a shield door that may be operated either manually or electrically. The water and mechanical shutters and shield door are electrically interlocked so that the shutters cannot be opened if the shield door is open. If the water and mechanical shutters are open, they will close automatically if the shield door is opened. The design features of the door are similar to those approved by the NRC for the existing medical therapy room and meets the existing TS 6.5 requirements. Therefore, the staff concludes that the design and operation of the medical therapy room door are acceptable.

2.5.7 Conclusions

The NRC staff reviewed the design of the shutters, the medical therapy room, and their controls and interlocks. The staff concludes from the discussion above that the controls and interlocks for the shutters and the medical therapy room are adequate as described and there is reasonable assurance that the medical therapy room will be operated safely.

2.6 Fuel Handling

The fission converter will use the same fuel as the MITR. Therefore, the handling considerations for fuel for the fission converter including security, storage, and quality assurance are the same as for the MITR fuel.

2.6.1 Fuel Movement

Fuel element movement will be accomplished using the same transfer cask as used for the MITR. Because of the decay heat generated in the fuel, specific rules have been developed and are included in the TSs for fuel removed from the MITR (current TS 3.10- 4). Similar TSs have been developed for the removal of fuel elements from the fission converter. Proposed TS 6.6.2.3-3 contains three conditions, one of which must be met, to transfer a fuel element from the fission converter to the transfer cask. The conditions are based on fission converter operating conditions the four days prior to transfer. The licensee assumed in calculating these conditions that the converter was operated for a long period of time (5 years) at its maximum operating power [250 kW(t)] prior to the four-day period. The reason for the proposed TS is to maintain the fuel clad temperature well below its softening temperature of 450 °C. The conditions during the four days prior to fuel transfer are either (1) continuous operation at or below 50 kW(t), (2) maximum operating time of 4.8 hours per day at or below 250 kW(t), or (3) maximum burnup of 436 kWh per fuel element. These conditions will result in a maximum fuel cladding temperature of 313 °C. In addition, the licensee has proposed TS 6.6.2.1-5 which limits the fuel burnup of fuel used in the fission converter to the existing TSs limit given in TS 3.11-2.e. The staff has reviewed the licensee's analysis, and because the proposed TS requirements will prevent the softening temperature of the fuel cladding from being reached, the conditions for fuel removal from the fission converter are acceptable to the staff.

2.6.2 Fuel Element Self-Protection

Because of the low power level and duty cycle of the fission converter and the fact that the fuel is high-enriched uranium, maintaining the self-protection of the fuel requires special consideration (10 CFR 73.60 is applicable). Self-protection is where fuel elements are irradiated such that the radiation levels of the fuel are so high (greater than 100 rems per hour at a distance of three feet) that the fuel cannot be easily moved without special shielding and thus is very difficult to divert. Calculations and measurements have shown that fuel discharged from the MITR will remain self-protecting for at least 10 years. However, if relatively fresh fuel is used in the converter, a strategy is necessary to ensure that the fuel is self-protecting. The licensee has prepared a strategy that depends on pre-irradiation of fresh fuel elements in the MITR core before they are placed in the fission converter. A protocol will be prepared and approved prior to each refueling of the fission converter to ensure self-protection of the fuel elements. Because the licensee must also maintain fuel self-protecting for the MITR, the licensee has developed acceptable methods of determining if a fuel element is self-protecting.

These methods are the basis for determining if fuel in the fission converter is self-protecting. Proposed TS 6.6.2.3-1 requires that all fuel elements used in the fission converter be maintained self-protecting. The TS further requires that the calculations or measurements documenting self-protection be approved by two licensed senior reactor operators.

Proposed TS 6.6.2.3-2 requires that fission converter fuel elements be stored in accordance with existing TS 3.10-1 and either TS 3.10-2 or 3.10-3 as applicable. TS 3.10-1 requires fuel element storage in accordance with the MITR security plan. TSs 3.10-2 and 3.10-3 contain locations where unirradiated and irradiated fuel may be stored. The licensee has also proposed a change to TS 3.10-3 to add a new TS section, 3.10-3.f. This would add the fission converter tank to the list of locations where irradiated fuel may be located. The licensee has also proposed the basis of the TS be updated to reflect the proposed change in the specification.

Because the licensee will insure that fuel used in the fission converter remains self-protecting, and because security of the fuel and fuel use locations will be in accordance with the existing TSs, as amended to include consideration of the fission converter, the security, storage and handling of the fission converter fuel is acceptable to the staff.

2.6.3 Conclusions

As discussed above, the staff concludes that there is reasonable assurance that the fuel will be handled safely and safeguarded adequately by the licensee. This conclusion is based on a technical review of the information provided by the licensee and the safe operating experience of the MITR staff using similar administrative controls and procedures under the existing TSs.

2.7 Accident Analysis

Accident analysis for the fission converter was performed based on the accident scenarios of the MITR.

2.7.1 Flow Blockage Accident

The maximum hypothetical accident (MHA) for the MITR is a coolant flow blockage of a maximum of 5 of the hottest adjacent coolant channels in the core. This leads to the release of the fission product inventory from 4 fuel plates to the coolant.

Similarly, for the fission converter, a flow blockage is the only accident scenario that leads to the release of fission product inventory. Similar to the MITR, 4 fuel plates are assumed to be damaged, releasing fission products to the fission converter primary coolant. Because of the light duty cycle of the fission converter and its low power level compared to the MITR, the fission product inventory in fuel elements in the fission converter will be much lower than those in the MITR. Elements that are transferred from the MITR to the fission converter will experience significant decay of short lived isotopes that can present a hazard during an accident, such as iodines. Because the fission converter is in the same containment structure as the reactor, the release scenarios once fission products reach the containment building atmosphere are the same for the MITR and the fission converter. Using the conservative assumptions of the analysis of the MITR, the licensee determined that the consequences of this fuel failure for the fission converter are approximately an order of magnitude less than the consequences of the MHA for the MITR. The licensee has calculated a maximum total effective dose equivalent of 65 mrem to the maximum exposed member of the public and a thyroid organ dose of 13 mrem to the maximum exposed member of the public. These doses are less than the 10 CFR Part 20 limits for exposure to the public.

A common mode failure and therefore a simultaneous occurrence of the MHA for the MITR and a flow blockage in the fission converter is not considered credible.

The flow blockage accident for the fission converter is well within the bounds of the MHA for the MITR and simultaneous occurrence is not considered credible. The staff concludes that the projected doses are acceptable for this unlikely event.

2.7.2 Insertion of Excess Reactivity

The licensee considered two scenarios:

(1) A step reactivity insertion in the MITR where the consequences propagate to the fission converter; and

(2) A step reactivity insertion in the fission converter itself.

For scenario 1, the licensee looked at a range of reactivity additions to the MITR. The current TSs limit the reactivity that may be added to the reactor by credible failure of experiments or components to 0.018 $\Delta k/k$. Recent calculations by the licensee to support renewal of the reactor license show a reactivity addition of up to 0.024 $\Delta k/k$ can occur before the reactor core experiences damage. The power of the fission converter is directly dependent on the thermal neutron flux coming from the MITR. The power level of the converter is also proportional to the power level of the reactor. Because of this, the important parameter is the total energy generated in the reactor during a step reactivity addition accident. MITR staff analysis shows that an accidental step reactivity addition into the MITR of 0.016 $\Delta k/k$ results in the maximum energy generation due to reactivity feedback effects (such as the generation of voids) that occur as the step addition is increased. The maximum energy step addition results in a maximum fuel temperature in the fission converter of 138 °C that is well below the softening temperature of the fuel cladding.

Based on a review of the licensee's evaluation of this accident, the staff concludes that there is reasonable assurance that the fission converter fuel will not be damaged due to a credible reactivity excursion in the MITR.

For scenario 2, an insertion of excess reactivity into the fission converter does not result in a power transient since the maximum k_{eff} of the converter is about 0.6. Each of the 11 grid positions is filled. Administrative controls on the movement of fuel will be used to prevent the accidental dropping of a 12th element on top of the converter elements. These controls include prior planning of all fuel movements with explicit listing of each move, the concurrence of the reactor console operator, the senior reactor operator in change and the reactor radiation protection person on duty before fuel is moved, and the movement of only one element at a time. Based on a review of the licensee's evaluation of this accident, the staff concludes that the design of the fission converter and the administrative controls that will be in place are sufficient to prevent a reactivity addition accident in the fission convertor.

The MITR staff have considerable experience in controlling reactivity at the MITR. They have well established administrative and operations procedures for handling the MITR fuel and controlling the addition of reactivity into the MITR. The staff has reviewed the licensee's evaluation of reactivity addition accidents in both the MITR and the fission converter and concludes that there is reasonable assurance that there will be no significant radiological risk to the health and safety of the operating staff or the public.

2.7.3 Loss of Primary Coolant

Although no credible scenario can be found which would result in a rapid and complete loss of primary coolant water from the fission converter tank, an analysis has been performed to determine the effect on fuel temperature of such an accident.

Using conservative assumptions, the licensee calculated the time dependent temperature increase for the hottest fuel plate upon loss of coolant. In about one hour, this temperature will reach 383 °C, which is 67 °C lower than the fuel softening temperature. After this time period, the temperature will decrease because of decreasing decay power.

Based on the staff's review of the licensee's analysis, the staff concludes that there is reasonable assurance that the complete and rapid loss of primary coolant will not lead to release of radioactive materials and, hence no risk to the MITR staff, the public or the environment.

2.7.4 Loss of Primary Coolant Flow

The fission converter is designed so that a loss of coolant flow (less than 50 gpm) will automatically initiate a reactor scram and a closure of the CCS, either of which will shut the converter down. Nevertheless, an analysis was performed by the licensee to determine the result if the reactor fails to scram but the CCS responds correctly and closes.

Using conservative assumptions, the analysis predicts that with zero flow and a CCS closure time of 60 seconds, the maximum fuel plate temperature in the fuel is 139 °C, which is well below the fuel softening temperature (450° C).

On the basis of the review of the licensee's analysis, the staff concludes there is reasonable assurance that the loss of primary coolant flow poses no risk to the health and safety of the MITR staff, the public or to the environment.

2.7.5 Loss of One of Two Primary Pumps

The primary coolant system of the fission converter is designed to use two primary pumps operating in parallel during normal operation. Either pump alone is sufficient to deliver a primary flow rate higher than the scram set point (50 gpm). It is intended that treatment of the patient will continue even if one of the pumps fails during irradiation. The licensee performed an analysis to show that the failure of one pump would not lead to excessive coolant temperature.

