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# AMMT FY23 HFIR Irradiation Test Matrix – Supported by the Design of a Miniature Bend Bar Irradiation Vehicle


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OAK RIDGE
National Laboratory

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Advanced Materials and Manufacturing Technologies Program

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## ABBREVIATIONS

| | |
|---|---|
| AMMT | Advanced Materials and Manufacturing Technologies |
| AM | additive manufacturing |
| ANSYS | Analysis System Code |
| AR | as received |
| ASME | American Society of Mechanical Engineers |
| BD | build direction |
| CINDAS | Center for Information and Numerical Data Analysis and Synthesis |
| DAC | design and analysis calculation |
| DED | directed energy deposition |
| DOE | US Department of Energy |
| DPA | displacements per atom |
| FY | fiscal year |
| GENBEN | General Bend Bar Specimen Capsule (see “M4CVN”) |
| GENTEN | General Tensile Specimen Capsule |
| HFIR | High Flux Isotope Reactor |
| HGR | heat generation rate |
| LPBF | laser powder bed fusion |
| M4CVN | miniature 4-Charpy V-notch bend bar specimen |
| MBS-1 | miniature bend bar slotted #1 specimen |
| MCNP | Monte Carlo N-Particle Code |
| MINBEN | Miniature Bend Bar Specimen Capsule (see “MBS-1”) |
| OD | outer diameter |
| ORNL | Oak Ridge National Laboratory |
| PIE | post-irradiation examination |
| PTP | peripheral target position |
| RD | rolling direction |
| RT | room temperature |
| SA | solution-annealed |
| SiC | silicon carbide |
| SR | stress-relieved |
| SS-J3 | small-sized Japanese specification #3 tensile specimen |
| TD | transverse direction |
| TRRH | target rod rabbit holder |

# ACKNOWLEDGMENTS

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**ABSTRACT**

With the continued advancement of additive manufacturing (AM) techniques, interest has grown in the development and qualification of steels produced via these methods for use in the structural components of advanced nuclear reactors. Therefore, it is crucial that the properties of these materials such as the tensile strength and fracture toughness be investigated following neutron irradiation to support their use in industry. To that end, a test plan to irradiate several tensile and bend bar specimens in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory was proposed, along with the development of a new "MINBEN" capsule design that features MBS-1 bend bar specimens that have a larger cross-sectional area than those of previous designs, which allows for higher temperature out-of-pile testing. The specimens include AM 316H stainless steel with wrought 316H and A709 stainless steels for reference, and they will be irradiated at 2 dpa and 10 dpa—corresponding to roughly 1 and 5 cycles at the HFIR midplane—at temperatures of 400°C and 600°C. The MINBEN design was found to be capable of providing specimen test plane average temperatures in the range of 220–660°C for six specimens, with a min-max spread in this temperature of ~40°C and a 95% confidence interval of ~24°C. This analysis shows that the capsule provides an effective vehicle for gathering needed high-temperature fracture toughness data.

# 1. INTRODUCTION

A major initiative of the US Department of Energy's (DOE's) Advanced Materials and Manufacturing Technologies (AMMT) program is the development of a qualification framework for components produced by additive manufacturing (AM) for structural applications in advanced nuclear reactor concepts. This initiative comprises (1) a reimagined framework for American Society of Mechanical Engineers (ASME) code qualification for AM components and (2), nuclear qualification through the investigation of appropriate irradiation degradation phenomena that are expected in the various extreme environments in proposed advanced reactors. Although structural materials away from the core are expected to experience minimal irradiation displacement damage (< 10 displacements per atom, or dpa) over the course of their lifetime, it is important to identify time, temperature, and irradiation damage thresholds above which performance degradation may limit component lifetime. These analyses will augment the thermal aging studies already incorporated into the ASME code qualification framework.

Consistent with this approach, the AMMT program is pursuing a plan to assess the deterioration of key performance metrics of AM 316H stainless steel—namely, fracture toughness and tensile properties—at operational temperatures relevant to this material system (400–600°C). Unfortunately, prior multi-notch bend bar samples were designed for room temperature (RT) evaluations only and lack sufficient thickness to provide accurate measurements at elevated test temperatures. In this work, a new miniature bend bar (MINBEN) irradiation vehicle, or *rabbit*, with larger cross-sectional area MBS-1 ("miniature bend bar slotted") specimens was designed for irradiation temperatures up to 660°C in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL).

This report outlines first the AMMT neutron irradiation matrix for AM 316H stainless steel samples, comprising both off-the-shelf tensile (GENTEN) rabbits and the new MINBEN bend bar rabbits. Additionally, the design of the new MINBEN irradiation vehicle is described, and examples of the design at conditions set to produce sample irradiation temperatures of 350°C and 550°C are provided as proofs-of-concept. Details on the existing GENTEN design can be found in ORNL/TM-2019-1310 [1].

# 2. AMMT TEST MATRIX

The GENTEN and MINBEN rabbits will be deployed in fiscal year 2024 (FY24) for the irradiation of 316H stainless steel specimens fabricated using laser powder bed fusion (LPBF). For this initial campaign, 316H samples will be irradiated in both stress-relieved (SR) and solution-annealed (SA) conditions at 400°C and 600°C for up to 10 dpa for two sets of printing parameters, resulting in two representative microstructures. For comparison, wrought variants of austenitic steels 316H and A709 will also be included.

Data from 400°C conditions will provide information on radiation-induced segregation, phase stability, and potential hardening or softening behavior at the lower bound of temperatures expected for structural materials in elevated temperature service. At 400°C, small vacancy clusters will be expected to form, stabilized by helium production in the mixed HFIR spectrum. Dislocation loops are also expected in austenitic steels irradiated in this temperature regime. Hardening in austenitic steels is expected to saturate in the 5–10 dpa range, so two irradiation doses (2 and 10 dpa) were chosen for this set of irradiation experiments. Data at 600°C will provide information on softening and microstructural stability in comparison with prior 316L data [2, 3]. These data will be compared with tensile data of aged specimens to assess differences in mechanical performance with and without neutron irradiation.

Irradiation 1(a) (see Table 1) includes eight rabbits spanning two irradiation doses and two irradiation temperatures. Each rabbit contains twelve materials, each with two SS-J3 ("small-sized Japanese specification #3") tensile specimens per GENTEN rabbit. Figure 1 shows a SS-J3 specimen with simplified dimensions, where the full details and the GENTEN capsule assembly can be found in drawings S16-18-FUSSAM01 and S18-39-GEN-TEN, respectively [4, 5]. Rabbit capsules are duplicated so that each of the twelve materials has four total specimens: two to be tested at RT and two to be tested at the irradiation temperature ($T_{irr}$) at a strain rate of $10^{-3}$ $s^{-1}$ during post-irradiation examination (PIE). Rabbits are duplicated (thereby irradiating only two specimens per material per rabbit) to ensure specimens remain comparable between different materials for a given dose and temperature condition if temperature deviations occur.

Irradiation 1(b) (see Table 2) comprises a similar matrix of materials as Irradiation 1(a), but it instead features a total of twelve rabbits to account for each MINBEN capsule having only six MBS-1 specimens. The MBS-1 specimen is shown in Figure 2 with simplified dimensions and has a single V-notch and two side grooves for quantitative fracture toughness measurements. Full details of the MBS-1 specimen and the MINBEN capsule assembly can be found in drawings HS-2023-002 and HS-2023-003, respectively [6, 7]. These specimens will be pre-cracked prior to irradiation and will be tested at RT and $T_{irr}$ during PIE. For both irradiation conditions, AM specimens will be tested in both the build direction (BD) and in the transverse direction (TD) to reveal any anisotropy in crack propagation behavior (for MBS-1 samples) and tensile anisotropy (for SS-J3 samples).

