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Oak Ridge National Laboratory ATF Neutron Irradiation Program Irradiation Vehicle Design Concepts

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/TM-2016/123

Materials Science and Technology Division

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OVERVIEW

The Japan Atomic Energy Agency (JAEA) under the Civil Nuclear Energy Working Group (CNWG) is engaged in a cooperative research effort with the U.S. Department of Energy (DOE) to explore issues related to nuclear energy, including research on accident-tolerant fuels and materials for use in light water reactors.

This work develops a draft technical plan for a neutron irradiation program on the candidate accident-tolerant fuel cladding materials and elements using the High Flux Isotope Reactor (HFIR) [1].

The research program requires the design of a detailed experiment, development of test vehicles, irradiation of test specimens, possible post irradiation examination and characterization of irradiated materials and the shipment of irradiated materials to Japan.

This report discusses the conceptual design, the development and irradiation of the test vehicles.

CONTENTS

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ACRONYMS

Acronym	Definition
2D or 3D	Two dimensional or Three dimensional
ASME	American Society of Mechanical Engineers
ASTM	ASTM International
ATF	Accident Tolerant Fuel
BOC	Beginning of cycle
CNWG	Civil Nuclear Energy Working Group
DOE	Department of Energy
dpa	displacements per atom
EFPD	Effective full power days
EOC	End of cycle
FEA	Finite Element Analysis
FT	Fracture toughness
HFIR	High Flux Isotope Reactor
HHF	High heat flux
ISO	International Organizations for Standardization
JAEA	Japan Atomic Energy Agency
NQA	Nuclear Quality Assurance
ORNL	Oak Ridge National Laboratory
PF	Peaking factor
PI	Principle Investigator
PTP	Peripheral target positions
QMS	Quality Management System
R&D	Research and Development
TRRH	Target rod rabbit holder
US	United States

1. INTRODUCTION

The proposed test matrix for this campaign suggested HFIR irradiation and is described in [1]. It stipulated conditions of 300°C for a total of 8dpa for both FeCrAl alloy and SiC composite specimens and test vehicle designs.

A total of 5 rabbit capsules are proposed that include one rabbit of FeCrAl miniature tensile design, one of FeCrAl miniature fracture toughness bar design, two of SiC clad tube design, and one of SiC flexural miniature bar design.

This report gives background on HFIR's rabbit irradiation facility and discusses the conceptual design details as well as typical design considerations. It also provides some information on the fabrication and assembly of the test vehicles and planned irradiation scenarios.

2. HFIR RABBIT IRRADIATION FACILITY

2.1 HIGH FLUX ISOTOPE REACTOR

HFIR is a beryllium-reflected, pressurized, light-water-cooled and moderated flux-trap-type reactor. The core consists of aluminum-clad involute-fuel plates, which currently utilizes highly enriched 235U fuel at a power level of 85 MW_{th}. A typical cycle is 24 to 25 effective full power days (EFPD) followed by an end-of-cycle outage for refueling. There are 6 to 7 fuel cycles each year.

The reactor core, illustrated in Figure 1, consists of two concentric annular regions, each approximately 61 cm in height. The flux trap is ~12.7 cm in diameter, and the outer fueled region is ~43.5 cm in diameter. The fuel region is surrounded by a beryllium annular reflector approximately 30.5 cm in thickness. The beryllium reflector is in turn backed up by a water reflector of effectively infinite thickness. In the axial direction, the reactor is reflected by water. The reactor core assembly is contained in a 2.44 m diameter pressure vessel, which is located in a 5.5 m cylindrical pool of water.

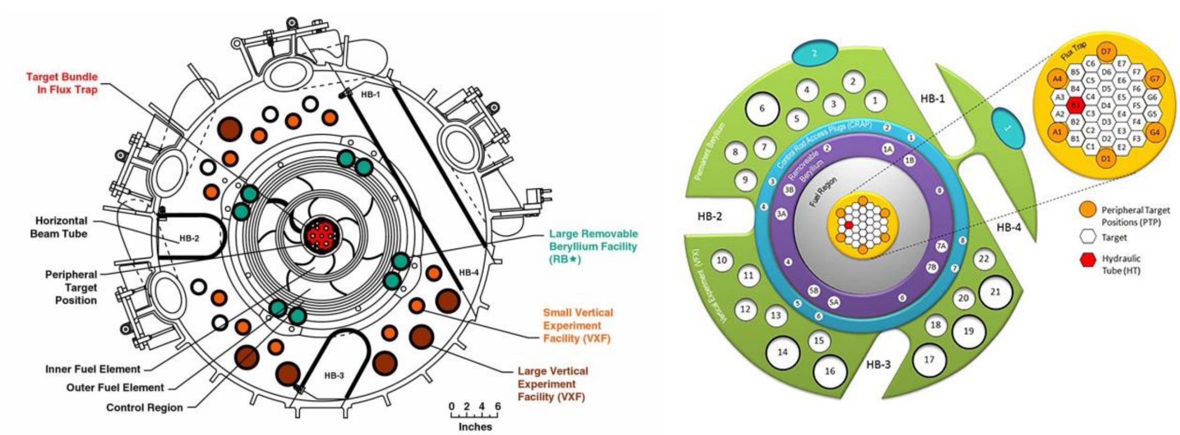

Figure 1: Cross-Section Illustration of HFIR and the primary experimental sites (left) and target regions (right)

Figure 2 shows the horizontal midplane of the neutron flux distribution at the core. The thermal flux peak at $2.5{\times}10^{15}$ n/cm^2.sec [E<0.4 eV] in the region of the flux trap, while the fast flux peaks at $1.11{\times}10^{15}$ n/cm^2.sec [E>0.1 MeV].

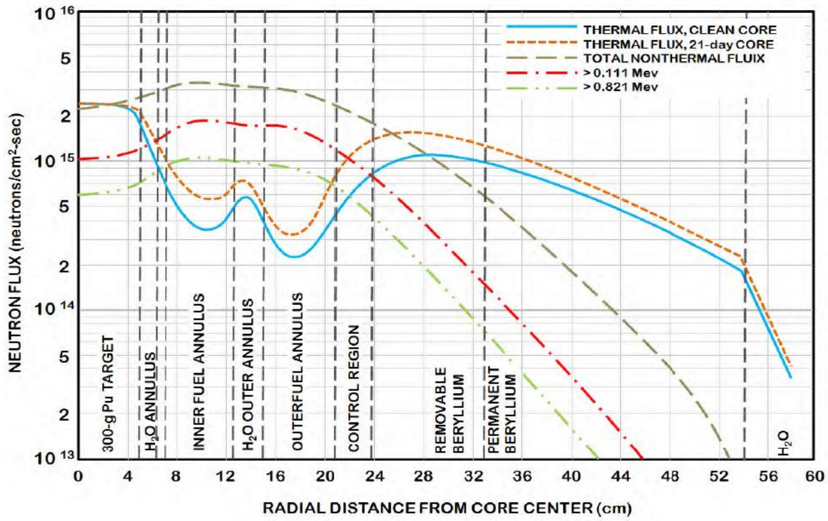

Figure 2: Neutron flux distributions at the core horizontal midplane with HFIR operating at 85MW [2]

2.2 NEUTRON FLUX SPECIFICATION AND DOSE RATES

The rabbit capsules will be irradiated within the flux trap target positions. The flux trap has the highest thermal fluxes in the reactor as well as the highest heat generation rates. The peripheral target positions (PTP), as shown in Figure 1, have the highest fast-neutron flux available to these experiments. For this reason these positions are in high demand. The fast flux in a PTP position is $1.11{\times}10^{15}$ n/cm^2.sec (E > 0.1 MeV) at the axial midplane, while the target rod rabbit holder (TRRH) positions have a peak fast flux of $1.09{\times}10^{15}$ n/cm^2.sec (E > 0.1 MeV). There are between 7 to 8 capsule positions in each target holder and flux values are calculated based on the axial peaking factor profile.