On the basis of the review of the licensee's analysis, the staff concludes that the loss of one of two primary coolant pumps is not a safety significant event.

2.7.6 Loss of Off Site Electrical Power

The MITR will scram for a loss of off site electrical power. This causes a shutdown of the fission converter. In addition, the water shutter of the fission converter will close automatically upon loss of power. The mechanical shutter will be closed manually. The medical room door can be operated manually.

Emergency power is available from the already operational MITR emergency power system. Although not needed to safely shut down the converter, it will be used to power some select fission converter equipment and instruments.

Based on the staff's review of licensee's application for license amendment, the staff concludes that the electrical power provisions and the manual backup provide reasonable assurance that loss of off site power will not lead to significant risk to the health and safety of the MITR staff, the public and the environment.

2.7.7 Loss of Heat Sink

The secondary cooling for the fission converter is provided by the secondary cooling system for the MITR. The reactor will scram for low secondary flow which turns off the fission converter. If the cooling tower heat transfer capacity is lost and the reactor and fission converter continue to operate (failure of the reactor to scram), an increase in the reactor primary coolant temperature will scram the reactor and an increase in the fission converter primary coolant temperature will cause the CCS to close.

Because of the slow response of the reactor to this transient, the reactor operator can also manually shut down the reactor.

After reviewing the licensee's analysis of this event, the staff concludes there are adequate and redundant controls to prevent a significant threat to the health and safety of the MITR staff, the public, and the environment due to a loss of heat sink.

2.7.8 Mishandling or Malfunction of Fuel

It is not possible to create an accident that was not analyzed by placing fuel elements in incorrect positions on the fission converter grid plate since all accident analyses have been performed with all 11 spaces containing fuel.

The same fuel handling tools and procedural considerations that are used for the MITR will also be used for the fission converter. The MITR fuel handling tools have safety locks to prevent dropping a fuel element. If a fuel element is dropped, the element will fall through water which will limit the fall speed and the impact force. In addition, the properties of the cermet fuel will limit the release of fission products should the clad be scratched or otherwise damaged.

Because the licensee will use licensed operators acting within the proposed TS and implementing procedures to move fuel elements, the staff concludes there is reasonable assurance that fuel will be placed correctly in the fission converter (i.e., 11 elements only in the natural circulation mode, 10 or 11 elements in the forced convection mode, and the elements placed plates on edge to the reactor in both circulation modes). Because of the design of the

MITR fuel elements and the fact they are handled in water, the staff concludes that the remote possibility of a dropped fission converter fuel element does not endanger the health and safety of the MITR staff, the public or the environment.

2.7.9 Experiment Malfunction

The licensee has requested the ability to conduct experiments in the fission convertor such as the replacement of a fuel element in the forced convection mode of operation with an irradiation facility. Experiments that are conducted in the fission converter will comply with MITR TSs that govern samples. A safety evaluation for the experiment will be required which will include experiment malfunction analysis. The licensee has a long history of the successful conduct of experiments.

The staff concludes, based on the safe operating experience of the MITR operations staff in analyzing and conducting experiments, that there is reasonable assurance that experiments will be adequately reviewed and performed safely and therefore, experiments performed in the fission converter would not pose a significant risk of radiation exposure to the MITR staff, the public or the environment.

2.7.10 Natural Disturbances

Safety analyses for natural disturbances for the MITR are directly applicable to the fission converter. By reexamining the MITR analyses for earthquakes, lightning and severe storms, the licensee has concluded that the consequences of these natural disturbances to the fission converter lead, at most, to a safe shutdown of the fission converter.

The staff has reviewed the licensee's analysis presented in the application for license amendment and concludes that there are no significant risks associated with the MITR site that make it unacceptable for operation of the fission converter.

2.7.11 Conclusions

The staff concludes that the licensee has postulated and analyzed sufficient accident initiating events and scenarios to demonstrate that the fission converter is designed acceptably to avoid inadvertent damage that could prevent a safe shutdown of the converter. The staff also concludes that there is no event that the fission converter could undergo that could lead to damage to the MITR. The worst accident that could happen in the converter, a flow blockage event, has consequences that are less than the allowed doses to members of the public given in 10 CFR Part 20. The staff concludes there is reasonable assurance that no credible accident would cause significant radiological risk to the MITR staff, the public, or the environment.

2.8 Instrumentation and Control System

The instrumentation and control system for the fission converter consists of nuclear instrumentation, thermal-hydraulic instrumentation, the fission converter shutdown system instrumentation and other process instrumentation.

2.8.1 Fission Converter Nuclear Instrumentation

The fission converter will be equipped with one or more neutron sensitive nuclear instruments. At least one will be operable before the fission converter is brought to power. Indication of power will be provided in the control room. During forced convection cooling, the occurrence of an over power condition will cause closure of the CCS. This will occur at 275 kW(t), which is 110 percent of the design power. This channel will also provide an alarm (proposed TS 6.6.2.5-3) at 110 percent or less of the converter's nominal operating power using forced convection cooling (to be verified during the start up tests).

The nominal power of the converter depends on the operating power of the MITR, the coolant type (H_2O or D_2O), and the U-235 content of the fuel. The over power protection of the reactor safety system provides protection to the fission converter during the forced convection mode.

For natural circulation operation of the converter, the nuclear instrumentation will be used in a similar manner. However, for additional conservatism, in the natural circulation mode, there will also be a reactor scram at the reactor power level corresponding to a fission converter power level of 20 kW(t) or less (proposed TS 6.6.2.5-4).

The staff has reviewed the nuclear instrumentation design described by the licensee and finds that it is adequate to ensure safe and reliable operation of the fission converter facility. The staff concludes that such a system, along with the other proposed instrumentation, will be effective in maintaining operation of the fission converter facility within the TSs.

2.8.2 Fission Converter Thermal Hydraulic Instrumentation

A thermocouple or equivalent device will be used to measure the outlet temperature of the coolant. The temperature will be indicated in the reactor control room and the signal will provide for automatic closure of the CCS in the event of an over-temperature.

A conductance-type probe or equivalent device will be used to measure the coolant level in the fission converter tank. The level will be indicated in the reactor control room and the signal will provide for automatic closure of the CCS and an automatic reactor scram in the event of low coolant level in the tank.

An orifice plate or equivalent device will be used to measure the primary flow. The flow will be indicated in the reactor control room and the signal will provide for automatic closure of the CCS and an automatic reactor scram in the event of a low flow rate only during forced convection mode.

The staff has reviewed the thermal hydraulic instrumentation design described by the licensee and finds that it is adequate to ensure safe and reliable operation of the fission converter facility. The staff concludes that such a system, along with the other proposed instrumentation, will be effective in maintaining operation of the fission converter facility within the TSs.

2.8.3 Fission Converter Shutdown System

The shutdown system of the converter may cause an automatic scram of the reactor, CCS closure or both. In addition, the converter may be shut down manually with a reactor scram.

Table 2 summarizes the protective actions when the fission converter is operating in the forced convection mode. Proposed TS 6.6.2.5-1 requires these channels to be operable to operate the fission converter.

Table 3 summarizes the protective actions when the fission converter is operating in the natural circulation mode. Proposed TS 6.6.2.5-1 requires these channels to be operable to operate the fission converter.

In addition to the above automatic actions, proposed TS 6.6.2.5-1 requires that a manual reactor minor scram button be available at the MRCP and be operable whenever the fission converter is in use (i.e., not shutdown or secured).

When the fission converter facility is either shutdown or secured, the automatic reactor scrams indicated in the tables above are not required.

The staff has reviewed the fission converter shutdown system design described by the licensee and finds that it is adequate to ensure safe and reliable operation of the fission converter facility. The staff concludes that such a system will give reasonable assurance that the fuel and cladding integrity will not be lost during reactor and fission converter facility operation.

2.8.4 Other Aspects of Instrumentation

Table 4 lists the instrumentation associated with the fission converter. The MRCP is a dedicated panel for devices, such as the shutters, that are related to the beam control and the use of the medical therapy room. The fission converter control panel (FCCP), which is near the MRCP, houses the control and display of the process system instrumentation.

The licensee has had considerable experience with similar instrumentation on their existing licensed BNCT facility and the MITR. The staff finds the proposed instrumentation for the fission converter facility acceptable.

The licensee proposes the use of emergency power. The reactor automatically scrams on loss of power with the coincidental shutdown of the fission converter and the closure of the water shutter by gravity (the mechanical shutter can be manually closed). Emergency power will provide information to the reactor operator and the fission converter user that the fission converter is shut down and assure personnel radiation safety. Proposed TS 6.6.2.5-2 specifies emergency power requirements. Table 6.6.2.5-2 of the TSs specifies the minimum equipment of the medical therapy room radiation monitor, the intercom between the medical control panel area and the reactor control room, the intercom between the medical control panel area and the medical therapy room, emergency lighting in the medical therapy room and associated medical control panel area, and the outlet temperature and coolant level channels to be supplied with emergency power for at least one hour following the loss of normal power. The licensee states that emergency power is not essential for converter safety. The staff finds that the emergency power supplied to the fission converter is not required for reactor or fission converter safety. The staff concludes that the proposed emergency power system provides additional assurance of the health and safety of the public, operations staff, and the environment and is therefore, acceptable.

The licensee has proposed TS requirements for surveillance of important instrumentation. Proposed TS 6.6.3-1 and 6.6.3-2 read as follows:

1. The following instruments or channels for the fission converter safety system will be tested at least monthly and each time before startup of the reactor if the reactor has been shut down more than 16 hours and if the fission converter facility will be used within that reactor operating period. The monthly requirement may be omitted if the fission converter facility will not be used during that month.

Instrument, Channel, or Interlock	Functional Test
Primary coolant flow	Automatic converter control shutter closure and reactor scram
Power level	Automatic converter control shutter closure
Primary coolant outlet temperature	Automatic converter control shutter closure
Fission converter tank coolant level	Automatic converter control shutter closure and reactor scram

2. The following instruments used in the fission converter facility shall be calibrated and trip points verified when initially installed, any time the instrument has been repaired, and at least annually:

    a. Neutron flux level channel,
    b. Primary coolant flow channel,
    c. Primary coolant outlet temperature channel, and
    d. Fission converter tank coolant level channel.

These surveillance intervals are similar to those for the MITR and those specified for this type of instrumentation in ANS/ANSI-15.1 and are therefore, acceptable to the staff.