Tables 1 and 2 outline the specimens in each HFIR rabbit. These specimens comprise LPBF 316H samples labeled M2B5-P35 and M2B6-P24. These names correspond to the build performed in FY23 on the Concept Laser M2, the build number, and the part number for cross-reference to the miniature Zeiss builds used for parametric optimization. These two printing parameters correspond to volumetric energy densities of 71 J/mm$^3$ (M2B5-P35) and 52 J/mm$^3$ (M2B6-P24). The former set of processing parameters has been shown to result in a large columnar grain structure, whereas the latter processing conditions result in a more refined globular grain structure with less grain texture. Detailed microscopy showing these microstructures will be covered in a companion milestone report and is not detailed here. For each of these larger builds, a printed plate (part 6 on each build) was sectioned into three vertical slices, and each slice was subjected to a different heat treatment, including stress relief, solution annealing, and hot isostatic pressing. For this irradiation campaign, stress-relieved and solution-annealed conditions are specifically of interest. Select bend bar and tensile specimens will be machined such that the notch and/or gauge are oriented along the BD or TD of the plate, as shown in Figure 3. Also included in this irradiation campaign are formerly printed directed energy deposition (DED) 316L specimens [8] and reference wrought 316H and A709 alloys.

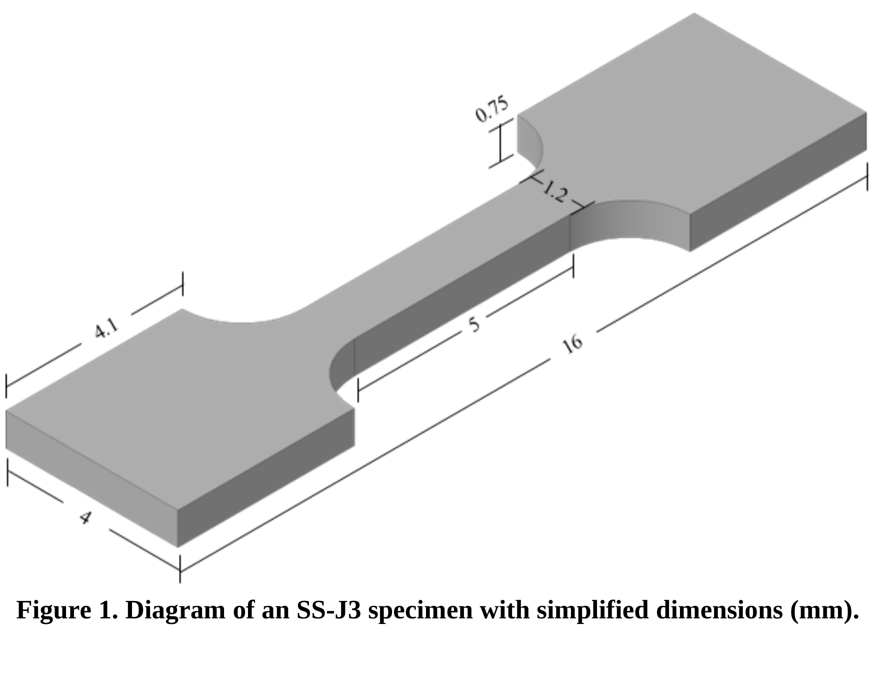



**Figure 1. Diagram of an SS-J3 specimen with simplified dimensions (mm).**

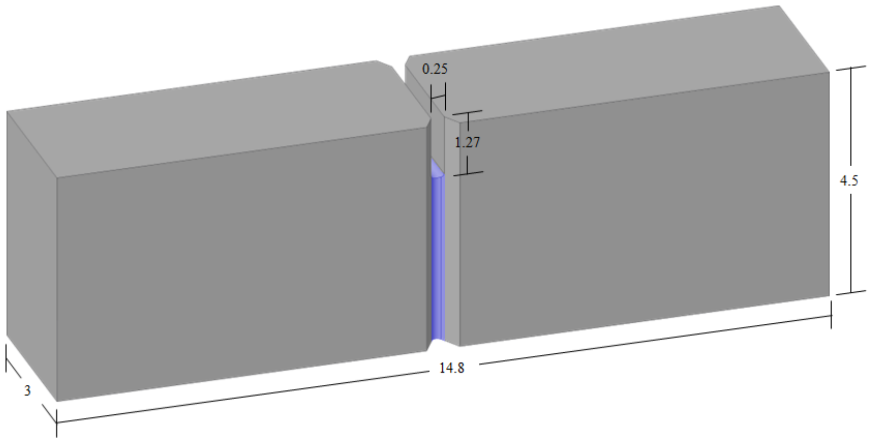
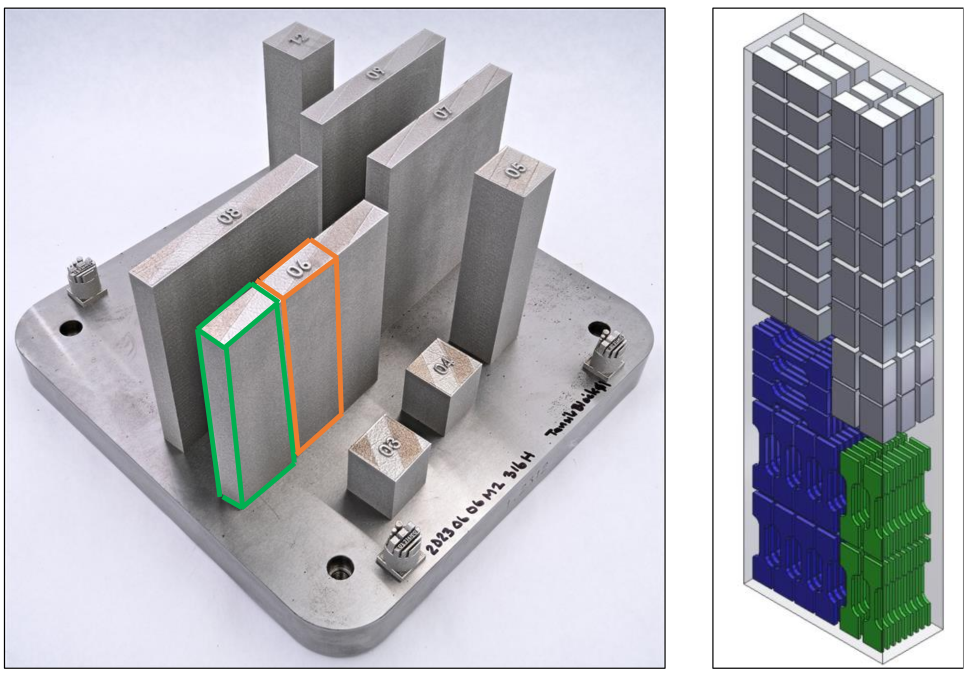



**Figure 2. Diagram of an MBS-1 specimen with simplified dimensions (mm).**

The area of interest under the test notch is referred to the *test plane* and is highlighted in blue. MINBEN experiment temperatures are optimized based on the average temperature of this region.



(a) (b)

**Figure 3. Machining plan for initial HFIR irradiation campaign.**

In (a), an overview image of build “2023-06-06 M2 316H Tensile Blocks 01” is shown with specified locations from which heat-treated specimens were extracted. In (b), the specimen locations are shown as submitted for machining.