The axial peaking factor (PF) profiles are defined by the functions (a) and (b) where the peaking factor is the ratio of the local flux at a distance, z , from the reactor midplane (in cm) to the flux at the reactor midplane.

$$\text{PTP:} \quad \mathrm{PF(z)} = 1 - 9.85.10^{-4}.z^2 \qquad (a)$$
$$\text{TRRH:} \quad \mathrm{PF(z)} = 1 + 1.95.10^{-4}.z - 9.75.10^{-4}.z^2 \qquad (b)$$

Fast neutron flux changes within ± 10% of the nominal values BOC (beginning of cycle) to EOC (End of cycle) as fuel gradually depletes.

Considering a typical 24 EFPD cycle, fluence values will range between ~1.4 to 2.5 x 10^{25} n/m^2 or ~1.2 to ~2.0 dpa/cycle for the FeCrAl alloy specimens and ~1.3 to ~2.3 dpa for the SiC composite specimens. To obtain 8 dpa would require between 4 to 6 cycles (~7 to 12 months of irradiation time) depending on the specimen material type.

2.3 TEMPERATURE RECORDING AND CONTROL

For the capsules proposed here, temperature control will be achieved by the setting of the initial gas gap between the capsule housing and the specimen holder. The capsules are sealed after assembly and filled with inert gas.

Heat is generated from the neutrons and gamma rays released from the reactor fuel, or in some instances due to materials that have significant heat generation from activation and decay. The average temperature drop across the holder/housing gas gap is determined by the total heat generation within the assembly, the size of the gas gap after thermal expansion (or material swelling) , and the thermal conductivity of the fill gas. Depending on the specific gap, heat flux, and fill gas, machining tolerances can be as small as +/- 10µm in order to achieve acceptable uncertainties in specimen temperatures (+/- ~20°C).

Finite element analysis (FEA) is used for the thermal design and analysis for the rabbit capsules. After a FEA model has been constructed in ANSYS (either 2D or 3D), thermal analysis is performed at full power operation. The temperature distribution within the holder assembly depends on the volumetric heating of the specimens and other capsule components, and the thermal coupling of specimens to the holder. It is possible to determine the expected temperature contours on a specific specimen.

Based on previous experience designing and irradiating rabbit capsules of various designs, the FEA temperature analysis is accurate typically to within +/- 10% of the difference between the design temperature and the coolant temperature. HFIR coolant water enters the core at 49°C and exists at 69°C. Mid core coolant temperature can be expected to be ~60°C. For rabbits designed for 300°C irradiation, the actual temperature is expected to be within +/- 20°C of the design temperature.

Rabbit capsules typically include passive SiC temperature monitors or thermometers that will be in close contact with the irradiated specimens. Dilatometry is used to obtain post-irradiation measured temperature.

3. RABBIT CONCEPT DESIGNS

The following concepts are based on previous designs for other programs with similar irradiation conditions but not necessarily the same materials. Additional analyses will have to be performed to determine the thermal design and safety bases for the capsules under consideration.

3.1 TYPICAL DESIGN AND ASSEMBLY PROCESS

Figure 3shows the typical process flow of the development of a rabbit capsule.
After the technical plan has been initiated, conceptual rabbit designs are generated based on input or requirements from the Principle Investigator (PI), previous designs, material types and suggested improvements.

Once a conceptual 3D model has been created in Pro-E, it is imported into ANSYS to perform 2D or 3D thermal analyses. Obtaining the desired temperatures can be an iterative process. Variables that can be controlled to give the desired temperatures are component materials, gas gaps, fill gas, etc.
Once the desired temperature results are achieved, the safety basis calculations need to be prepared as part of HFIR's quality and safety control.

During the assembly, all components and specimens are marked for identification and detailed loading list records are captured and compiled. This forms part of the pre-irradiation information database.

Depending on the number of different designs and number of capsules the entire design/fabrication process can take 6 to 12 months to complete.

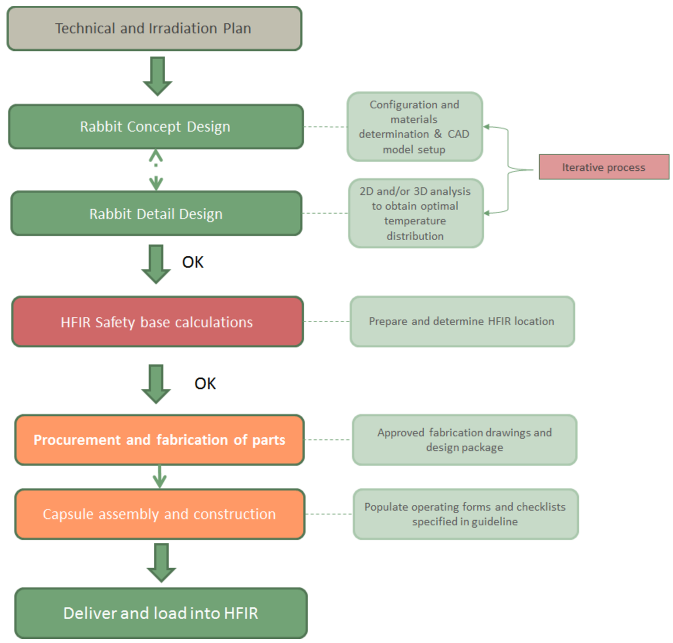

Figure 3: Typical rabbit design and assembly process

3.2 MINIATURE TENSILE DESIGN

3.2.1 Design Description

This conceptual design is suggested for the FeCrAl alloy tensile specimens.
The design configuration is based on a previous design case which makes use of modular assemblies inside the standard rabbit housing.

This versatile loading configuration is developed to provide flexibility in specimen loading with a useful range of irradiation temperatures.

The specimens are supported by steel chevrons or coffins, depending on specimen type, to equalize heat generation between the different geometries. Each holder sub-assembly contains 4 "quadrants" that contain specimens, chevrons and thermometry liners. The quadrants are pressed into each of the 4 corners of the square cutout in the holders using a steel spring pin. The holders have raised 'standoff' features to center the holder assembly within the housing. Grafoil is used to separate the holder sub-assemblies from the cool bottom of the aluminum housing. Figure 4 shows an expanded view of an assembly with 12 SSJ2 tensile specimens, chevrons, thermometry liners and the steel spring pin.

The overall design is shown in the view of Figure 5. The capsule contains three identical specimen assemblies. Each assembly contains 12 FeCrAl alloy tensile specimens and 4 passive Silicon Carbide (SiC) thermometry pieces. The tensile specimens are fitted with stainless steel chevrons to equalize heat generation and heat transfer in the gauge length of the specimens. Stainless steel was also selected for the

FeCrAl specimen material. The three assemblies are set within aluminum housings that are fabricated from alloy 6061. The entire assembly in Figure 5 is shown within the standard Al6061 housing.