The licensee has proposed a surveillance requirement (TS 6.6.3-3) for the neutron flux level channel and fission converter primary system heat balance as follows:

3. The neutron flux level channel and a fission converter primary system heat balance shall be checked against each other at least annually and when design changes in the reactor and/or the fission converter are made that may affect the existing calibration result.

These surveillance intervals are also similar to those for the MITR and those specified for this type of instrumentation in ANS/ANSI-15.1 and are therefore, acceptable to the staff.

2.8.5 Conclusions

The MITR operations staff has considerable experience in the design and implementation of reliable, predictable, and redundant instrumentation systems. Upon review of the licensee's information, the staff concludes that the instrumentation is adequate to ensure the safe operation of the fission converter facility within the limits of the TSs. The staff further concludes that there is reasonable assurance that the fission converter shutdown system will prevent a safety limit being exceeded.

2.9 Pre-Operational Tests and Initial Operation and Operator Training

Pre-operational tests will be performed to ensure that the fission converter has been constructed and will operate in accordance with the licensee's design. Dummy fuel elements that replicate flow conditions are available for the pre-operational tests. The tests will be used to establish compliance with the approved TSs. All tests will be conducted in accordance with the existing MITR quality assurance program.

The tests will include component inspection, instrument calibration, and verification that performance objectives are met and the interlocks are operational. Non-nuclear instruments, such as those used for measuring system pressure, temperature, and flow, will be calibrated before the initial start up to ensure that they meet the requirements of the TSs.

Fuel will be loaded into the fission converter element-by-element. Because the licensee intends to initially operate the fission converter with heavy water coolant, irradiated fuel elements loaded into the converter will result in a large amount of photoneutrons, making the use of an inverse count rate verses element loading plot questionable. However, the licensee will verify that the converter is subcritical. Nuclear instruments can only be calibrated after the initial start up of the converter. Therefore, the converter will be operated at a low power level while the initial calibration is performed. Because the reactor currently operates at half the converter design reactor power level of 10 MW(t), there is a large margin of safety with respect to the power level safety limits. The nuclear instruments will be calibrated using a calorimetric or a flux plot method.

After initial fuel loading, additional measurements will be performed before converter power is raised. Measurements will be made of the fuel region flow distribution, reactivity worth of the CCS, and the integral and differential worth of the CCS.

Converter power will be raised to maximum power in a step wise process. The following measurements or tests will be performed:

(1) Bulk coolant temperature correlation to calculated temperature distribution in the converter,

(2) Process parameters such as inlet and outlet temperatures,

(3) Radiation surveys, and

(4) Nuclear instrument calibration.

The step-wise increase in converter power and the above measurements and tests will be repeated if:

(1) The MITR power is increased,
(2) The coolant is changed from H_2O to D_2O,
(3) Fresh fuel is used in place of burned fuel, and
(4) The aluminum block is removed or replaced with another approved unit.

Operator training for reactor operators will consist of specialized instruction on the design and operation of the fission converter. The licensee has successfully conducted a similar training program for the existing facility. This training will be followed by a written examination equivalent to a requalification examination. Future reactor operator candidates will receive training on the converter as part of their initial qualification. If non-licensed individuals are to be used to operate the fission converter, a written qualification program will be prepared for their training. The operation of the CCS or any other mechanism which may affect the reactivity or power level of the reactor will be accomplished only with the knowledge and consent of an operator or senior reactor operator present at the reactor controls in accordance with the requirements of 10 CFR 50.54(j).

A detailed start up program that includes pre-operational tests and initial operation will be prepared before these activities commence. It will be reviewed as part of the NRC inspection program for start up of the fission converter.

A start up report that includes pre-operational tests and initial operation will be prepared by the licensee and submitted to the NRC.

The staff reviewed the licensee's proposed pre-operational tests and plans for initial operation. The staff finds that initial testing is comprehensive and the approach to initial operation is conservative and will verify that the facility was constructed in accordance with its design and will operate within design constraints and the TSs. Therefore, the staff concludes that pre-operational tests and plans for initial operation of the fission converter facility are acceptable.

The licensee is experienced in training of licensed reactor operators and has successfully trained reactor operators and staff in the operation of the current facility. The staff concludes that because the training program is based on the approved requalification program and training for the existing facility, there is reasonable assurance that the operation of the fission converter will be performed by properly trained staff in accordance with the regulations.

2.10 Proposed Changes to the Technical Specifications

This section of the safety evaluation report discusses changes and additions to the TSs requested by the licensee for the fission converter facility that were not discussed in the various sections above.

The licensee proposed updates to the table of contents to reflect the proposed changes to the TSs. This change is administrative in nature and is acceptable to the staff.

The licensee has proposed a new TS section, 6.6, "Design and Operation of the Fission Converter Facility." The proposed applicability section of the TS reads as follows:

Applicability

This specification applies to the operation of the Fission Converter Facility. It does not pertain to the use made of the fission converter beam nor does it apply to the associated medical therapy facility. Use of that facility for the treatment of human patients and/or investigatory studies that involve humans shall be in accordance with the provisions of TS# 6.5 and its associated quality management program.

The provisions of this specification are only applicable if fuel is present in the fission converter tank.

The proposed TS 6.6 does not apply to the use of the medical therapy facility for irradiation of humans. The existing TS 6.5 contains requirements for the medical use of the convertor and the associated medical therapy facility. As discussed in various sections above, the staff used the requirements of TS 6.5 in its evaluation of some aspects of the design and use of the fission converter and the medical therapy facility. The licensee has applied for a separate license amendment for the use of the fission converter facility on humans. The proposed applicability of TS 6.6 also states that the provisions of the TS do not apply if there is no fuel in the converter tank. Without fuel, the converter is not operable and safety concerns do not exist. Because TS 6.5 will govern the use of the fission converter for medical use and because the converter is not operable without fuel, the licensee's proposed applicability section for TS 6.6 is acceptable to the staff.

The licensee has proposed two definitions related to the fission converter, "fission converter shutdown" and "fission converter secured." The definitions of these terms are:

Fission Converter Shutdown

That condition where the converter control shutter is fully inserted or where the reactor is in a shutdown condition. The fission converter is considered to be operating whenever this condition is not met.

Fission Converter Secured

The overall condition where there is no fuel in the fission converter or where all of the following conditions are satisfied:

(a) The fission converter is shut down,

(b) The converter control shutter (CCS) control panel key switch is in the off position and the key is in proper custody, and

(c) There is no work in progress within the converter tank involving fuel.

These definitions are similar to the standard definitions for reactors. They have been modified to be specific to the fission converter. These definitions are used to determine when other TSs are applicable. Because the proposed definitions are similar to accepted definitions for non-power reactors and they determine when other TS are applicable, they are acceptable to the staff.

The fission converter fueled region may be used for experiments similar to the core of the MITR. The licensee has proposed TS 6.6.4-4 which requires experiments run in the fission converter fuel region to meet certain design requirements. The proposed TS reads:

4. The fueled region of the fission converter may contain sample assemblies provided that they conform to the requirements of TS# 6.6.2.1(4). Design of the sample assemblies shall also conform to the following criteria:

   a. they shall be secured either by a mechanical device or by gravity to prevent movement during fission converter operation,

   b. materials of construction shall be radiation resistant and compatible with those used in the fission converter fueled region and primary coolant system,

   c. sufficient cooling shall be provided to insure structural integrity of the assembly and to preclude any boiling of the primary coolant, and

   d. the size of the irradiation thimble shall be less than 16 square inches in cross section.

The proposed TS requirements are based on the current requirements for experiments placed into the reactor which are applicable to the fission converter. The purpose of these restrictions is to protect the integrity of the fission converter fuel elements. Because these requirements are based on the existing TS requirements for experiments which are acceptable to the staff and applicable to the fission converter, the staff finds that they are sufficient to protect the integrity of the fission converter fuel elements and therefore, are acceptable to the staff.

The licensee has proposed reporting requirements for the fission converter in TS 6.6.5 which reads as follows:

1. A written report to the U. S. Nuclear Regulartory Commission Attn: Document Control Desk, U.S. NRC, Washington, D.C. shall be made within 90 days after completion of the startup testing of the fission converter that is required upon receipt of a new facility license or an amendment to the license authorizing an increase in fission converter power level. This report shall describe the measured values of the operating conditions or characteristics of the reactor under the new conditions, including:

   a. An evaluation of facility performance to date in comparison with design predictions and specifications; and

   b. A reassessment of the safety evaluation submitted with the license application in light of measured operating characteristics when such measurements indicate that there may be substantial variance from prior evaluation.

2. The startup report shall include the following items:

   a. calculation of k-effective for the initial fuel loading,

b. measurements and comparison to prediction of flow disparity,

c. determination and comparisons to prediction of nuclear hot channel factor, and

d. fission converter power measurements and calibrations.

The start up testing program for the fission converter is discussed in Section 2.9 above. The purpose of this TS is to ensure that the results of important aspects of the start up program are reported to NRC. The staff has determined that the information in the start up testing program report is sufficient to report the results of important measurements to NRC.

The licensee has also proposed changes to the existing TS for the MITR because of the installation of the fission converter. The licensee has proposed a change to TS 1.1, the definition of "reactor secured." One of the current conditions that must be met as part of the definition of reactor secure is:

3. no work in progress within the main core tank involving fuel or experiments, or maintenance of the core structure, installed control blades, or installed control blade drives when not visibly decoupled from the control blade.

It is proposed that this be changed to:

3. no work in progress within the main core tank and/or the fission converter tank involving fuel or experiments, or maintenance of the core structure, installed control blades, or installed control blade drives when not visibly decoupled from the control blade.

This change extends the definition to include the fission converter. The definition is used in other TSs to determine when systems need to be operable. Extending the definition to the fission converter is acceptable to the staff because work involving the fission converter tank may involve radioactive material in the form of fuel or experiments that should be worked on under controlled conditions that accompany the reactor not being secured.

The licensee is proposing changes to TS 3.8(4) which has requirements for sampling the tritium content of secondary water if the reactor heavy water heat exchangers are being used and to monitor heavy water levels in the heavy water dump tank. The proposed changes would also require sampling of secondary water for tritium if heavy water is used in the fission converter and require the fission converter tank level to be monitored. The purpose of this TS is to help ensure that discharges of tritium from the facility are below regulatory limits by monitoring for leakage of tritium into the secondary system. Because the changes extend the current requirements on heavy water monitoring to the fission converter, they are acceptable to the staff.