**Table 1. Irradiation matrix for the tensile specimens (GENTEN).**

| Irradiation 1(a) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Rabbit #** | **Material*** | **Condition**** | **Orientation***** | **Specimen Type** | **Specimens** | **Dose (dpa)** | **HFIR Cycles** | **Temp (°C)** |
| **1 & 2** | M2B5-P35 | SR | BD | SS-J3 | 2 | 2 | 1 | 400 |
| | M2B5-P35 | SR | TD | | 2 | | | |
| | M2B6-P24 | SR | BD | | 2 | | | |
| | M2B6-P24 | SR | TD | | 2 | | | |
| | M2B5-P35 | SA | BD | | 2 | | | |
| | M2B5-P35 | SA | TD | | 2 | | | |
| | M2B6-P24 | SA | BD | | 2 | | | |
| | M2B6-P24 | SA | TD | | 2 | | | |
| | DED 316L | SR | RD | | 2 | | | |
| | DED 316L | SR | TD | | 2 | | | |
| | Wrought 316H | AR | RD | | 2 | | | |
| | A709 | AR | RD | | 2 | | | |
| **3 & 4** | M2B5-P35 | SR | BD | SS-J3 | 2 | 10 | 5 | 400 |
| | M2B5-P35 | SR | TD | | 2 | | | |
| | M2B6-P24 | SR | BD | | 2 | | | |
| | M2B6-P24 | SR | TD | | 2 | | | |
| | M2B5-P35 | SA | BD | | 2 | | | |
| | M2B5-P35 | SA | TD | | 2 | | | |
| | M2B6-P24 | SA | BD | | 2 | | | |
| | M2B6-P24 | SA | TD | | 2 | | | |
| | DED 316L | SR | RD | | 2 | | | |
| | DED 316L | SR | TD | | 2 | | | |
| | Wrought 316H | AR | RD | | 2 | | | |
| | A709 | AR | RD | | 2 | | | |
| **5 & 6** | M2B5-P35 | SR | BD | SS-J3 | 2 | 2 | 1 | 600 |
| | M2B5-P35 | SR | TD | | 2 | | | |
| | M2B6-P24 | SR | BD | | 2 | | | |
| | M2B6-P24 | SR | TD | | 2 | | | |
| | M2B5-P35 | SA | BD | | 2 | | | |
| | M2B5-P35 | SA | TD | | 2 | | | |
| | M2B6-P24 | SA | BD | | 2 | | | |
| | M2B6-P24 | SA | TD | | 2 | | | |
| | DED 316L | SR | RD | | 2 | | | |
| | DED 316L | SR | TD | | 2 | | | |
| | Wrought 316H | AR | RD | | 2 | | | |
| | A709 | AR | RD | | 2 | | | |
| **7 & 8** | M2B5-P35 | SR | BD | SS-J3 | 2 | 10 | 5 | 600 |
| | M2B5-P35 | SR | TD | | 2 | | | |
| | M2B6-P24 | SR | BD | | 2 | | | |
| | M2B6-P24 | SR | TD | | 2 | | | |
| | M2B5-P35 | SA | BD | | 2 | | | |
| | M2B5-P35 | SA | TD | | 2 | | | |
| | M2B6-P24 | SA | BD | | 2 | | | |
| | M2B6-P24 | SA | TD | | 2 | | | |
| | DED 316L | SR | RD | | 2 | | | |
| | DED 316L | SR | TD | | 2 | | | |
| | Wrought 316H | AR | RD | | 2 | | | |
| | A709 | AR | RD | | 2 | | | |

* Specimen M2B5-P35 corresponds to parameters used to print larger FY23 Build "2023-06-06 M2 316H Tensile Blocks 01", whereas specimen M2B6-P24 corresponds to parameters used to print larger FY23 Build "2023-06-12 M2 316H Tensile Blocks 02"

** SR = stress-relieved for 24 h at 650°C, SA = solution-annealed at 1150°C for 1 h, AR = as-received from vendor (see vendor specifications for prior thermomechanical processing)

*** BD = build direction, TD = transverse direction, RD = prior plate rolling direction

**Table 2. Irradiation matrix for the fracture toughness specimens (MINBEN).**

| Rabbit # | Material* | Condition** | Orientation*** | Specimen Type | Specimens | Dose (dpa) | HFIR Cycles | Temp (°C) |
|---|---|---|---|---|---|---|---|---|
| **Irradiation 1(b)** | | | | | | | | |
| **1** | M2B5-P35 | SR | BD | MBS-1 | 2 | 2 | 1 | 400 |
| | M2B5-P35 | SR | TD | | 2 | | | |
| | M2B6-P24 | SR | BD | | 2 | | | |
| **2** | M2B6-P24 | SR | TD | MBS-1 | 2 | 2 | 1 | 400 |
| | M2B5-P35 | SA | BD | | 2 | | | |
| | M2B6-P24 | SA | BD | | 2 | | | |
| **3** | DED 316L | SR | RD | MBS-1 | 2 | 2 | 1 | 400 |
| | Wrought 316H | AR | RD | | 2 | | | |
| | A709 | AR | RD | | 2 | | | |
| **4** | M2B5-P35 | SR | BD | MBS-1 | 2 | 10 | 5 | 400 |
| | M2B5-P35 | SR | TD | | 2 | | | |
| | M2B6-P24 | SR | BD | | 2 | | | |
| **5** | M2B6-P24 | SR | TD | MBS-1 | 2 | 10 | 5 | 400 |
| | M2B5-P35 | SA | BD | | 2 | | | |
| | M2B6-P24 | SA | BD | | 2 | | | |
| **6** | DED 316L | SR | RD | MBS-1 | 2 | 10 | 5 | 400 |
| | Wrought 316H | AR | RD | | 2 | | | |
| | A709 | AR | RD | | 2 | | | |
| **7** | M2B5-P35 | SR | BD | MBS-1 | 2 | 2 | 1 | 600 |
| | M2B5-P35 | SR | TD | | 2 | | | |
| | M2B6-P24 | SR | BD | | 2 | | | |
| **8** | M2B6-P24 | SR | TD | MBS-1 | 2 | 2 | 1 | 600 |
| | M2B5-P35 | SA | BD | | 2 | | | |
| | M2B6-P24 | SA | BD | | 2 | | | |
| **9** | DED 316L | SR | RD | MBS-1 | 2 | 2 | 1 | 600 |
| | Wrought 316H | AR | RD | | 2 | | | |
| | A709 | AR | RD | | 2 | | | |
| **10** | M2B5-P35 | SR | BD | MBS-1 | 2 | 10 | 5 | 600 |
| | M2B5-P35 | SR | TD | | 2 | | | |
| | M2B6-P24 | SR | BD | | 2 | | | |
| **11** | M2B6-P24 | SR | TD | MBS-1 | 2 | 10 | 5 | 600 |
| | M2B5-P35 | SA | BD | | 2 | | | |
| | M2B6-P24 | SA | BD | | 2 | | | |
| **12** | DED 316L | SR | RD | MBS-1 | 2 | 10 | 5 | 600 |
| | Wrought 316H | AR | RD | | 2 | | | |
| | A709 | AR | RD | | 2 | | | |

* Specimen M2B5-P35 corresponds to parameters used to print larger FY23 Build "2023-06-06 M2 316H Tensile Blocks 01", whereas specimen M2B6-P24 corresponds to parameters used to print larger FY23 Build "2023-06-12 M2 316H Tensile Blocks 02"

** SR = stress-relieved for 24 h at 650°C, SA = solution-annealed at 1150°C for 1 h, AR = as-received from vendor (see vendor specifications for prior thermomechanical processing)

*** BD = build direction, TD = transverse direction, RD = prior plate rolling direction

## 3. BEND BAR (MBS-1) EXPERIMENTAL DESIGN CONCEPT

Rabbit capsules are standard, 64 mm long aluminum cylinders used for irradiating a variety of samples in HFIR. For this experiment, the capsules will be loaded in a target rod rabbit holder (TRRH) or a peripheral target position (PTP) in the flux trap located at the center of the reactor core. Because HFIR operates continuously at a reactor power of 85 MW, the specimens will be exposed to a nearly constant fast neutron flux of ~$1\times10^{15}$ n/cm$^2$s (E > 0.1 MeV) during each ~24-day cycle. The outer surfaces of the capsules are exposed to reactor coolant in the range of 50–60°C.