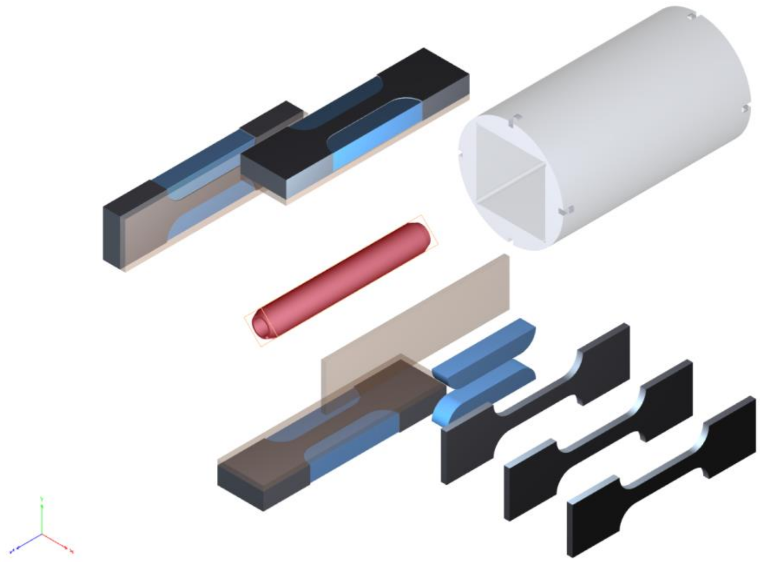

Figure 4: Expanded view of a holder sub-assembly with 12 SSJ2 tensile specimens, chevrons, thermometry liners and steel

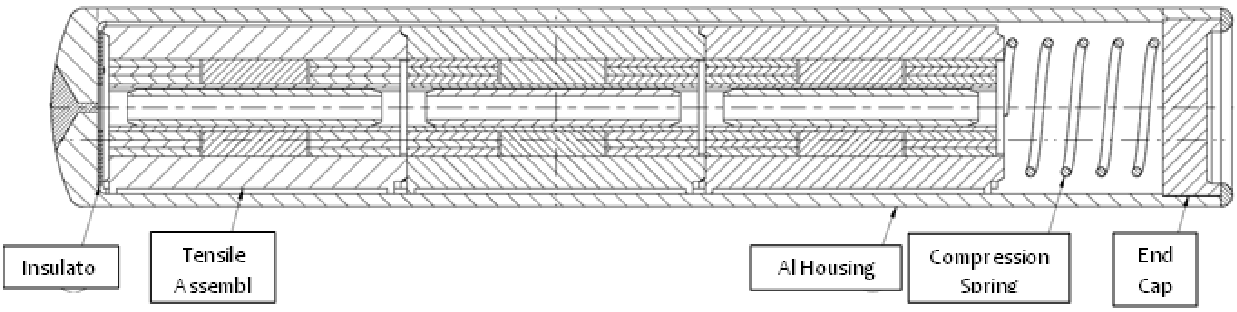

Figure 5: View of the SS-J2 Tensile Irradiation Capsule Design

The model of the assembly design has been created in Pro-E to provide geometry data for ANSYS workbench.

3.2.2 Model

For the ANSYS FEA model design, a 3D model of the capsule is suggested to estimate operating temperatures.

Figure 6 is a typical 3D meshed model of an assembly created in ANSYS.

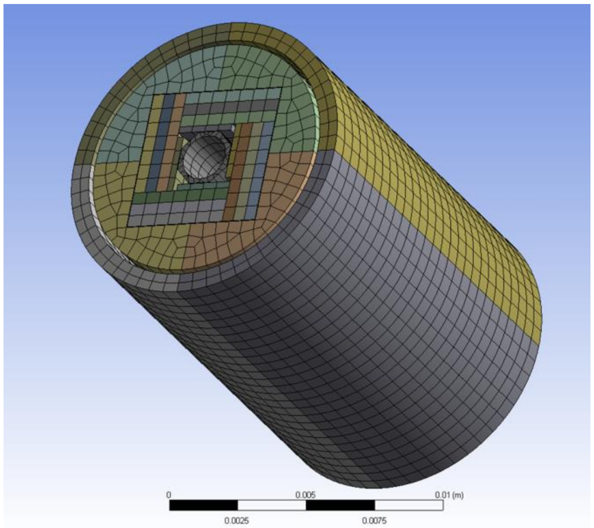

Figure 6: Meshed model of the sub-capsule assembly

3.2.3 Computations and Thermal Analysis

The thermal design target is typically setup according to the Test Matrix conditions. The FEA is optimized to get the best temperature distribution over the specimen region.

Given the modular nature of the design, a single tensile configuration layer located at the capsule centerline was analyzed for thermal performance. Scoping analyses can be executed to show that all generic configurations of SS-J2 tensile specimens perform in the same fashion. It is therefore possible to get analysis results per specimen as shown in Figure 7.

The specimen temperature is controlled by the axial location, fill gas, and the size of the gap between the holder and housing.

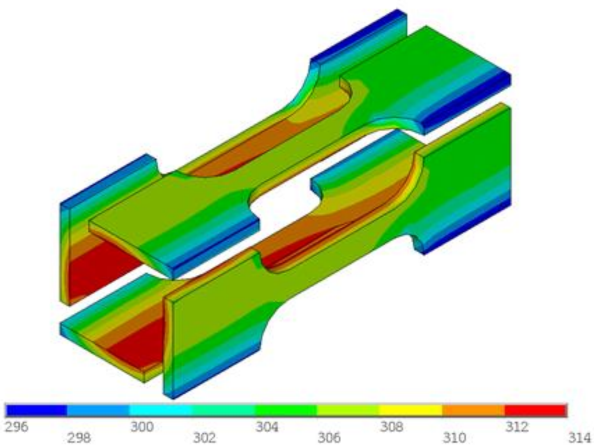

Figure 7: Temperature contour plot for SS-J2 example

3.3 MINIATURE FRACTURE TOUGHNESS BAR DESIGN

3.3.1 Design Description

This conceptual fracture toughness (FT) bend bar experiments are designed to irradiate FeCrAl alloy specimens in the flux trap of the HFIR.
Different from the tensile design, the suggested FT bend bar design does not allow a modular design. The geometrical constraints of the specimens do not tolerate for similar sub-capsule flexibility.

The design layout includes 4 miniature bars from FeCrAl alloy with 4 passive SiC thermometers (shown in Figure 8). The heat generated from the bars will be transferred through a plate filler piece from 304SS which is located between the bars and the thermometers on the top and bottom of the assembly. Grafoil support discs will be place between the bars with a centering titanium thimble and a SiC retainer spring in the center for positioning within the housing and to separate the internal assembly from the potential cool bottom of the aluminum housing. Refer to APPENDIX A for conceptual drawing.

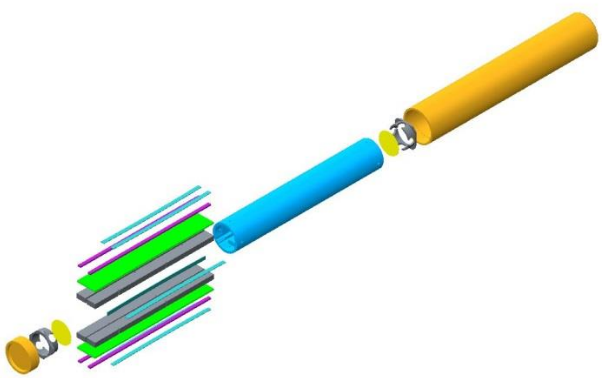

Figure 8: Exploded view of the fracture toughness beam design

3.3.2 Model

For the ANSYS FEA design, a 3D model has been created of the capsule but due to the 90° symmetry, only a section of the model will be analyzed as shown in Figure 9. This procedure will save time and costs as it reduces the simulation complexity. Similar to the previous design, the geometry can be imported into ANSYS Workbench for the FEA design.