3.0 ENVIRONMENTAL CONSIDERATION

This amendment involves changes in the installation or use of a facility component located within the restricted area as defined in 10 CFR Part 20 or changes in inspection and surveillance requirements. The staff has determined that this amendment involves no significant increase in the amounts, and no significant change in the types, of any effluents that may be released off site, and no significant increase in individual or cumulative occupational radiation exposure. Accordingly, this amendment meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9).

This amendment also involves changes in recordkeeping, reporting, or administrative procedures or requirements. Accordingly, the amendment meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(10).

Pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the issuance of this amendment.

4.0 CONCLUSIONS

Based on the staff's review of the licensee's amendment application, it is concluded that the licensee is adequately cognizant of the requirements for the safe design, construction and operation of the fission converter facility and associated medical therapy room. The application provided reasonable evidence that the licensee designed, and will construct, test and operate the facility in accordance with the information in its application, applicable regulations, and the proposed TSs.

Based on its review, the staff concludes that operation of the fission converter within the limits of the TSs will not result in offsite radiation exposures in excess of 10 CFR Part 20 limits. Furthermore, the limiting conditions for operation, surveillance requirements, and fission converter safety system will limit the likelihood of malfunctions and mitigate the consequences to the public of off-normal or accident events.

The staff has concluded, on the basis of the considerations discussed above, that (1) because the amendment does not involve a significant increase in the probability or consequences of accidents previously evaluated, or create the possibility of a new or different kind of accident from any accident previously evaluated, and does not involve a significant reduction in a margin of safety, the amendment does not involve a significant hazards consideration; (2) there is reasonable assurance that the health and safety of the public will not be endangered by the proposed activities; and (3) such activities will be conducted in compliance with the Commission's regulations and the issuance of this amendment will not be inimical to the common defense and security or the health and safety of the public.

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Date: Decebmer 21, 1999

Attachment: Table and Figures

TABLE 1 SUMMARY OF SHUTTER CONTROLS

A. Fission Converter Operation Control Panel (Located in the reactor control room)

A1. Fission Converter ON/OFF Key Switch
This key switch enables flow and level scrams as well as interlocks B1 through B3. It also energizes the fission converter operation control panel.

A2. CCS OPEN button

A3. CCS CLOSE button

A4. CCS Remote Open Permission Key Switch

The above controls are provided with indicator lights.

B. Interlocks

B1. Fission Converter Primary Flow Scram (forced convection) / CCS Open Interlock (TS 6.6.4-7.a)

B2. Fission Converter Coolant Level Scram / CCS Open Interlock (TS 6.6.4-7.b)

B3. Medical Room Shield Door / Water Shutter and Mechanical Shutter Open Interlock

B4. Loss of Electrical Power / Water Shutter Close Interlock

B5. MRCP Key Switch Off / Water Shutter and Mechanical Shutter Close Interlock (TS 6.6.4-7.c)

B6. CCS Key Switch in Off Position / CCS Automatic Closure Interlock (TS 6.6.4-7.d)

B7. Reactor Start Up / CCS Fully Closed Interlock (TS 6.6.4-7.e)

TABLE 1 SUMMARY OF SHUTTER CONTROLS (cont.)

C. Fission Converter Medical Room Control Panel (MRCP)

C1. ON/OFF Key Switch

C2. Minor Scram Button

C3. CCS Close Button

C4. CCS OPEN/CLOSE Display

C5. Mechanical Shutter OPEN/CLOSE buttons and displays

C6. Water Shutter OPEN/CLOSE Buttons and Displays

C7. Medical Room door OPEN/CLOSE Display

C8. CCS OPEN Button (operable only with remote permission key switch in control room ON, see A4)

D. Medical Room Emergency Control Panel (MRECP) (Inside the medical room)

D1. CCS CLOSE Button
D2. Mechanical Shutter CLOSE Button
D3. Water Shutter CLOSE Button

E. Emergency Manual Shutter Controls

E1. Manual Closing of the Mechanical Shutter
E2. Manual Opening of the Fission Converter Medical Room Shield Door

Table 2 Minimum TS Required Safety Channels While Operating with Forced Convection Flow

Channel	Automatic Reactor Scram*	Automatic CCS Closure	Setpoint Range
Power		X	≤ 300 kW(t)
Outlet Temperature		X	≤ 60 °C
Coolant Level	X	X	≥ 2.1 m
Primary Flow	X	X	≥ 45 gpm
Manual Reactor Minor Scram from the Fission Converter Medical Control Panel	X		

* Scram is not required if the fission converter is in either a shutdown or a secured condition.

Table 3 Minimum TS Required Safety Channels While Operating without Forced Convection Flow

Channel	Automatic Reactor Scram*	Automatic CCS Closure	Setpoint Range
Power	X**	X	≤ 20 kW(t)
Outlet Temperature		X	≤ 60 °C
Coolant Level	X	X	≥ 2.5 m
Manual Reactor Minor Scram from the Fission Converter Medical Control Panel	X		

* Scram is not required if the fission converter is in either a shutdown or a secured condition.
** For natural convection operation only.

Table 4 Fission Converter Instrumentation

Parameter	Instrument	Readout Location	Alarm
SAFETY RELATED			
Design power	Neutron detector	CR	Yes
Outlet temperature	Thermocouple or equivalent	CR	Yes
Coolant level (Trip point)	Conductance level probe or equivalent	CR	Yes
Primary flow rate	Orifice plate or equivalent	CR	Yes
NON SAFETY RELATED			
Nominal operating power	Neutron detector	CR	Yes
Hx Secondary flow rate	Flow switch	Local or FCCP	Yes
Primary inlet temperature	Thermocouple or equivalent	Local or FCCP	No
Secondary outlet temperature	Thermocouple or equivalent	Local or FCCP	No
Secondary inlet temperature	Thermocouple or equivalent	Local or FCCP	No
Cleanup system temperature	Thermocouple or equivalent	Local or FCCP	Yes
Coolant conductivity-Ion column inlet	Conductivity probe	Local or FCCP	Yes
Coolant conductivity-Ion column outlet	Conductivity probe	Local or FCCP	No
Cleanup system flow rate	Rotometer or equivalent	Local or FCCP	No
Coolant level indication	Coolant level sensor	Local or FCCP	No
Leak detection	Leak tape or equivalent	Local or FCCP	Yes
Primary coolant pressure (@HX)	Pressure gauge	Local or FCCP	No
Secondary coolant pressure (@Hx)	Pressure gauge	Local or FCCP	No
Medical room gamma monitor	Gamma detector	CR and MRCP	No
CCS position	Limit switches	CR and MRCP	Yes
Mechanical shutter position	Limit switches	CR and MRCP	No
Water shutter tank level	Level probe	CR and MRCP	No
Water shutter upper tank level	Level probe	Local	Yes
Medical room door position	Limit switches	CR and MRCP	Yes
Storage tank level	Gauge	Local or FCCP	No

MRCP: Fission Converter Medical Room Control Panel
CR: Control Room
FCCP: Fission Converter Control Panel