For this experiment, the MINBEN capsule is loaded with a holder that contains six MBS-1 ("miniature bend bar slotted") specimens, four pieces of silicon carbide (SiC) passive thermometry, and an assortment of thin shims and SiC springs to keep the components in close thermal contact. The MBS-1 specimens feature a single test notch and two support grooves for three-point bend testing, which form an area of interest hereinafter referred to as the *test plane* (see Figure 2). At either end of the holder, two wires and a few molybdenum foils hold the components within, and centering tabs and two wave springs center it in the capsule. The holder can be made of either aluminum or molybdenum for lower or higher temperature irradiations, respectively, and the temperature is controlled via the outer diameter (OD) by altering the width of the insulating helium gas gap between the holder and the housing. The experiment is shown in Figure 4, with an additional exploded view of the holder provided in Figure 5.This design is a modified version of the previous GENBEN ("generic bend bar") capsule described in ORNL/TM-2019/1310 [1], which featured four M4CVN ("miniature 4-Charpy V-notch") bend bar specimens with roughly half of the cross-sectional area per part as the current MBS-1 specimens. This change is expected to expand fracture test temperatures to high temperatures (i.e., up to 660°C) and enhance the accuracy of results.

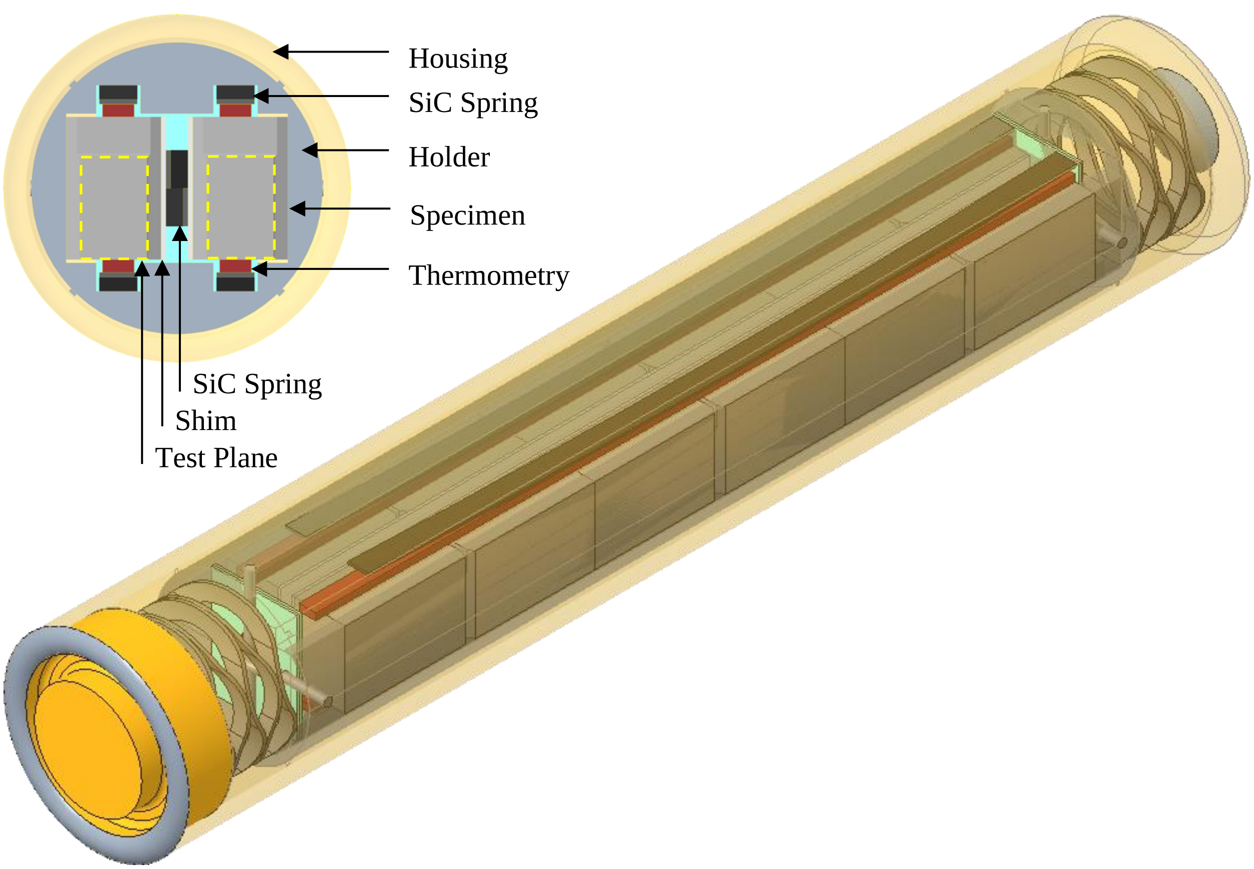



**Figure 4. Design of the MINBEN capsule containing six MBS-1 specimens.**

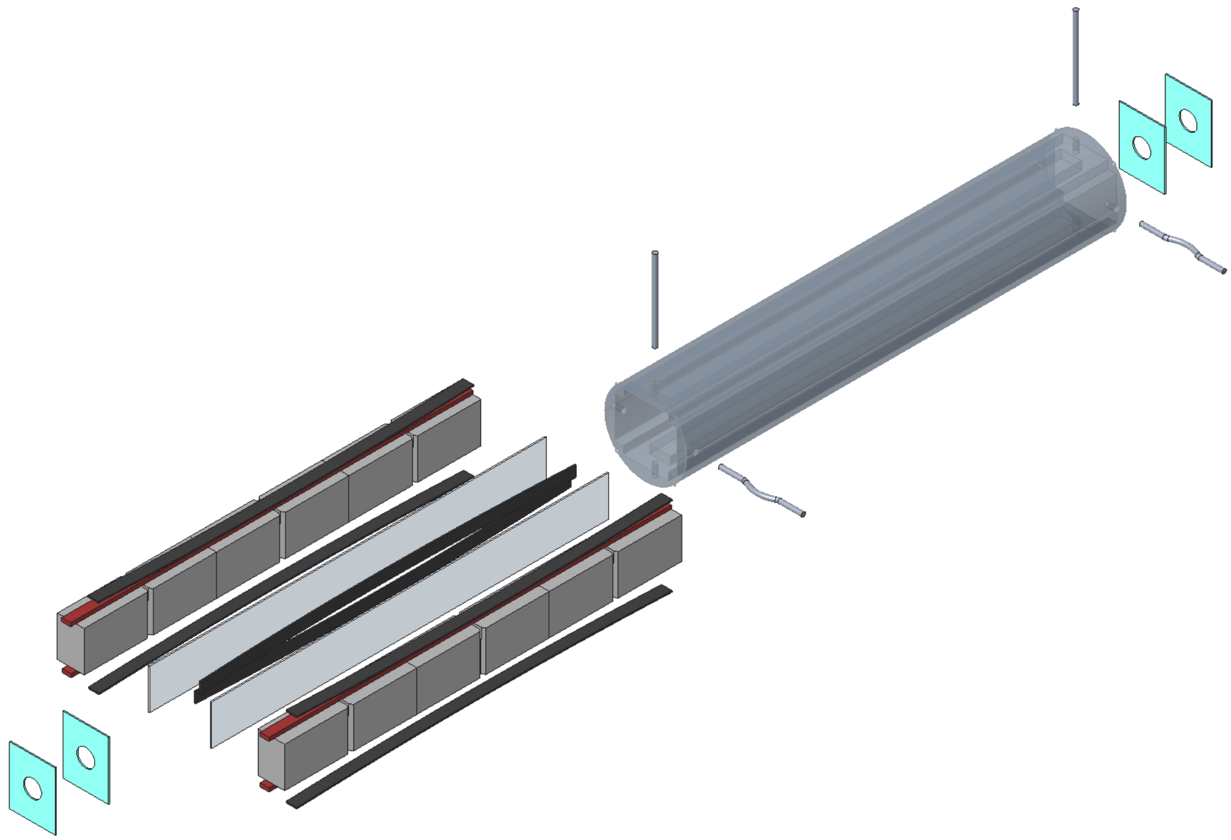


**Figure 5. Exploded view of the interior components of the MINBEN capsule**.

To calculate temperatures within the experiment, the ANSYS finite element software was used with custom, user-defined macros. More information on these macros can be found in Design and Analysis Calculation (DAC) 11-13-ANSYS02, Rev. 7, which is available by request [9]. Additionally, a set of temperature-dependent—and in certain cases, dose-dependent—material properties were calculated using a database of DACs maintained by the ORNL Irradiation Engineering Group. These properties are obtained from the Center for Information and Numerical Data Analysis and Synthesis (CINDAS) [10], MatWeb [11], and a variety of literature sources. Table 3 lists the previously approved DACs that were used in this calculation. Note that certain parts, such as the specimens and the holder, can be modeled as several different materials. For this report, the specimens were modeled using 304 stainless steel due to its near-identical thermal properties to the materials of interest in Section 2.