Figure 9: 90° Symmetry section of the fracture toughness beam capsule design

3.3.3 Computations and Thermal Analysis

For the FeCrAl Bend Bar irradiation experiments, the specimen temperature can be controlled by the axial location, fill gas, and the size of the gap between the holder and housing.

Figure 10 shows typical thermal analysis results that was perform on a metal alloy assembly. These types of contour plots can be expected when doing a thermal analysis for the FeCrAl alloy.

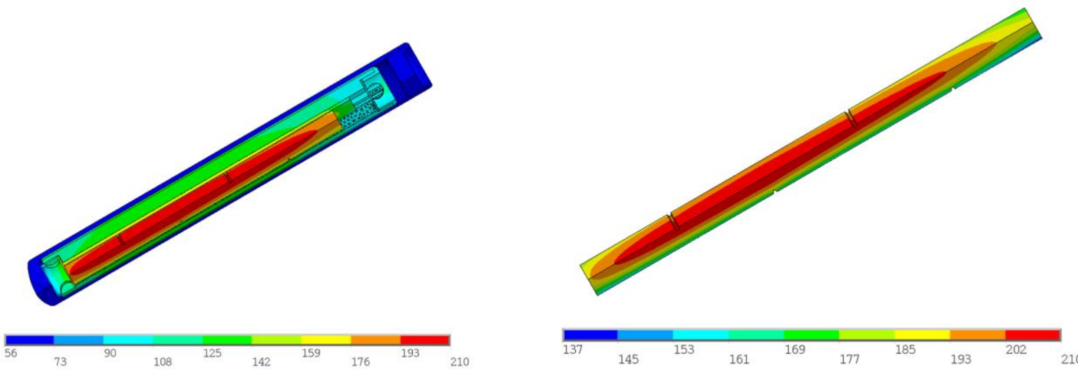

Figure 10: Typical temperature contour plot of the 90° symmetrical cut and specimen example

3.4 MINIATURE FLEXURAL MINIATURE BAR DESIGN

3.4.1 Design Description

Figure 11 shows the miniature flexural bar concept design which is suggested for SiC composites. The overall assembly has twenty miniature flexure specimens. Four SiC liners are placed in to the inside wall of the holder to eliminate the direct interaction between the holder material and the specimen material. There are also passive SiC thermometry bars against the specimens. The thermometry and specimens are pushed to the inside surfaces of the holder with SiC springs. A vanadium alloy (V-4Cr-4Ti) is suggested as the holder material to contain specimens designed to achieve 300°C. Insulator discs are used at the top and bottom of the assembly to eliminate the axial heat loss. Refer to APPENDIX A for conceptual drawing.

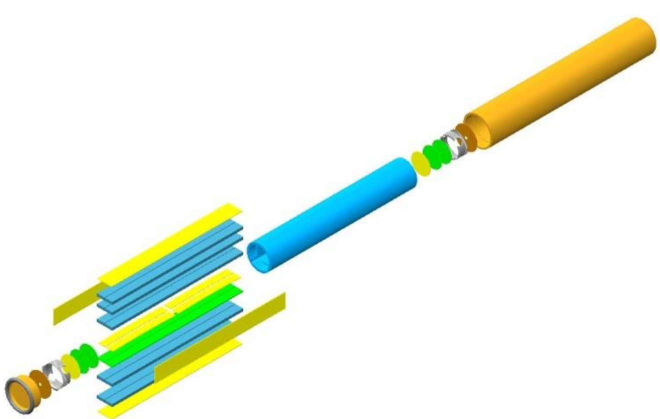

Figure 11: Layout of the composite flexural beam capsule design

An important design consideration in the case of SiC composite is the effect of specimen swelling inside the holder during irradiation. Therefore enough space should be allowed to not compromise the material effects.

3.4.2 Model

The design drawings for this design, similar to the other designs, created in Pro-E. The Pro-E 3D assemblies were imported directly into ANSYS Workbench. Due to the symmetrical configuration a 180° FEA is proposed. Figure 12 shows the 3D meshed model of a 180° section. For this view, some parts are hidden in to improve clarity.

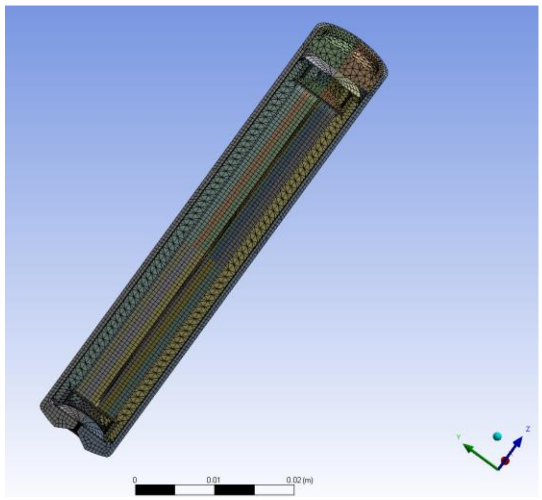

Figure 12: 180° Section meshed model for the flexural beam capsule design

3.4.3 Computations and Thermal Analysis

The purpose of irradiation of the flexural bend bars is to determine the effects of neutron irradiation in SiC composites in conditions relevant with light water reactor fuel structures. The specimen temperature is controlled by the axial location, fill gas, and the size of the gap between the holder and housing. Figure 13 shows typical temperature contour plots for this design.

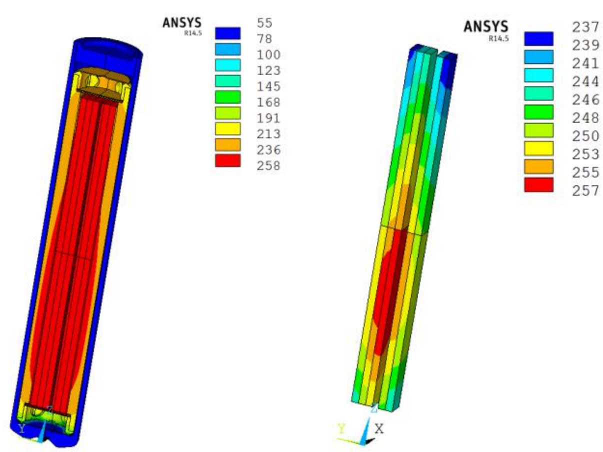

Figure 13: Temperature contour plot for the composite flexural beam capsule (left) and specimen stack (right)

3.5 CLAD TUBE DESIGN

3.5.1 Design Description

This clad tube concept design, shown in Figure 14, is specifically suggested for SiC composite material. The purpose of the cladding rabbit experiment is to irradiate SiC composite specimens in the flux trap of the HFIR under representative light water reactor conditions. These conditions include a heat flux of approximately 0.6 MW/m^2 and a clad outer surface temperature of 300 °C.

The goal is for the clad outer surface temperature to remain approximately constant throughout the irradiation, as the cladding specimen will swell. The specimens are surrounded by a tight fitting aluminum sleeve and an embossed aluminum foil that compresses with the swelling of the cladding specimens.

This design is heavily dependent on contact resistance at the clad/sleeve interface, the sleeve/foil interface, and the foil/housing interface. The contact resistance depends significantly on the surface roughness of the contacting surfaces.

A molybdenum heater is located inside the cladding to provide the required heat flux. The primary outer containment is an Al-6061 tube with an outer diameter of 10.96 mm (0.432"). To obtain the required temperatures helium or a helium/argon mixture is suggested as the fill gas.