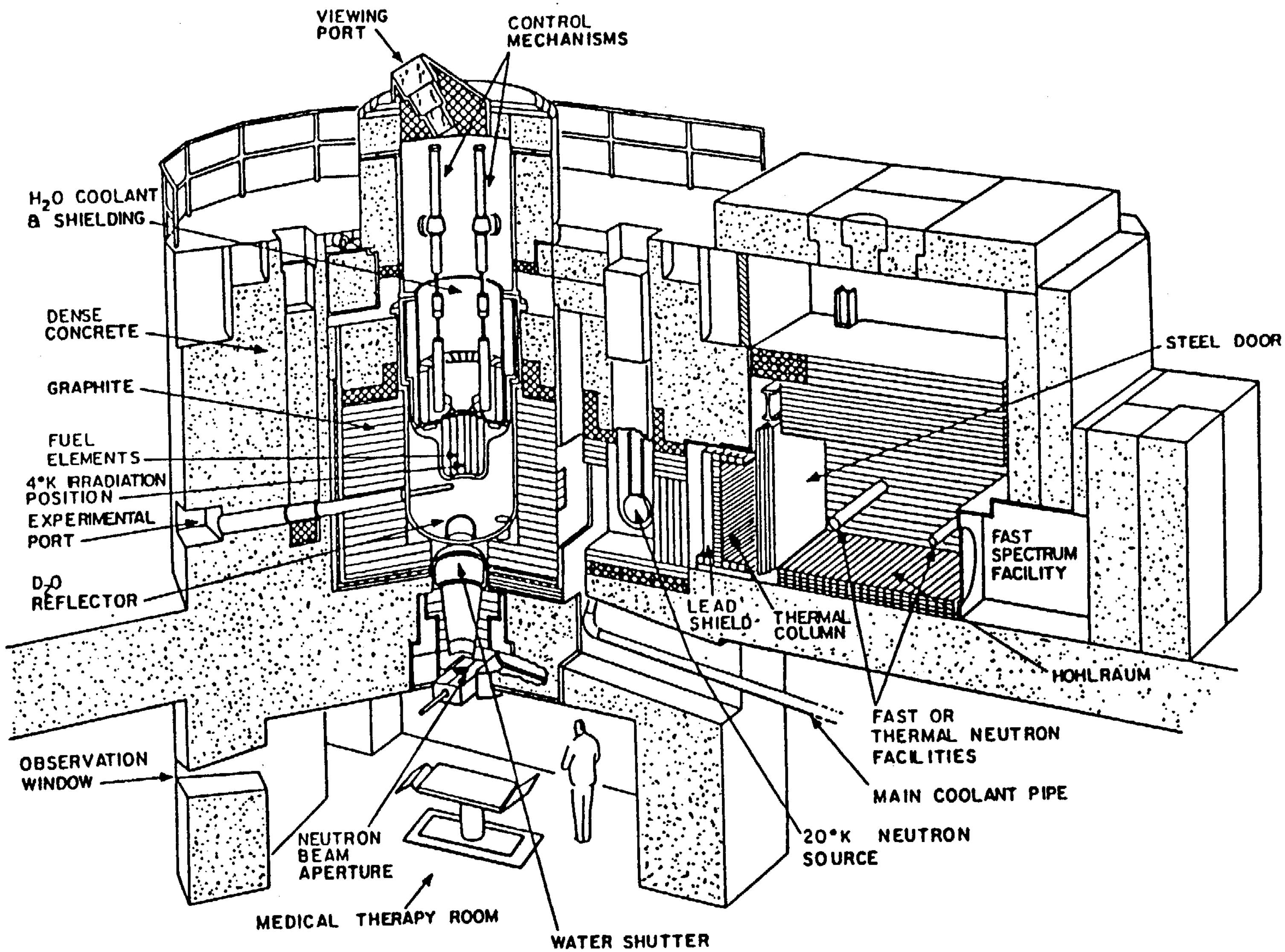

Figure 1 View of the MIT Research Reactor Showing the Major Components

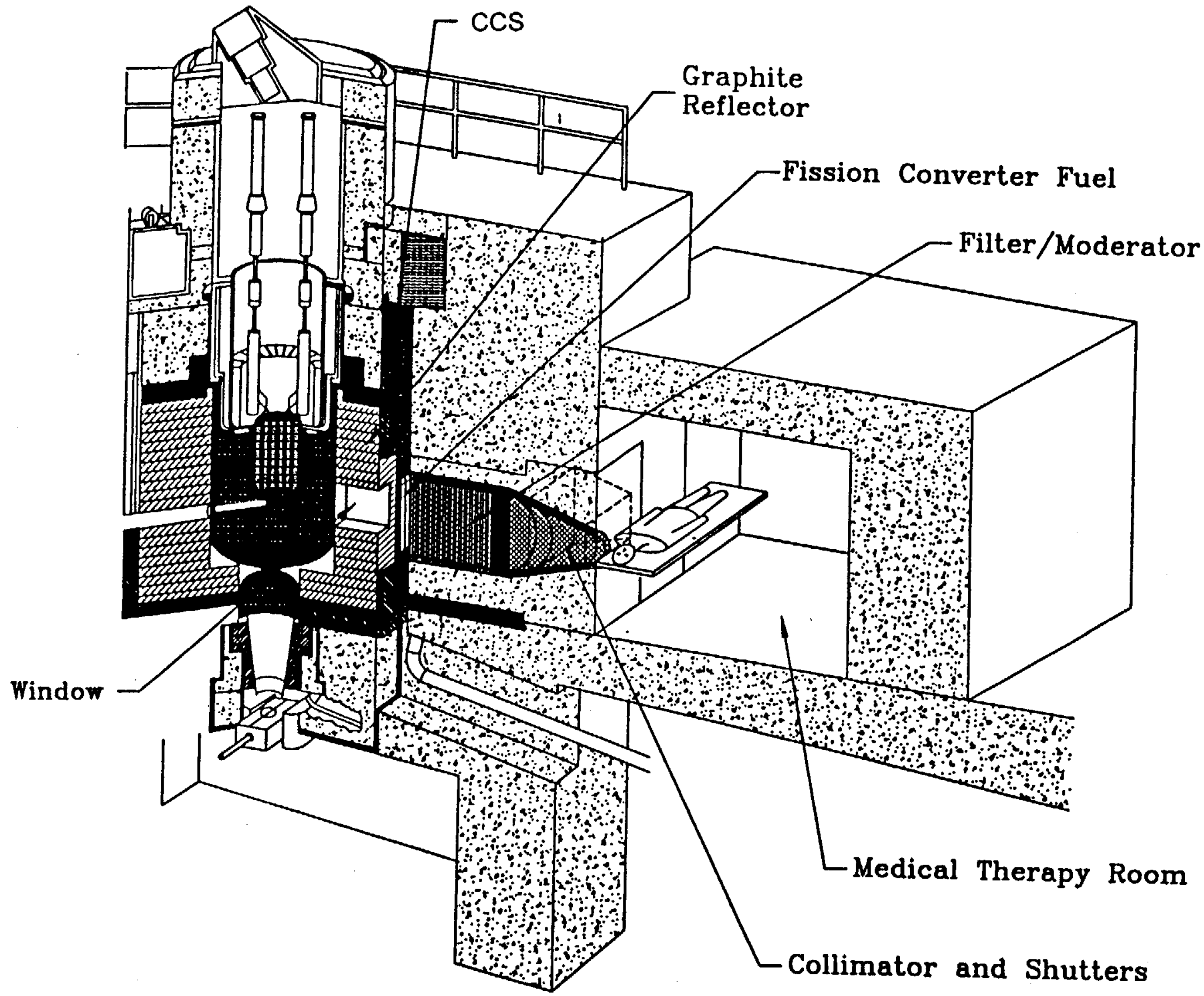

Figure 2 Isometric View of MIT Fission Converter Beam and Medical Therapy Room

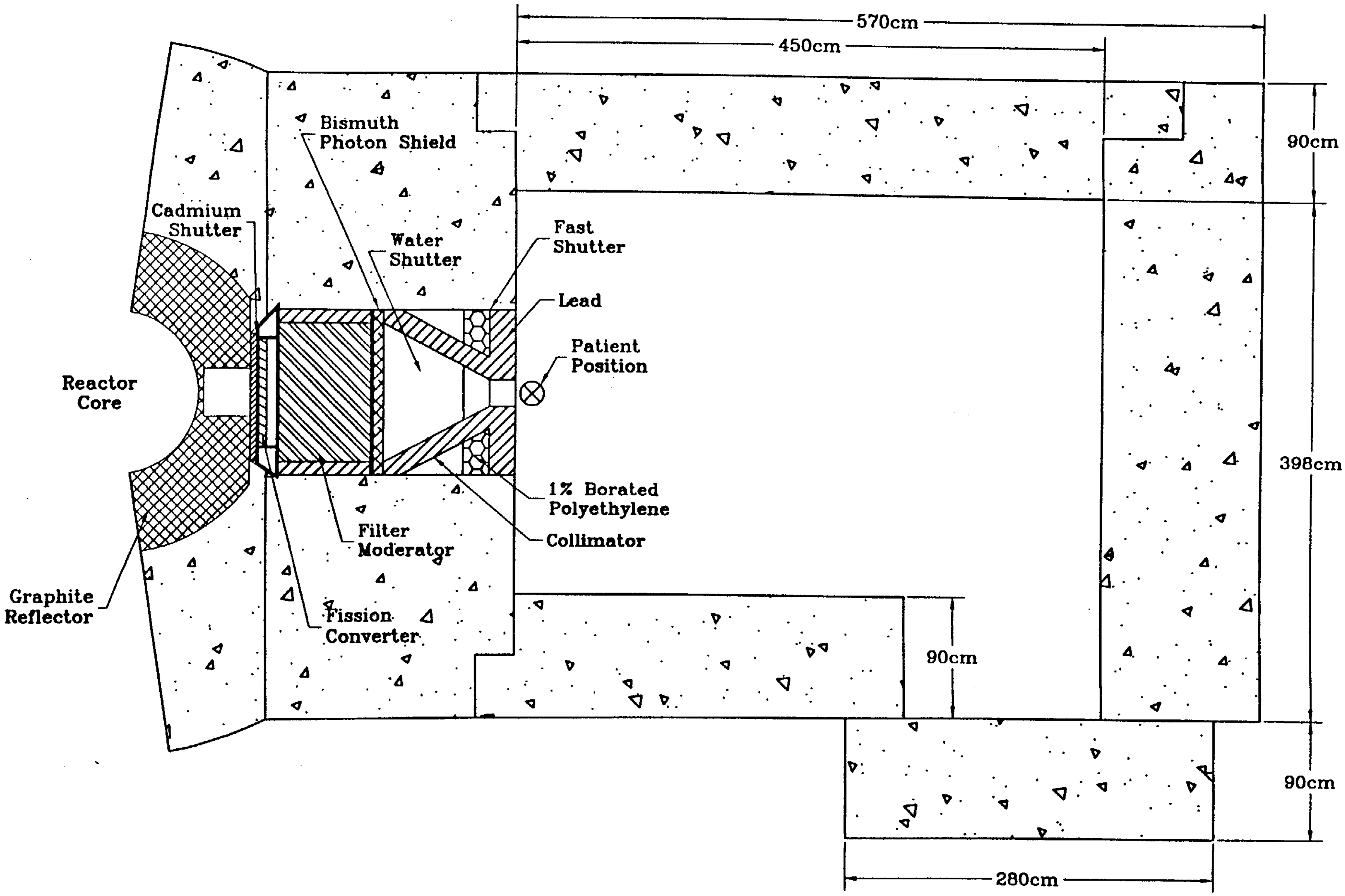