**Table 3. Experiment materials and material property references.**

| Material | Part(s) | Reference DAC |
|---|---|---|
| Aluminum | End cap, holder, housing | DAC-10-03-PROP_AL6061 [12] |
| FeCrAl | Specimen | DAC-16-02-PROP_FeCrAl [13] |
| Helium | Fill gas | DAC-10-02-PROP_HELIUM [14] |
| Inconel | Specimen | DAC-13-01-PROP_INCONEL [15] |
| Molybdenum | Foil, holder, wire | DAC-10-11-PROP_MOLY [16] |
| Silicon carbide | Shim, specimen, spring, thermometry | DAC-10-06-PROP_SIC(IRR) [17] |
| Steel (SS304) | Shim, specimen, wave spring | DAC-10-16-PROP_SS304 [18] |
| Steel (F82H) | Specimen | DAC-10-10-PROP_F82H [19] |

Boundary conditions and peak heat generation rates (HGRs) are provided in Table 4. HGRs include contributions from prompt neutrons, prompt gamma photons, fission product decay photons, and decay of activation sources; these were calculated using the Monte Carlo N-Particle (MCNP) transport code. As this is an unfueled experiment, heating is dominated by the gamma absorption components. Axial power profiles specific to the HFIR flux trap were then used to scale the peak heating rates calculated via MCNP to their in-situ values. Convective heat transfer coefficients and bulk coolant temperatures were calculated using turbulent flow correlations and applied to the outer surface of the rabbit housing.

**Table 4. Thermal boundary conditions.**

| Parameter | PTP value | TRRH value | Reference |
|---|---|---|---|
| Convective heat transfer coefficient | 48.4 $kW/m^2 \cdot K$ | 47.1 $kW/m^2 \cdot K$ | DAC-11-01-RAB03 Rev. 0 [20] |
| Bulk coolant temperature | 54°C | 52°C | DAC-11-01-RAB03 Rev. 0 [20] |
| Power profile correlating parameter (upper) | 30.39 cm | 30.39 cm | C-HFIR-2012-035 Rev. 0 [21] |
| Power profile correlating parameter (lower) | 29.70 cm | 29.70 cm | C-HFIR-2012-035 Rev. 0 [21] |
| Peak HGR for aluminum | 32.1 W/g | 31.3 W/g | C-HFIR-2012-035 Rev. 0 [21] |
| Peak HGR for FeCrAl | 34.4 W/g | 33.5 W/g | C-HFIR-2017-011 Rev. 0 [22] |
| Peak HGR for Inconel | 36.7 W/g | 35.7 W/g | C-HFIR-2017-011 Rev. 0 [22] |
| Peak HGR for molybdenum | 42.9 W/g | 42.0 W/g | C-HFIR-2012-035 Rev. 0 [21] |
| Peak HGR for silicon carbide | 32.9 W/g | 31.7 W/g | C-HFIR-2012-035 Rev. 0 [21] |
| Peak HGR for steel | 38.8 W/g | 38.1 W/g | C-HFIR-2012-035 Rev. 0 [21] |

Lastly, the model was parameterized and used to construct response surfaces with the ANSYS DesignXplorer software package. This is a fitted model of the system's response to many inputs, and it allows for quick and accurate prediction of results. The MBS-1 test plane average temperature has been calculated as a function of the holder material, OD, and vertical position in the reactor for a constant housing inner diameter of 9.519 mm. These values are provided in the following section. Full dimensions for each component can be found in the drawings listed in Table 5 while the capsule assembly itself can be found on drawings HS-2023-003 and X3E020977A633 [7, 23]. These are available by request.

**Table 5. MINBEN part drawings.**

| Part | Drawing |
|---|---|
| End cap, housing | X3E020977A634 [24] |
| Foil, shim, specimen, thermometry | HS-2023-002 [6] |
| Holder, spring, wave spring, wire | S18-41-GEN-BEN [25] |

## 4. BEND BAR (MBS-1) ANALYSIS RESULTS

With the model constructed as described above, the experiment was analyzed for the cases of either an aluminum or molybdenum holder, SS304 specimens and shims, and a helium fill gas. Averages and ranges for the test plane temperatures in reactor positions TRRH2, 3, 5, and 6 are provided in Table 6, where test plane temperatures of 350°C and 550°C were targeted as proofs-of-concept for the aluminum and molybdenum holders, respectively. Table 7 displays these same data but for all four of the SiC thermometry pieces instead. On average, the min-max spread in the test plane temperature is ~40°C for both types of holders with a 95% confidence interval of ~24°C, and the thermometry pieces were generally ~12°C lower in temperature than the specimen test plane. Additional details for each of these cases can be found in Appendix A. The full response surface for the test plane average temperature as a function of holder material, vertical position in the reactor, and holder OD is provided in Figure 6, and Figures 7 and 8 show temperature contours for the 350°C and 550°C cases, respectively, in position TRRH2. For the current design space, the entire range of possible test plane average temperatures is approximately 220–660°C.

**Table 6. Average, min, and max temperatures (°C) for each test plane as a function of holder material and reactor position.**

Specimen test plane temperatures of 350°C and 550°C were targeted for aluminum and molybdenum holders, respectively.

| | Reactor Position<br>Mat./Holder OD (mm) | TRRH2<br>Al 9.20 | TRRH3<br>Al 9.26 | TRRH5<br>Al 9.27 | TRRH6<br>Al 9.22 | TRRH2<br>Mo 9.18 | TRRH3<br>Mo 9.25 | TRRH5<br>Mo 9.26 | TRRH6<br>Mo 9.21 |
|---|---|---|---|---|---|---|---|---|---|
| **Test Plane*** | | **Temperature (°C)** | | | | | | | |
| **ALL** | **Avg** | 349 | 350 | 350 | 351 | 552 | 547 | 547 | 548 |
| | **Min** | 314 | 315 | 310 | 311 | 512 | 509 | 505 | 503 |
| | **Max** | 364 | 367 | 367 | 371 | 571 | 564 | 564 | 570 |
| **1A (Top)** | **Avg** | 353 | 351 | 343 | 340 | 561 | 550 | 536 | 530 |
| | **Min** | 323 | 319 | 310 | 311 | 534 | 519 | 505 | 503 |
| | **Max** | 364 | 364 | 356 | 351 | 571 | 562 | 548 | 541 |
| **1B (Top)** | **Avg** | 353 | 351 | 343 | 340 | 561 | 550 | 536 | 531 |
| | **Min** | 325 | 319 | 312 | 312 | 535 | 520 | 507 | 505 |
| | **Max** | 364 | 364 | 356 | 352 | 571 | 562 | 548 | 542 |
| **2A** | **Avg** | 352 | 354 | 354 | 355 | 557 | 552 | 552 | 553 |
| | **Min** | 333 | 332 | 332 | 335 | 540 | 532 | 532 | 535 |
| | **Max** | 363 | 367 | 367 | 366 | 567 | 564 | 564 | 564 |
| **2B** | **Avg** | 352 | 354 | 354 | 355 | 557 | 552 | 552 | 553 |
| | **Min** | 333 | 332 | 322 | 335 | 540 | 532 | 522 | 526 |
| | **Max** | 363 | 367 | 367 | 366 | 567 | 563 | 564 | 563 |
| **3A** | **Avg** | 341 | 346 | 354 | 359 | 537 | 539 | 552 | 560 |
| | **Min** | 314 | 315 | 322 | 329 | 512 | 509 | 521 | 532 |
| | **Max** | 352 | 359 | 367 | 371 | 548 | 550 | 564 | 570 |
| **3B** | **Avg** | 341 | 346 | 354 | 359 | 537 | 538 | 552 | 560 |
| | **Min** | 315 | 315 | 321 | 329 | 512 | 509 | 521 | 532 |
| | **Max** | 352 | 359 | 367 | 371 | 549 | 551 | 564 | 570 |