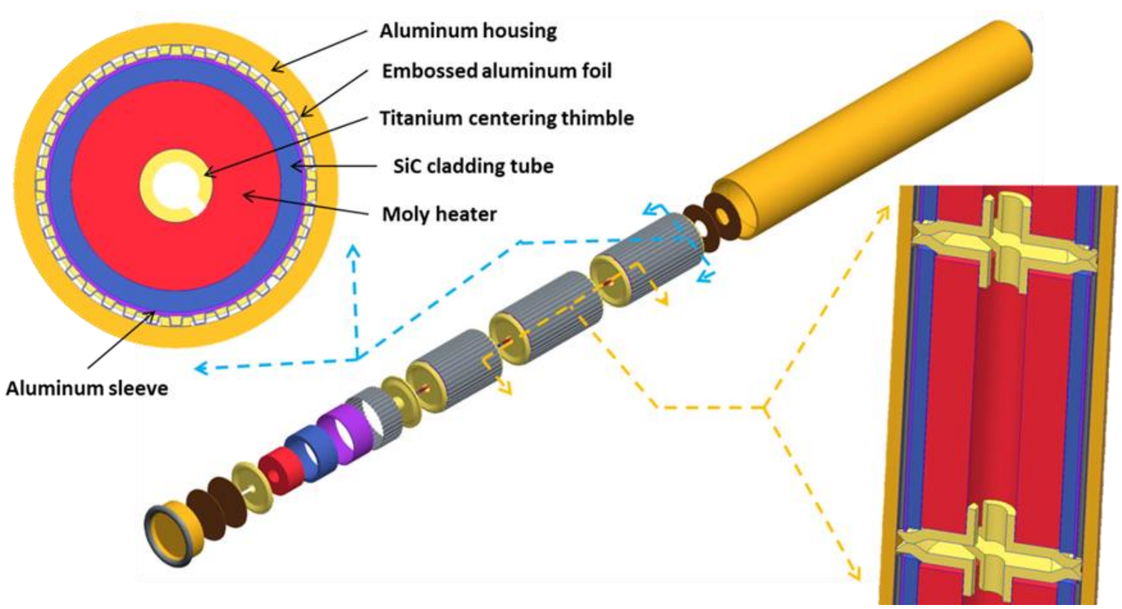

Figure 14: The design concept for the SiC clad tube with an internal moly heater

3.5.2 Model

Similar to other designs, the layout drawings for the clad tube design are created in Pro-E, and the Pro-E assemblies were imported directly into ANSYS Workbench for the 3D ANSYS model.
The geometric FEA model shown in Figure 16 is essentially identical to that used to create the design drawings (Figure 14). Minor differences between the geometric model used in ANSYS and the Pro-E model are that the ANSYS model ignores minor features such as welds and quartz wool.

In order to model the swelling of the cladding and the compression of the embossed aluminum foil, a 2D slice of one sub-assembly is suggested for modelling (Figure 15). This strategy was validated with an experimental approach and will be applied again. A full 3D model of the foil compression is not advised due to the small mesh size required to simulate foil compression. The excluded input from the 3D model (the embossed aluminum foil) will be supported from output generated by the 2D model.

Due to symmetrical characteristics only a 90° slice is proposed. By simplifying the model the simulation run time can be reduced, producing the same calculation results.

Figure 15 and Figure 16 show examples of the meshed 2D slice and 3D models, respectively. The 2D model will be used to determine the effective thermal contact conductance between the aluminum sleeve and the capsule housing. The effective gas gap between the sleeve and the housing will be optimized in the 3D model until the contact conductance through this gas gap is equal to the calculated contact conductance in the 2D model that included the compressed aluminum foil.

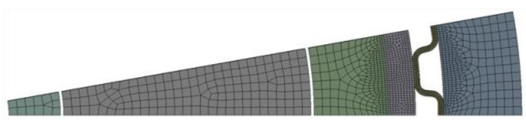

Figure 15: A 2D slice of the model

Figure 16: The 3D 90°C meshed slice of model

3.5.3 Computations and Thermal Analysis

For thermal computations, the model will implement previous analysis and validated experiments that were conducted to establish the contact resistances between contacting parts. These include the SiC clad/sleeve interface, the sleeve/foil interface, and the foil/housing interface. The contact resistance depends on the surface roughness of each contacting surface. Apart from micro-hardness and surface roughness, the contact conductance is also sensitive to the inert gas that fills the rabbit.

Figure 17 shows the results of an experiment that was performed to validate the models that are used to predict contact resistance across the embossed foil. Heat flux is plotted vs. temperature difference across the embossed foil determined from the experiments and the finite element models using both helium and neon fill gases. Bilinear isotropic hardening models will be applied for the analysis of the aluminum foil, sleeve and housing materials due to the plastic strain that the foil undergoes.

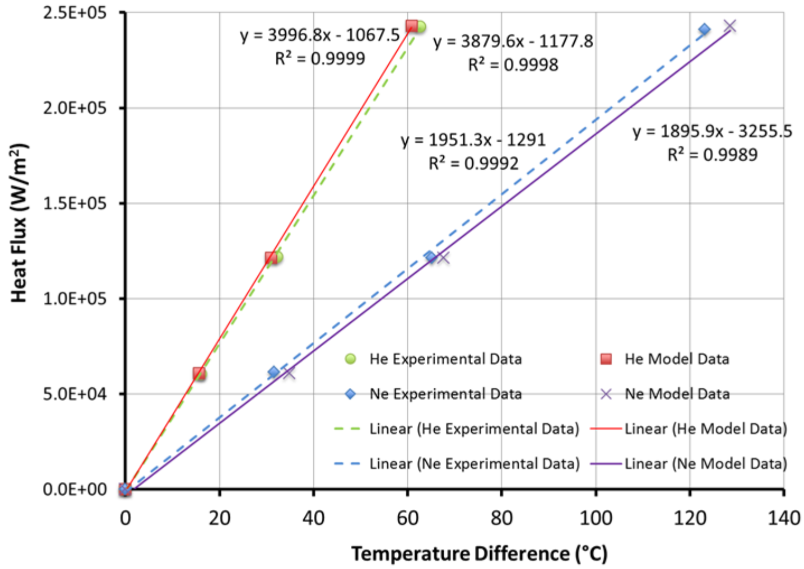

Figure 17: Heat flux vs. temperature difference determined from the experiments and the finite element models using both helium and neon fill gases.

The thermal analysis will require two finite element models: a 2D model to determine the swelling of the clad and the compression of the embossed aluminum foil, and a 3D model that will use the output of the 2D model to determine the temperature contours (Figure 18) for all the capsule components.

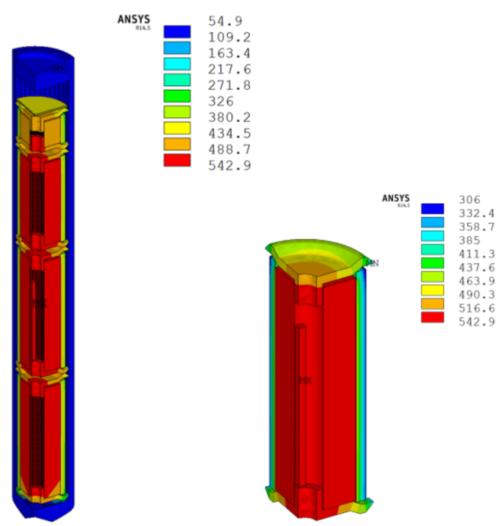

Figure 18: Typical temperature contour plots of a 90°C sliced 3D model on this design

4. FABRICATION AND ASSEMBLY

ORNL has a standard operating guideline for the preparation of sealed HFIR rabbit capsules [7]. This section provides a brief summary of the procedure.