Figure 3 Top View of the Fission Converter Facility

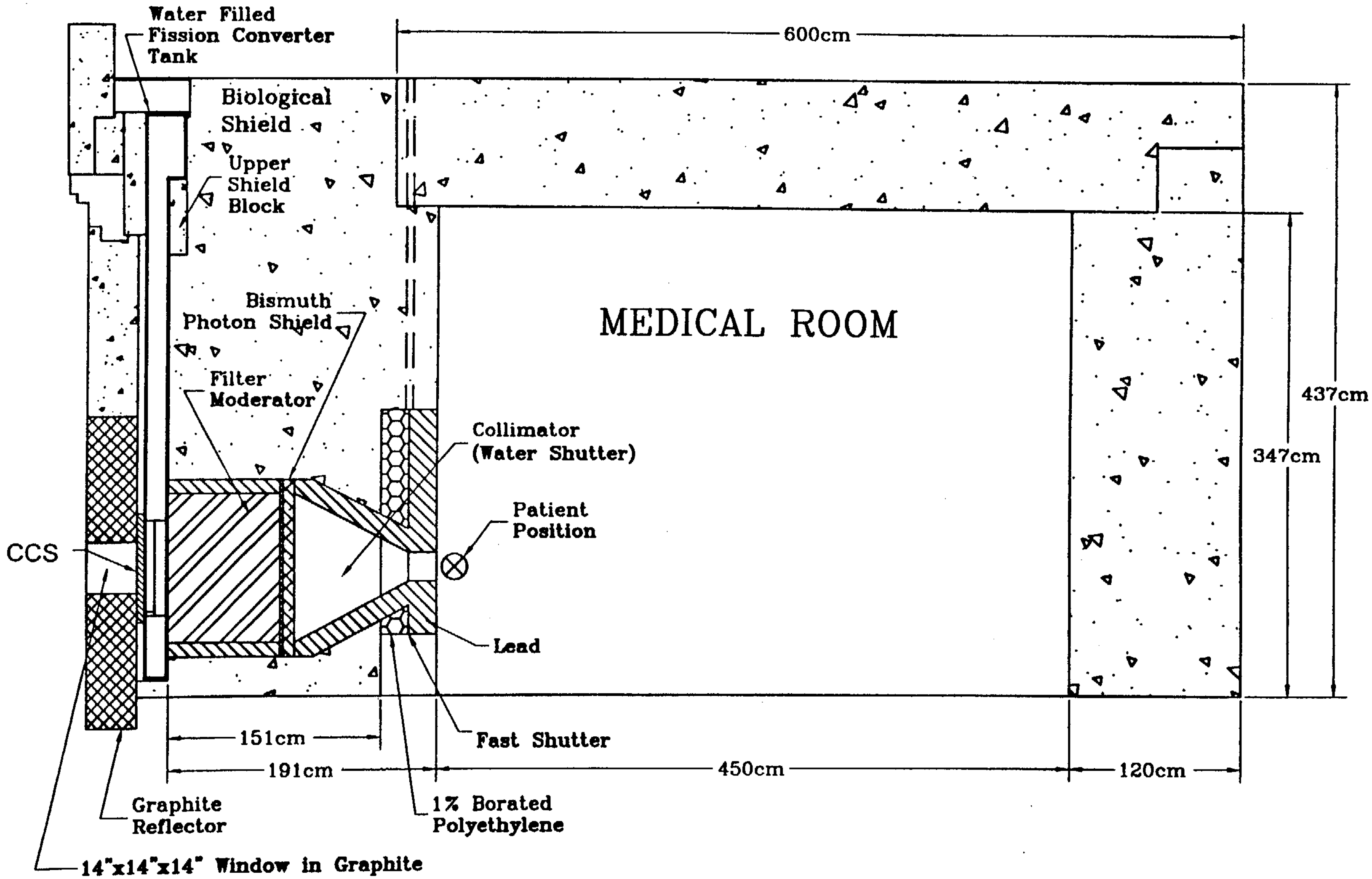

Figure 4 Side View of the Fission Converter Facility

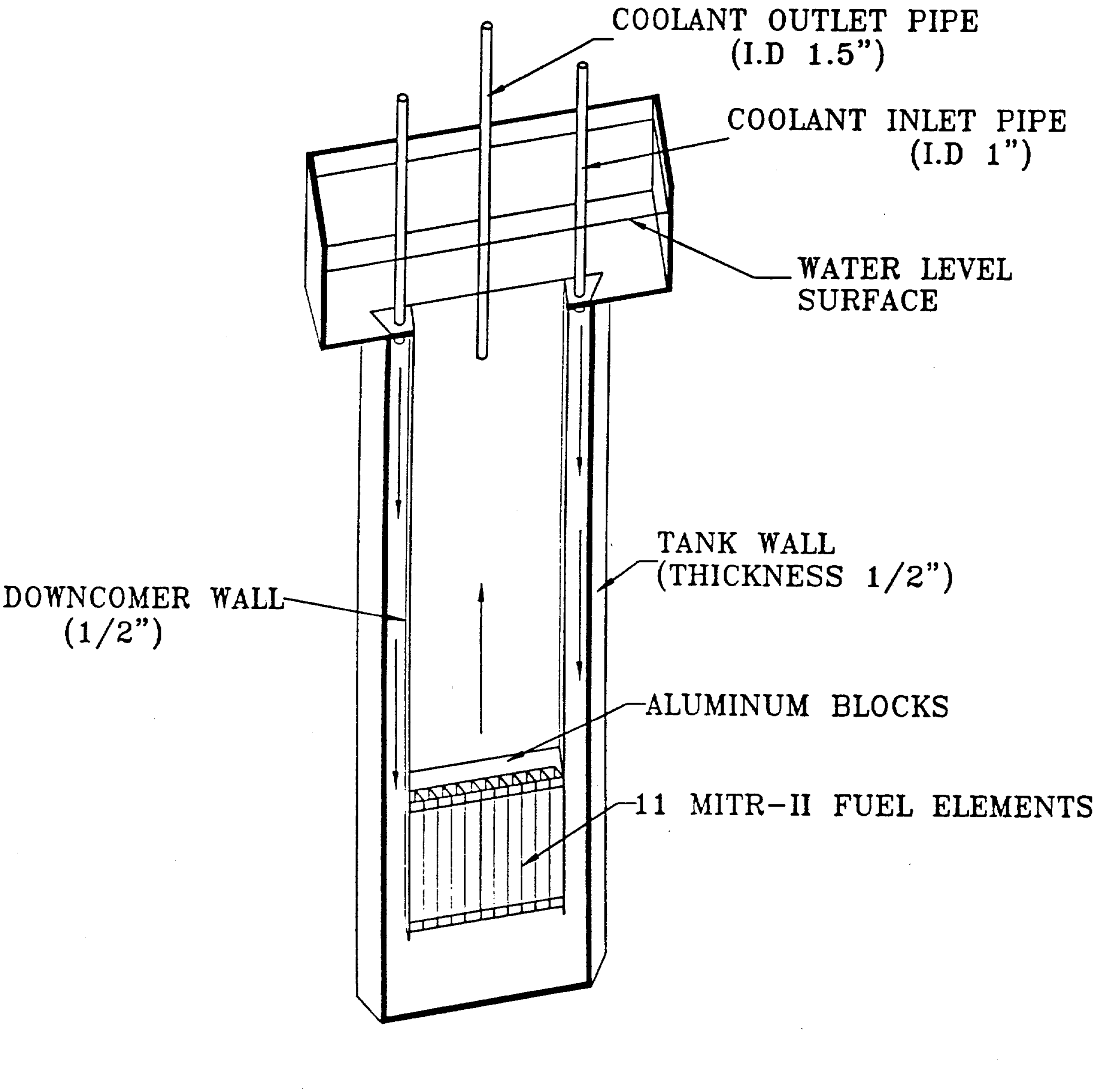

Figure 5 Isometric View of Fission Converter Tank Design

Note: Tank is not symmetrical because of different structures at both ends.