* Specimen test planes are designated by their position in the stack (#1–3) and the side of the capsule on which they are located (A or B), where "ALL" is the aggregate value from all six positions. This can be observed in Figure 7 and Figure **8**.

**Table 7. Average, min, and max temperatures (°C) for all four pieces of SiC thermometry as a function of holder material and reactor position.**

Specimen test plane temperatures of 350°C and 550°C were targeted for aluminum and molybdenum holders, respectively.

| Reactor Position<br>Holder OD (mm) | TRRH2<br>Al 9.20 | TRRH3<br>Al 9.26 | TRRH5<br>Al 9.27 | TRRH6<br>Al 9.22 | TRRH2<br>Mo 9.18 | TRRH3<br>Mo 9.25 | TRRH5<br>Mo 9.26 | TRRH6<br>Mo 9.21 |
|---|---|---|---|---|---|---|---|---|
| | | | | **Temperature (°C)** | | | | |
| **Avg** | 337 | 337 | 337 | 339 | 541 | 534 | 534 | 536 |
| **Min** | 304 | 304 | 312 | 317 | 502 | 499 | 508 | 503 |
| **Max** | 349 | 347 | 350 | 355 | 557 | 546 | 547 | 555 |

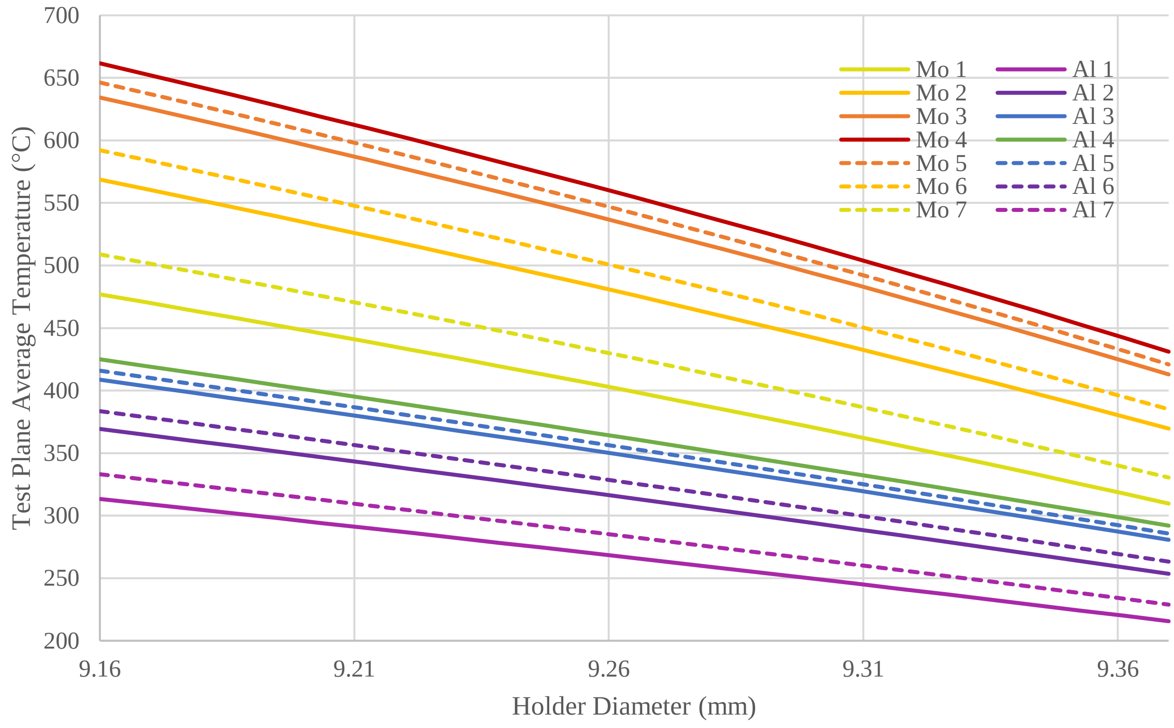



**Figure 6. MBS-1 test plane average temperature (°C) with a helium capsule fill gas as a function of holder material, vertical position in the reactor, and holder OD (mm).**