To initiate fabrication it is required that each designer should submit a design package that includes a fabrication request sheet, a complete set of drawings that describe all the capsule parts, a customer supplied specimen loading list and any additional instructions.

Parts fabrication can only start once the design package has been completed, reviewed and approved. All parts shall be fabricated or machined according to approved drawings. All primary components will be engraved and inspected for conformance. All materials to be included in the assembly must be supported by documentation showing elemental composition.

Before assembly all parts must be cleaned, identified and assigned. At this point capsule assembly can commence by carefully loading or inserting the specimens and internal parts into the various holders.
Once the assembly has been completed the end caps are e-beam welded according to specified procedures, cleaned and then helium leak tested. The next step is to fill the capsules with the required gas and to perform the final seal.

As a last step, a hydrostatic test as well as a final leak check is performed before it is cleaned for a final time. After the capsule and QA package is approved, it is delivered to the HFIR for irradiation.

5. QUALITY ASSURANCE

Capsule design, fabrication, and assembly are conducted under a quality assurance program based on and compliant with the ASME NQA-1-2008 quality assurance standard, *Quality Assurance Requirements for Nuclear Facility Applications*.

6. REFERENCES

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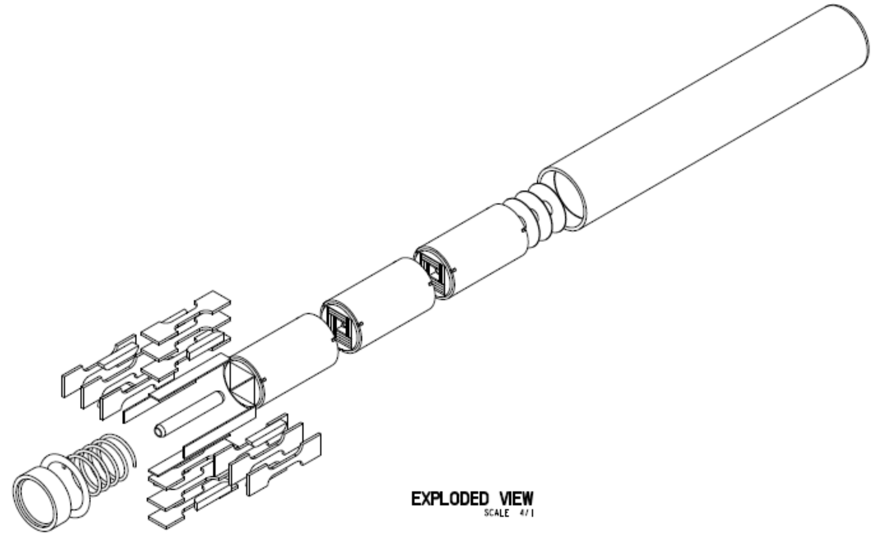
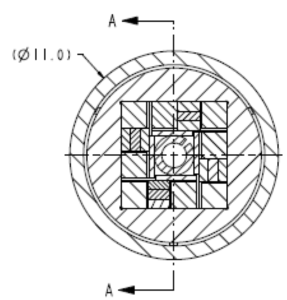
[7] J.L. McDuffee. "Standard Operating Guideline for the Preparation of Sealed Unfinned HFR Rabbit Capsules" (AP-RSND-20977-020)
[8] Geringer J.W, Katoh Y., "ATF Neutron Irradiation Program Post Irradiation Plan" (ORNL/TM-2016/124)

APPENDIX A. Concept Design Drawings

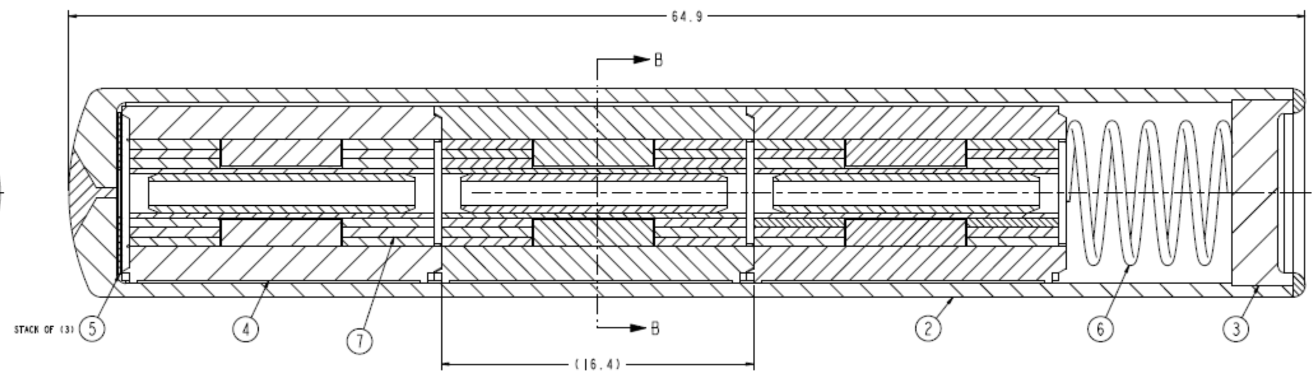
I. Miniature Tensile Specimen Design
II. Miniature Fracture Toughness Bar Specimen Design
III. Miniature Flexural Bar Specimen Design
IV. Clad Tube Specimen Design



EXPLODED VIEW
SCALE 4/1



SECTION B-B



1 SECTION A-A
CAPSULE ASSEMBLY
SCALE 12/1

EXAMPLE ONLY

36		TENSILE SPECIMEN	7
1		COMPRESSION SPRING	6
3		DISK	5
3		SPECIMEN HOLDER ASM	4
1		HOUSING END CAP	3
1		HOUSING	2
1		CAPSULE ASSEMBLY	1
	CAGE CODE	NOMENCLATURE OR DESCRIPTION	FIND NO

REV	DESCRIPTION	BY	TL	DATE	TR	DATE	LOA	DATE	HRIR S	DATE	HFIR QA	DATE

SCALE NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
X DECIMALS ±.1
XX DECIMALS ±.05
ANGLES ±0° 15'
BREAK SHARP EDGES .02 MAX
FINISH 63 RMS
FILLETS .02 MAX

DES
DRW
TL
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DRAWING APPROVALS DATE