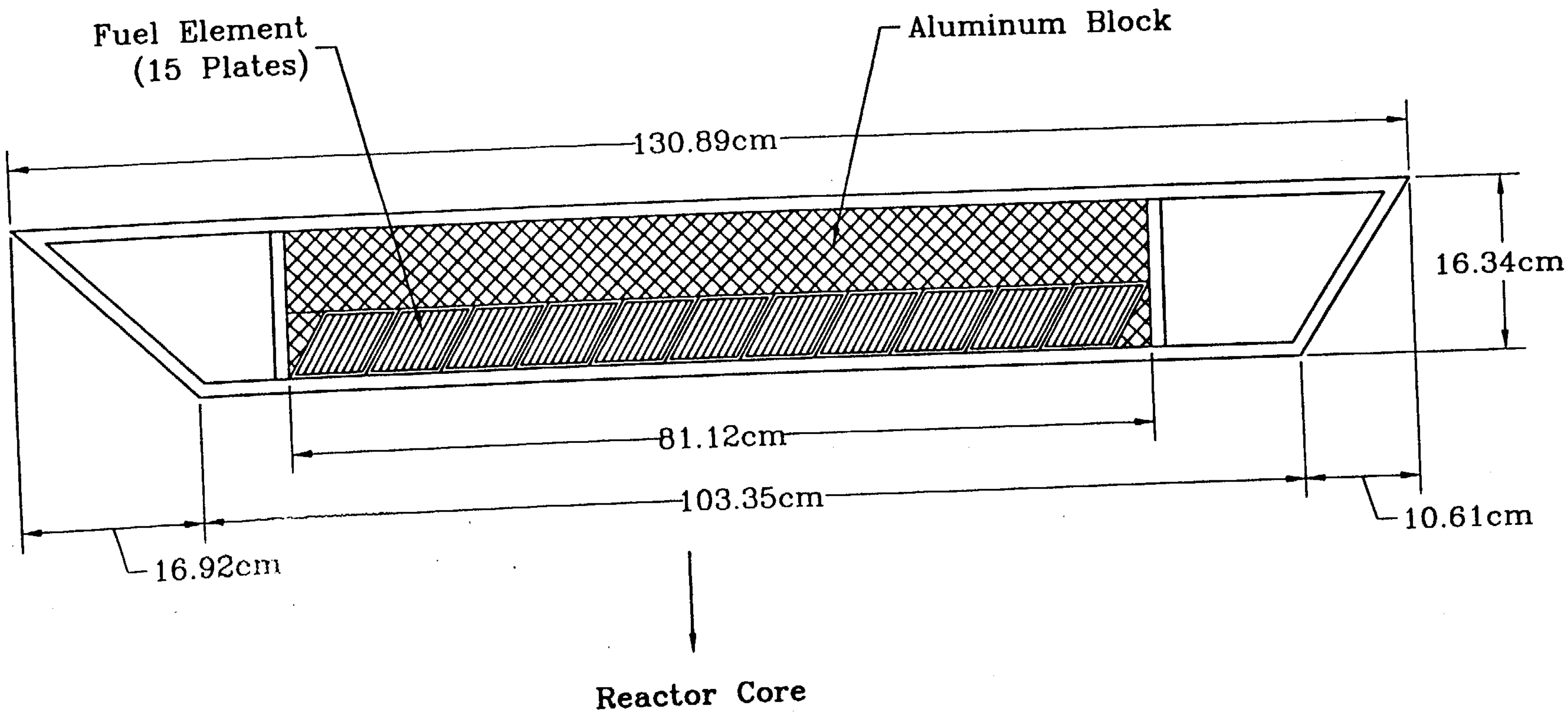

Figure 6 Cross-sectional View of the Fission Converter Tank – Lower Section

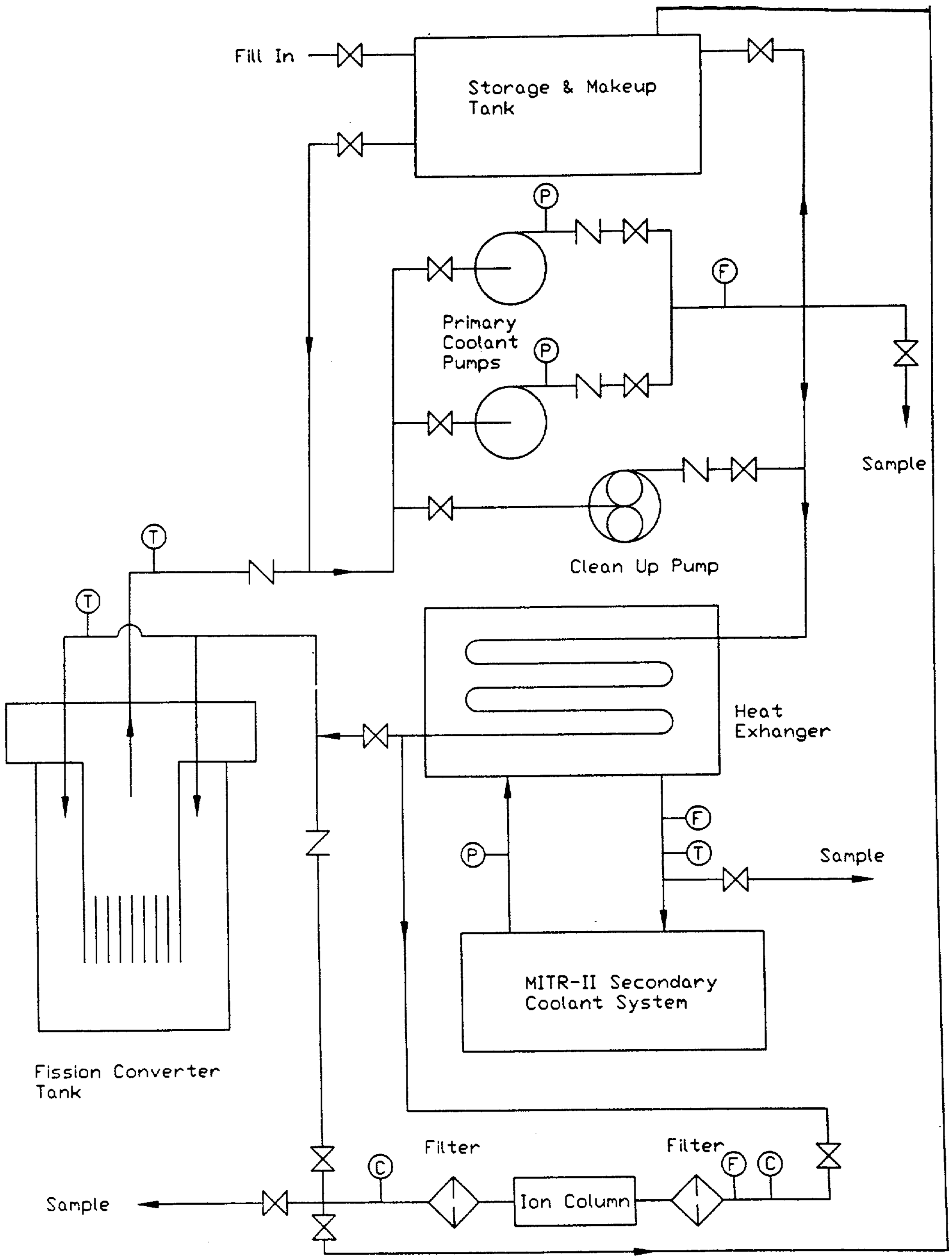

Figure 7 Schematic Drawing of Fission Converter Heat Removal System

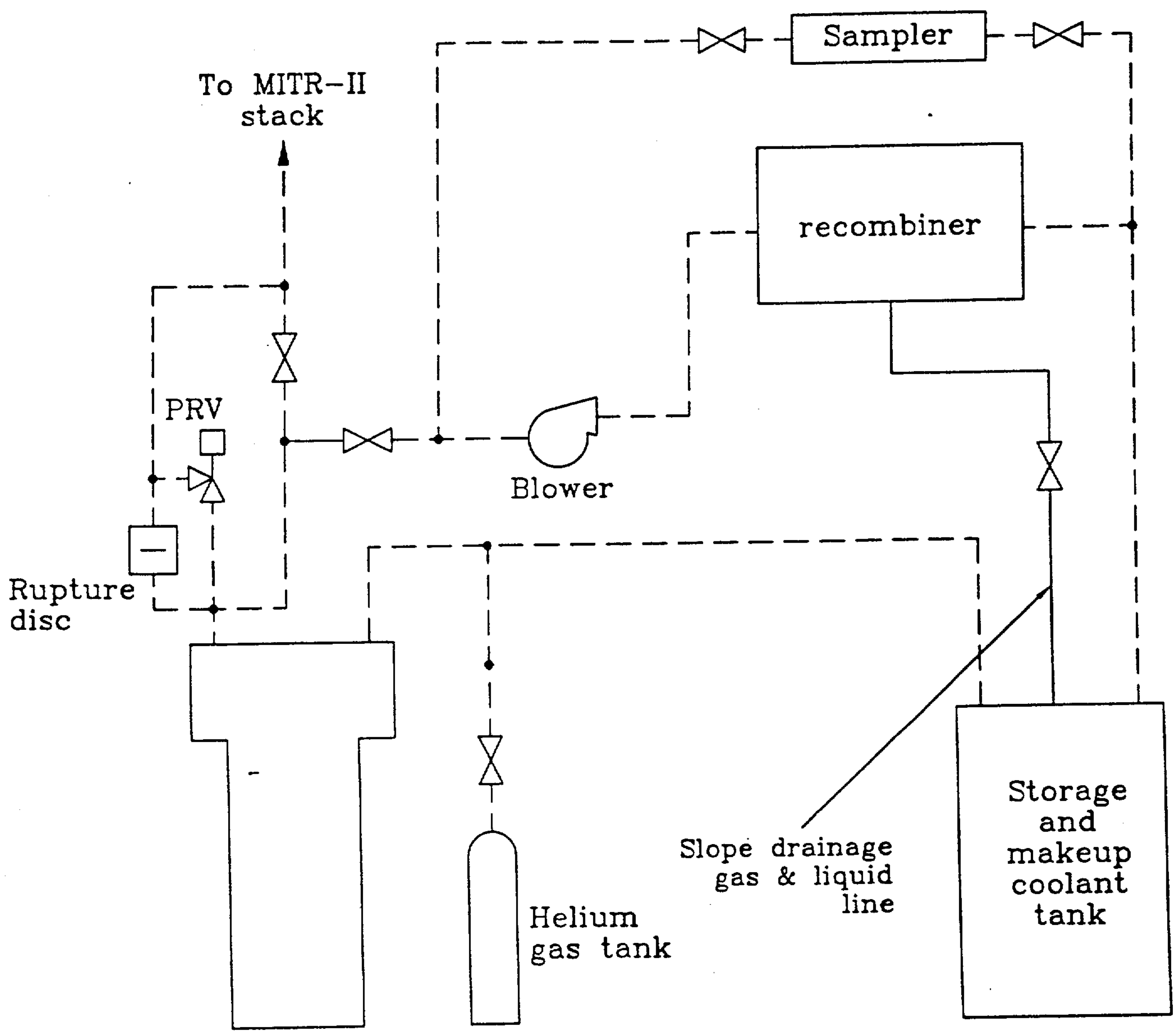

Figure 8 Schematic Drawing of Fission Converter Cover Gas System

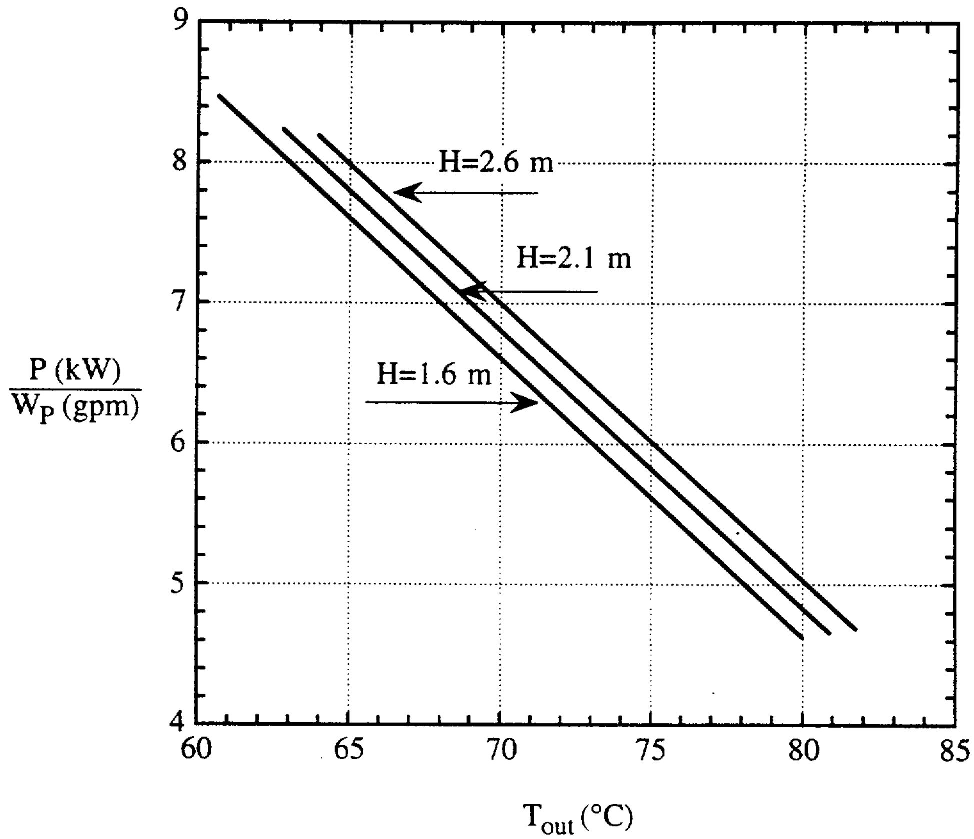

Figure 9 Fission Converter Safety Limits for Forced Convection.
(for either ten or eleven fuel elements)