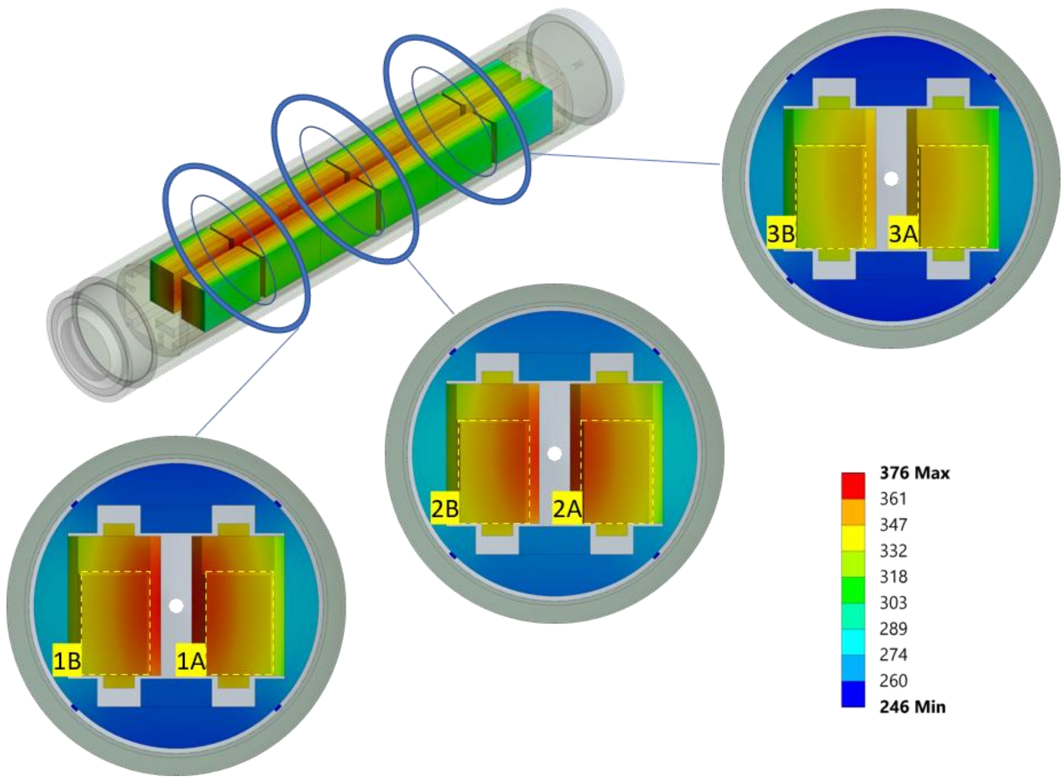



**Figure 7. Temperature contours for the 350°C case with a 9.20 mm OD aluminum holder in TRRH2.**

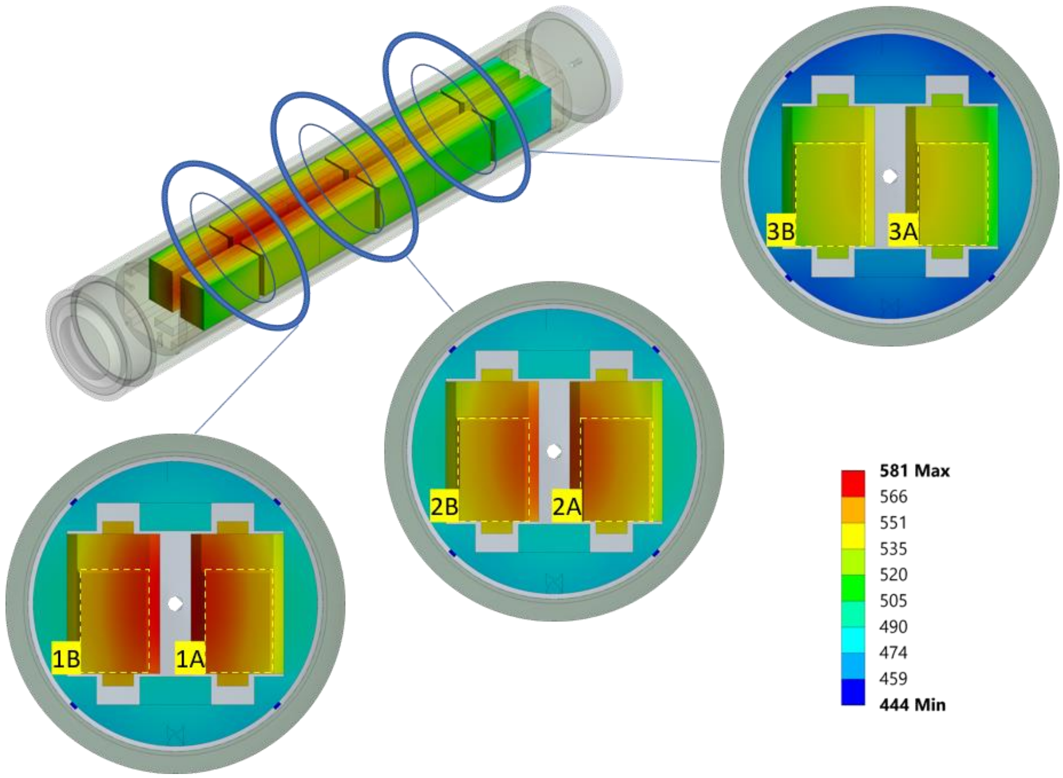



**Figure 8. Temperature contours for the 550°C case with a 9.18 mm OD molybdenum holder in TRRH2.**

## 5. CONCLUSION

This report presents a test plan to irradiate several types of additively manufactured tensile and bend bar specimens in the flux trap of HFIR, along with a newly developed MBS-1 bend bar capsule design that allows for higher temperature out-of-pile testing thanks to an increase in the specimen cross-sectional area. These specimens will consist of 316H stainless steel produced using the Concept Laser M2 LPBF machine at either 52 $J/mm^3$ or 71 $J/mm^3$ (designated as M2B6-P24 or M2B5-P35), previously printed DED 316L specimens, and wrought 316H and A709 steels for comparison. The printed specimens will be aligned with either the BD or the TD and will be irradiated at either 2 or 10 dpa at temperatures of either 400°C or 600°C. The new MINBEN capsule design contains a total of six MBS-1 specimens and four pieces of SiC passive thermometry held within a variable OD holder. Varying this parameter enables the specimen test plane average temperature to be set to anywhere from 220°C to 660°C, with a min-max spread of ~40°C and a 95% confidence interval of ~24°C. Correspondingly, the average temperature of the SiC thermometry was generally found to be ~12°C lower than the test plane temperature. Future efforts will look to proceed with the assembly and insertion of these capsules, followed by PIE both at RT and the temperature of irradiation. This work will provide valuable data for the implementation of additively manufactured steels in advanced nuclear reactor structural components.

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# APPENDIX A. ANSYS OUTPUT FILES

# APPENDIX A. ANSYS OUTPUT FILES

## A-1. 9.20 mm Al Holder in TRRH2 ANSYS Summary

******************************************************************************
OUTPUT SUMMARY FILE
******************************************************************************

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INPUTS

* Symmetry angle: 360.00 degrees
* Housing fill gas: 100HE_0A
* Holder material: Aluminum
* Specimen material: SS304
* Shim material: SS304
* Radiative heat transfer included
* 3D problem geometry
* Target temperature: 350.0 °C
* Target dose (in SiC): 20.000 dpa
* Irradiation facility: TRRH
* Axial position: 2
* Axial peaking factor above the core midplane: 30.390 cm
* Axial peaking factor below the core midplane: 29.700 cm
* Housing Inner Diameter: 9.519 mm
* Holder Outer Diameter: 9.200 mm
* Holder Tab Outer Diameter: 9.400 mm
* Design basis
* Nominal geometry

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BOUNDARY CONDITIONS

Heat generation rate scaling factor = 1.0000
Heat transfer coefficient = 47100. $W/m^2 \cdot °C$
Bulk coolant temperature = 52.0 °C

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HEAT GENERATION

| Part | Material | Heat Gen. @Midplane (W/kg) | ------ Heat Load ----- @Midplane (W) | @Location (W) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 31300. | 19.4 | 17.1 |
| 2) Holder | AL-6061 | 31300. | 117.4 | 94.8 |
| 3) TM_1A | SiC(Irr) | 31700. | 1.8 | 1.5 |
| 4) TM_1B | SiC(Irr) | 31700. | 1.8 | 1.5 |
| 5) TM_2B | SiC(Irr) | 31700. | 1.8 | 1.5 |
| 6) TM_2A | SiC(Irr) | 31700. | 1.8 | 1.5 |
| 7) Shim_A | SS304 | 38100. | 9.2 | 7.4 |
| 8) Shim_B | SS304 | 38100. | 9.2 | 7.4 |
| 9) Spring_Retainer_2 | SiC(Irr) | 31700. | 0.8 | 0.6 |
| 10) Spring_Retainer_1 | SiC(Irr) | 31700. | 0.8 | 0.6 |
| 11) Spring_TM_1A | SiC(Irr) | 31700. | 0.8 | 0.6 |
| 12) Spring_TM_1B | SiC(Irr) | 31700. | 0.8 | 0.6 |
| 13) Spring_TM_2A | SiC(Irr) | 31700. | 0.8 | 0.6 |
| 14) Spring_TM_2B | SiC(Irr) | 31700. | 0.8 | 0.6 |
| 15) Disk_3 | Moly | 42000. | 1.7 | 1.3 |
| 16) Disk_4 | Moly | 42000. | 1.7 | 1.3 |
| 17) Disk_2 | Moly | 42000. | 1.7 | 1.4 |
| 18) Disk_1 | Moly | 42000. | 1.7 | 1.4 |
| 19) Wire_2A | Moly | 42000. | 0.8 | 0.6 |
| 20) Wire_1A | Moly | 42000. | 0.8 | 0.7 |
| 21) Wire_1B | Moly | 42000. | 0.8 | 0.7 |
| 22) Wire_2B | Moly | 42000. | 0.8 | 0.6 |
| 23) Housing_High | AL-6061 | 31300. | 5.1 | 4.5 |
| 24) Housing_Low | AL-6061 | 31300. | 15.4 | 11.2 |
| 25) Housing_Mid | AL-6061 | 31300. | 113.8 | 92.0 |