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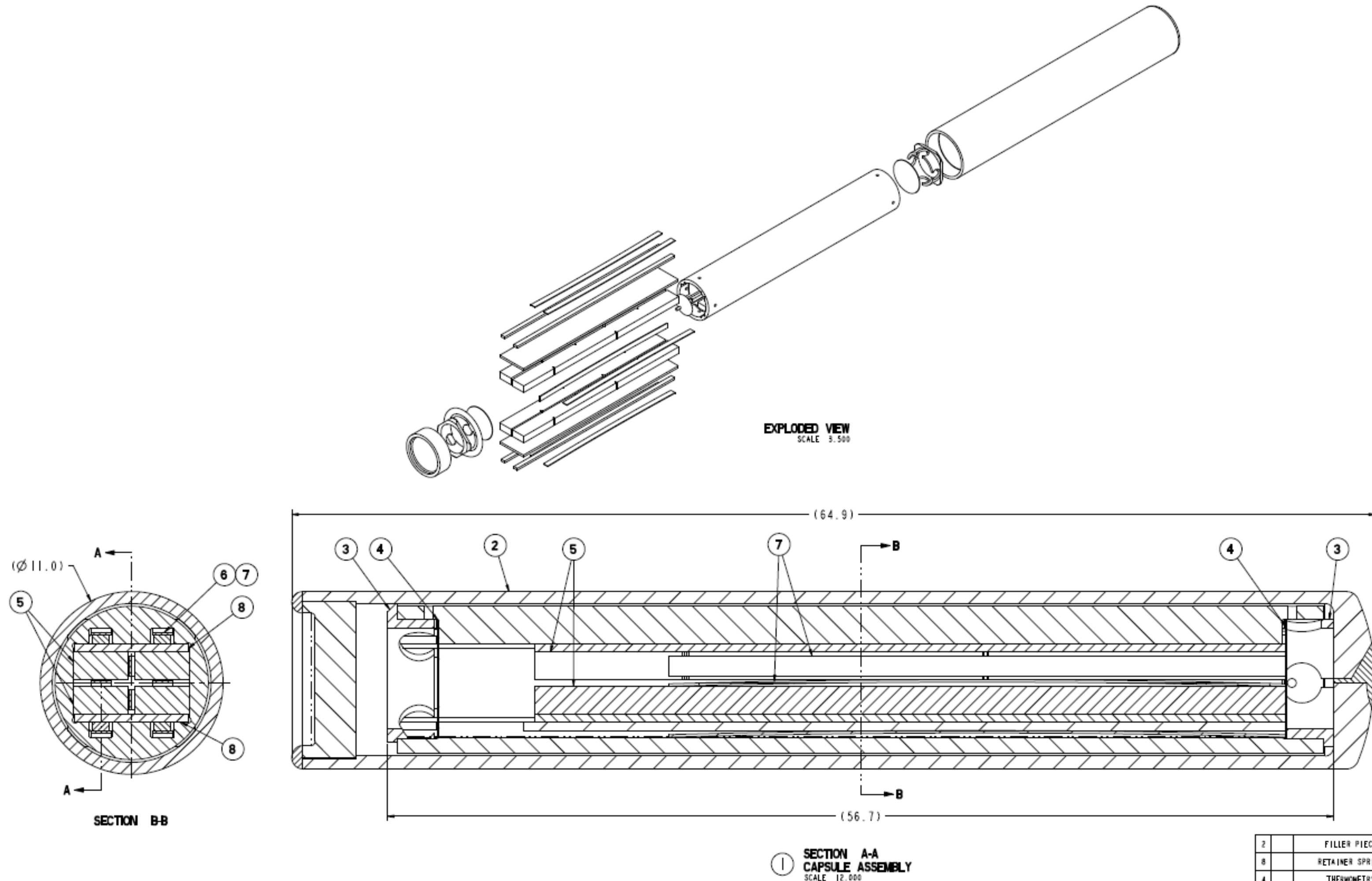
Oak Ridge National Laboratory
managed for the DEPARTMENT OF ENERGY under U.S. GOVERNMENT contract DE-AC05-00OR22725
UT-BATTELLE, LLC. Oak Ridge, Tennessee

PROJECT NAME
IRRADIATION CAPSULE

MINIATURE TENSILE DESIGN (SSJ2)

VERSION NO.	PLANT	BLDG	FL	SHT OF	TYPE	CLASS
	ORNL			1 1		
RELEASE LEVEL	EJN					REV

THIS DRAWING PRODUCED ON PRO-ENGINEER



EXAMPLE ONLY

QTY	CAGE CODE	NOMENCLATURE OR DESCRIPTION	FIND NO
2		FILLER PIECE	8
8		RETAINER SPRING	7
4		THERMOMETRY	6
4		TOUGHNESS SPECIMEN	5
2		SUPPORT DISK	4
2		CENTERING THIMBLE	3
1		HOUSING	2
1		CAPSULE ASSEMBLY	1

REV	DESCRIPTION	BY	TL	DATE	TR	DATE	LOA	DATE	HFIR S	DATE	HFIR QA	DATE

SCALE NOTED

TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
X DECIMALS ±.1
XX DECIMALS ±.05
ANGLES ±0° 15'
BREAK SHARP EDGES .02 MAX
FINISH 63 RMS
FILLETS .02 MAX

DES
DRW
TL
TR
LOA
HFIR S
HFIR QA
DRAWING APPROVALS | DATE

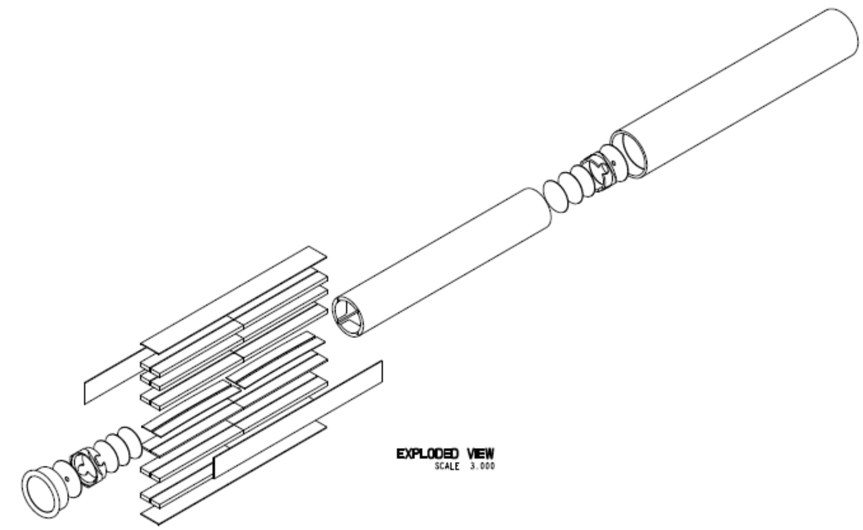
UT-BATTELLE
Oak Ridge National Laboratory
managed for the DEPARTMENT OF ENERGY under U.S. GOVERNMENT contract DE-AC05-00OR22725
UT-BATTELLE, LLC. Oak Ridge, Tennessee