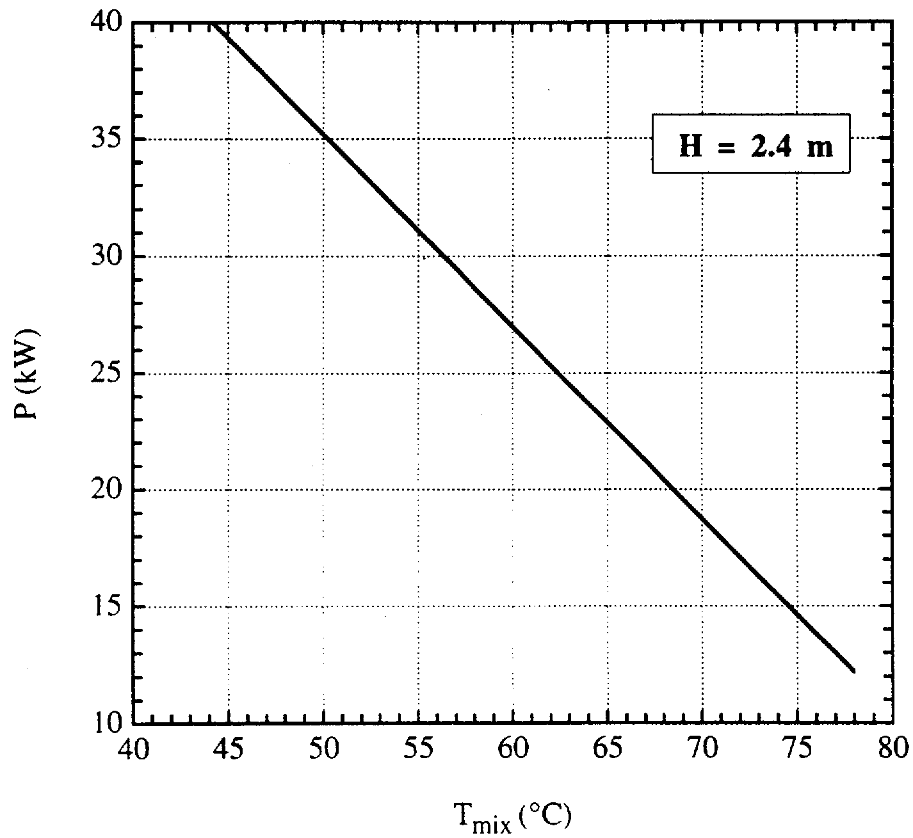

Figure 10 Fission Converter Safety Limits for Natural Convection. (for eleven fuel elements only)

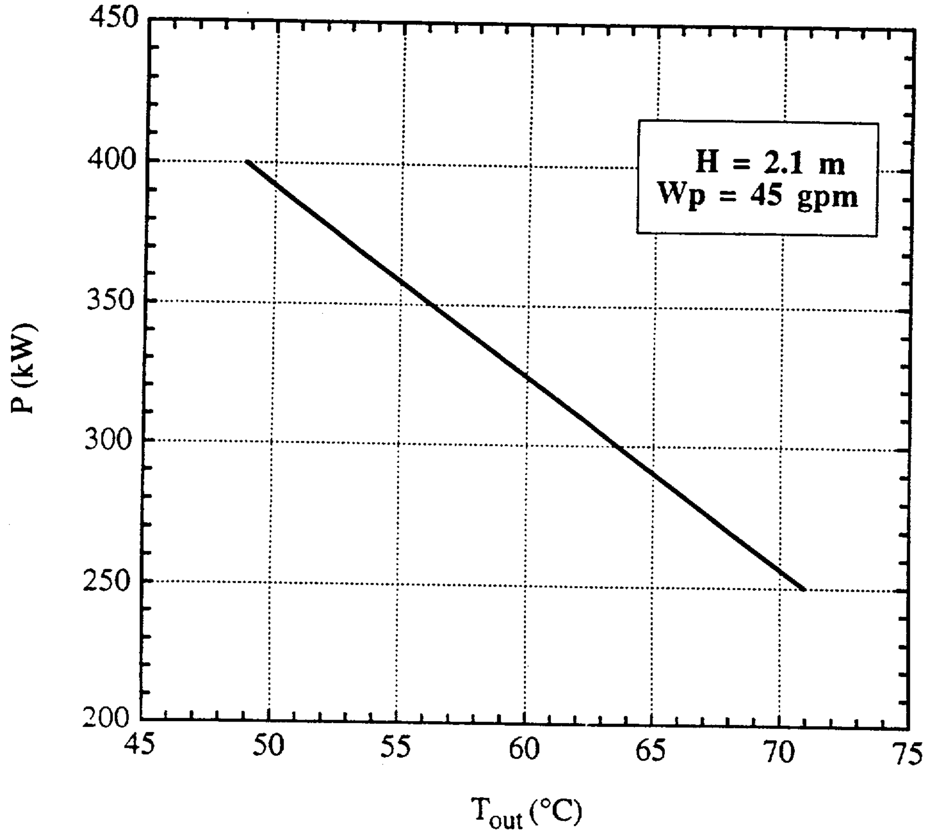

Figure 11 Fission Converter Limiting Safety System Settings for Operation with Forced Convection (for either ten or eleven fuel elements)

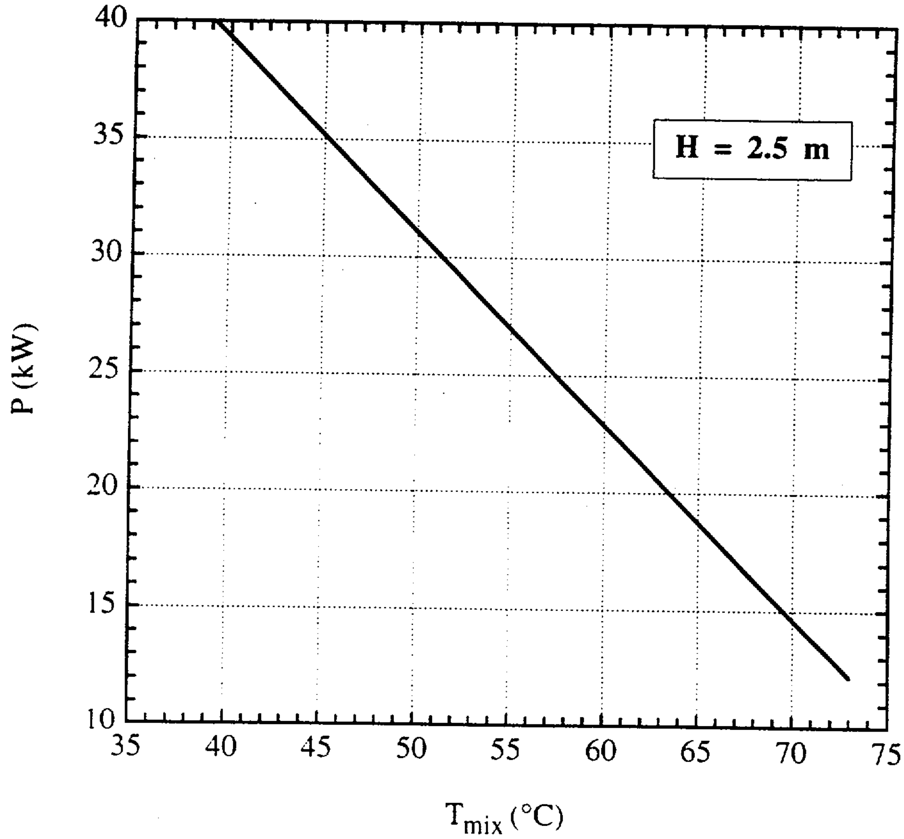

Figure 12 Fission Converter LSSS for Operation with Natural Convection (for eleven fuel elements only)

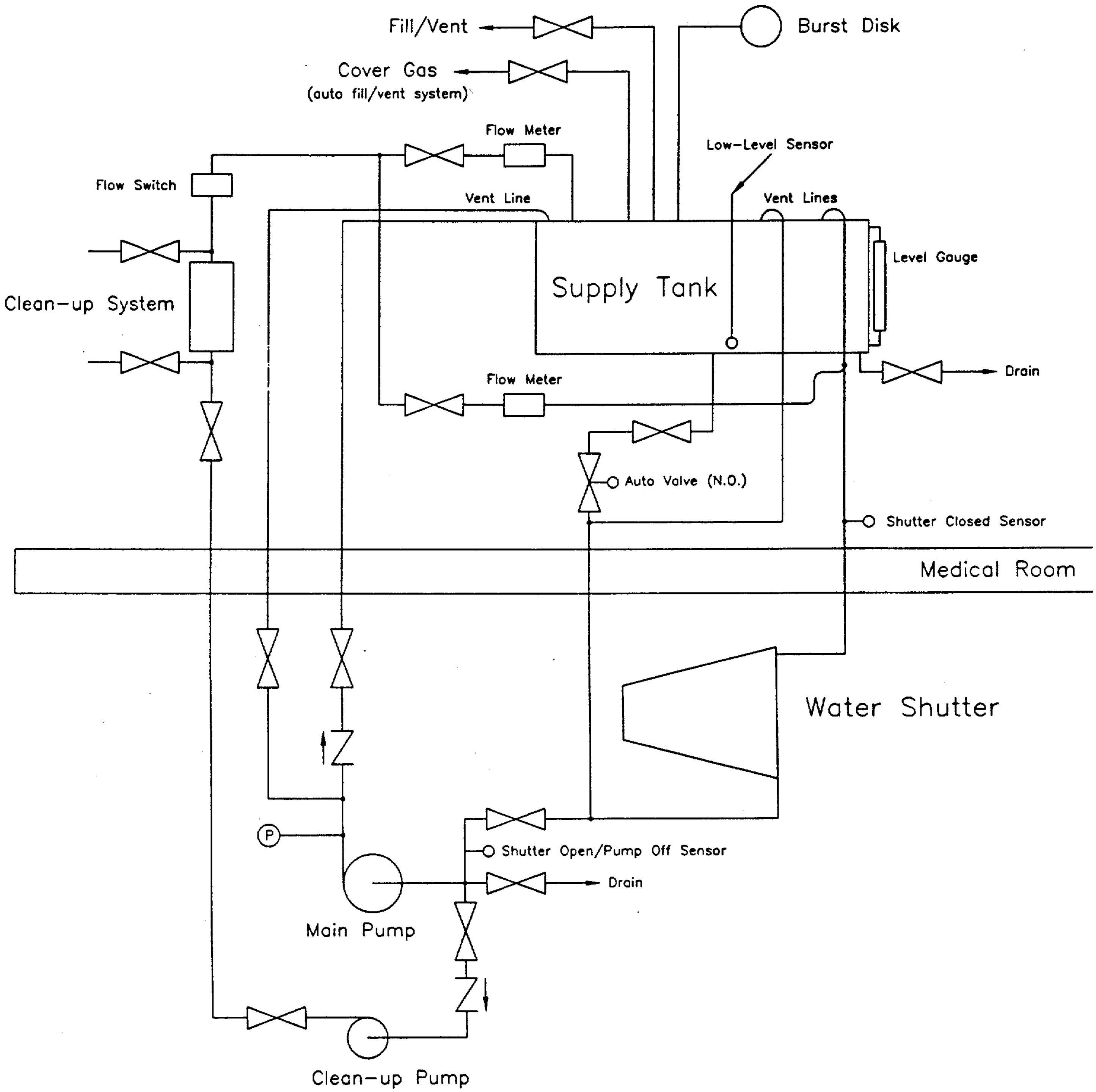

Figure 13 Fission Converter Water Shutter System