PROJECT NAME
IRRADIATION CAPSULE

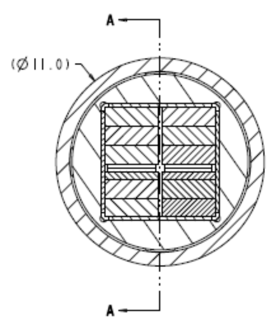
MINIATURE FRACTURE TOUGHNESS
BAR DESIGN

VERSION NO. | PLANT ORNL | BLDG | FL | SHT OF | TYPE | CLASS
RELEASE LEVEL WIP | EJN | REV

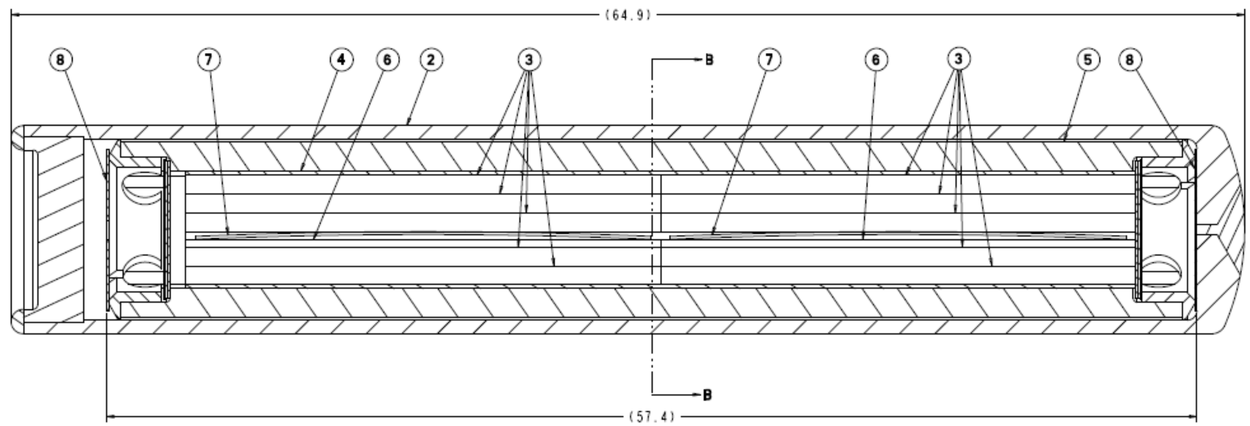
THIS DRAWING PRODUCED ON PRO-ENGINEER



EXPLODED VIEW
SCALE 3.000



SECTION B-B



1 CAPSULE ASSEMBLY
SECTION A-A
SCALE 12.000

EXAMPLE ONLY

2		DISC	8
4		SPRING	7
4		THERMOMETRY	6
1		HOLDER	5
4		LINER	4
20		SPECIMEN	3
1		HOUSING	2
1		CAPSULE ASSEMBLY	1
	CAGE CODE	NOMENCLATURE OR DESCRIPTION	FIND NO

THIS DRAWING PRODUCED ON PRO-ENGINEER

REV	DESCRIPTION	BY	TL	DATE	TR	DATE	LOA	DATE	HRIR S	DATE	HFIR QA	DATE

SCALE NOTED
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS
X DECIMALS ±.1
XX DECIMALS ±.03
ANGLES
FINISH
FILLETS .02 MAX

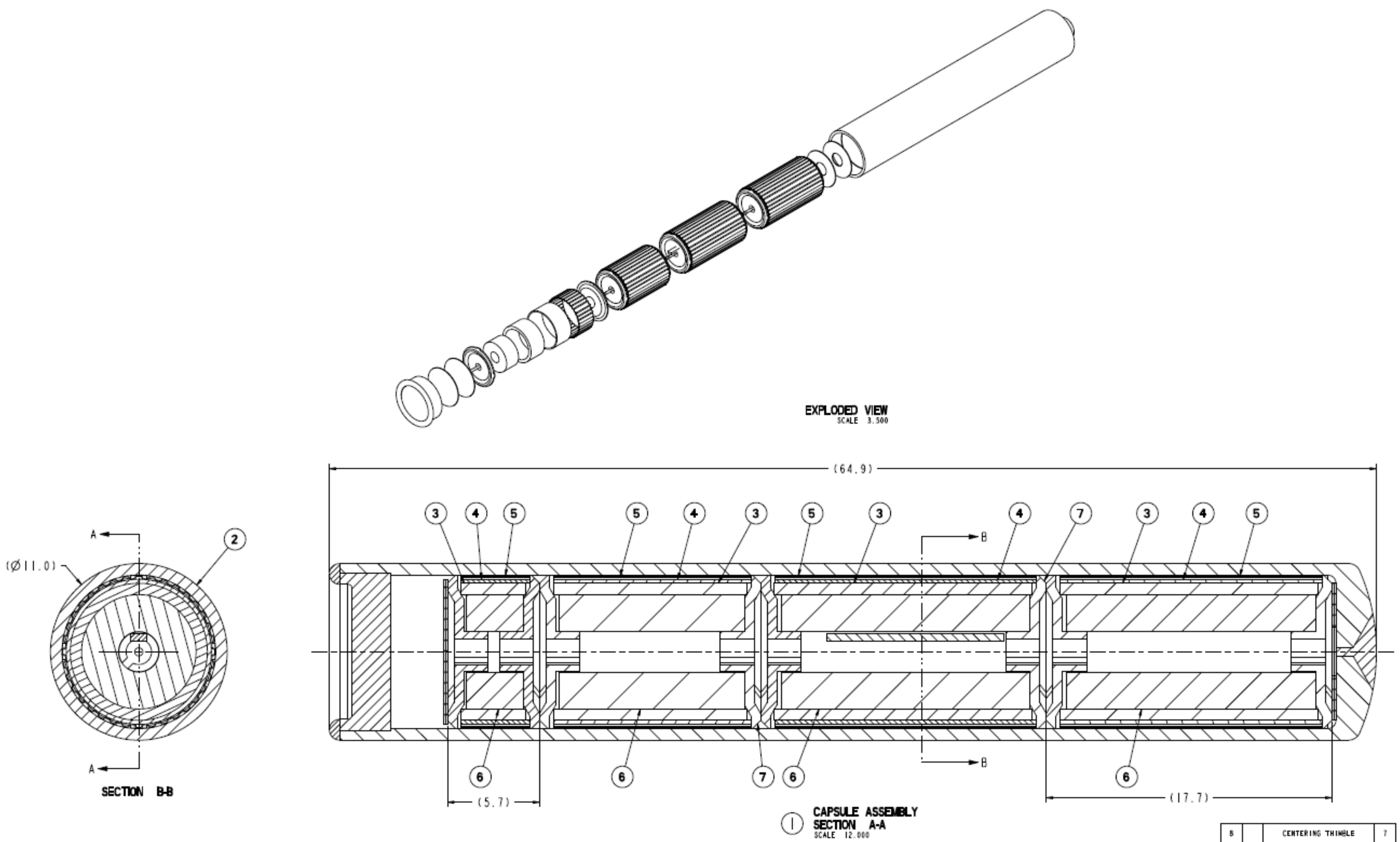
DES
DRW
TL
TR
LOA
HFIR S
HFIR QA
DRAWING APPROVALS DATE

UT-BATTELLE
Oak Ridge National Laboratory

IRRADIATION CAPSULE

MINIATURE FLEXURAL BAR DESIGN

VERSION NO. | PLANT ORNL | BLDG | FL | SHT OF | TYPE | CLASS
RELEASE LEVEL WIP | EJN | REV



EXAMPLE ONLY

8		CENTERING THIMBLE	7
4		HEATER	6
4		FOIL	5
4		SLEEVE	4
4		SPECIMEN	3
1		HOUSING	2
1		CAPSULE ASSEMBLY	1
	CAGE CODE	NOMENCLATURE OR DESCRIPTION	FIND NO

REV	DESCRIPTION	BY	TL	DATE	TR	DATE	LOA	DATE	HFIR S	DATE	HFIR QA	DATE

THIS DRAWING PRODUCED ON PRO-ENGINEER

SCALE NOTED

TOLERANCES UNLESS OTHERWISE SPECIFIED

FRACTIONS
X DECIMALS ±.1
XX DECIMALS ±.05
ANGLES ±0° 15'
BREAK SHARP EDGES .02 MAX
FINISH 63 RMS
FILLETS .02 MAX

DES
DRW
TL
TR
LOA
HFIR S
HFIR QA
DRAWING APPROVALS | DATE

UT-BATTELLE

Oak Ridge National Laboratory

UT-BATTELLE, LLC. Oak Ridge, Tennessee

IRRADIATION CAPSULE

CLAD TUBE DESIGN

VERSION NO.	PLANT	BLDG	FL	SHT	OF	TYPE	CLASS
	ORNL			1	1		

RELEASE LEVEL | EJN | REV

APPENDIX B. HFIR USER GUIDE