| | | | | |
|---|---|---|---|---|
| 26) Specimen_3A_Low | SS304 | 38100. | 30.0 | 22.7 |
| 27) Specimen_3A_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 28) Specimen_3A_High | SS304 | 38100. | 30.0 | 23.3 |
| 29) Specimen_2A_Low | SS304 | 38100. | 30.0 | 23.9 |
| 30) Specimen_2A_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 31) Specimen_2A_High | SS304 | 38100. | 30.0 | 24.4 |
| 32) Specimen_1A_Low | SS304 | 38100. | 30.0 | 25.0 |
| 33) Specimen_1A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 34) Specimen_1A_High | SS304 | 38100. | 30.0 | 25.5 |
| 35) Specimen_3B_Low | SS304 | 38100. | 30.0 | 22.7 |
| 36) Specimen_3B_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 37) Specimen_3B_High | SS304 | 38100. | 30.0 | 23.3 |
| 38) Specimen_2B_Low | SS304 | 38100. | 30.0 | 23.9 |
| 39) Specimen_2B_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 40) Specimen_2B_High | SS304 | 38100. | 30.0 | 24.4 |
| 41) Specimen_1B_Low | SS304 | 38100. | 30.0 | 25.0 |
| 42) Specimen_1B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 43) Specimen_1B_High | SS304 | 38100. | 30.0 | 25.5 |
| | | | 674.0 | 544.2 |

CAPSULE TEMPERATURE SUMMARY

| Name | Material | Tavg | Tmin | Tmax | T.025 | T.975 |
|---|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 69. | 67. | 71. | 67. | 71. |
| 2) Holder | AL-6061 | 264. | 246. | 284. | 249. | 281. |
| 3) TM_1A | SiC(Irr) | 337. | 304. | 349. | 317. | 346. |
| 4) TM_1B | SiC(Irr) | 337. | 304. | 349. | 317. | 346. |
| 5) TM_2B | SiC(Irr) | 337. | 304. | 349. | 317. | 346. |
| 6) TM_2A | SiC(Irr) | 337. | 304. | 349. | 317. | 346. |
| 7) Shim_A | SS304 | 359. | 317. | 370. | 334. | 369. |
| 8) Shim_B | SS304 | 358. | 317. | 370. | 334. | 369. |
| 9) Spring_Retainer_2 | SiC(Irr) | 365. | 323. | 376. | 339. | 375. |
| 10) Spring_Retainer_1 | SiC(Irr) | 365. | 314. | 376. | 339. | 375. |
| 11) Spring_TM_1A | SiC(Irr) | 306. | 258. | 336. | 263. | 334. |
| 12) Spring_TM_1B | SiC(Irr) | 306. | 258. | 336. | 263. | 333. |
| 13) Spring_TM_2A | SiC(Irr) | 306. | 258. | 337. | 263. | 335. |
| 14) Spring_TM_2B | SiC(Irr) | 306. | 258. | 337. | 263. | 334. |
| 15) Disk_3 | Moly | 305. | 285. | 317. | 288. | 315. |
| 16) Disk_4 | Moly | 304. | 292. | 313. | 295. | 312. |
| 17) Disk_2 | Moly | 277. | 267. | 282. | 269. | 282. |
| 18) Disk_1 | Moly | 278. | 272. | 282. | 273. | 282. |
| 19) Wire_2A | Moly | 278. | 260. | 289. | 261. | 289. |
| 20) Wire_1A | Moly | 269. | 254. | 279. | 255. | 279. |
| 21) Wire_1B | Moly | 273. | 257. | 283. | 258. | 283. |
| 22) Wire_2B | Moly | 280. | 265. | 290. | 265. | 290. |
| 23) Housing_High | AL-6061 | 56. | 56. | 57. | 56. | 56. |
| 24) Housing_Low | AL-6061 | 59. | 57. | 60. | 57. | 60. |
| 25) Housing_Mid | AL-6061 | 58. | 54. | 60. | 54. | 60. |
| 26) Specimen_3A_Low | SS304 | 327. | 287. | 352. | 299. | 348. |
| 27) Specimen_3A_TestPlane | SS304 | 341. | 314. | 352. | 328. | 350. |
| 28) Specimen_3A_High | SS304 | 339. | 303. | 359. | 311. | 357. |
| 29) Specimen_2A_Low | SS304 | 344. | 307. | 365. | 316. | 362. |
| 30) Specimen_2A_TestPlane | SS304 | 352. | 333. | 363. | 339. | 362. |
| 31) Specimen_2A_High | SS304 | 348. | 311. | 367. | 319. | 365. |
| 32) Specimen_1A_Low | SS304 | 348. | 310. | 368. | 319. | 366. |
| 33) Specimen_1A_TestPlane | SS304 | 353. | 323. | 364. | 339. | 363. |
| 34) Specimen_1A_High | SS304 | 342. | 297. | 366. | 309. | 362. |
| 35) Specimen_3B_Low | SS304 | 327. | 287. | 352. | 299. | 348. |
| 36) Specimen_3B_TestPlane | SS304 | 341. | 315. | 352. | 328. | 350. |
| 37) Specimen_3B_High | SS304 | 339. | 303. | 359. | 311. | 357. |
| 38) Specimen_2B_Low | SS304 | 344. | 307. | 365. | 316. | 362. |
| 39) Specimen_2B_TestPlane | SS304 | 352. | 333. | 363. | 339. | 362. |
| 40) Specimen_2B_High | SS304 | 347. | 311. | 367. | 319. | 365. |
| 41) Specimen_1B_Low | SS304 | 348. | 311. | 369. | 319. | 366. |
| 42) Specimen_1B_TestPlane | SS304 | 353. | 325. | 364. | 340. | 363. |
| 43) Specimen_1B_High | SS304 | 342. | 297. | 366. | 309. | 363. |

PROPERTY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Thermal Cond. (W/m*C) | Thermal Exp. Coeff. (um/m*C) | Emis (---) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 167.778 | 24.21 | 0.050 |
| 2) Holder | AL-6061 | 176.000 | 25.13 | 0.055 |
| 3) TM_1A | SiC(Irr) | 6.653 | 3.37 | 0.900 |
| 4) TM_1B | SiC(Irr) | 6.654 | 3.37 | 0.900 |
| 5) TM_2B | SiC(Irr) | 6.657 | 3.37 | 0.900 |
| 6) TM_2A | SiC(Irr) | 6.658 | 3.37 | 0.900 |
| 7) Shim_A | SS304 | 20.241 | 20.02 | 0.143 |
| 8) Shim_B | SS304 | 20.241 | 20.02 | 0.143 |
| 9) Spring_Retainer_2 | SiC(Irr) | 7.093 | 3.45 | 0.900 |
| 10) Spring_Retainer_1 | SiC(Irr) | 7.091 | 3.45 | 0.900 |
| 11) Spring_TM_1A | SiC(Irr) | 6.152 | 3.29 | 0.900 |
| 12) Spring_TM_1B | SiC(Irr) | 6.152 | 3.29 | 0.900 |
| 13) Spring_TM_2A | SiC(Irr) | 6.156 | 3.29 | 0.900 |
| 14) Spring_TM_2B | SiC(Irr) | 6.155 | 3.29 | 0.900 |
| 15) Disk_3 | Moly | 126.885 | 5.03 | 0.058 |
| 16) Disk_4 | Moly | 126.918 | 5.03 | 0.058 |
| 17) Disk_2 | Moly | 128.009 | 5.01 | 0.055 |
| 18) Disk_1 | Moly | 127.963 | 5.01 | 0.055 |
| 19) Wire_2A | Moly | 127.974 | 5.01 | 0.055 |
| 20) Wire_1A | Moly | 128.331 | 5.01 | 0.054 |
| 21) Wire_1B | Moly | 128.171 | 5.01 | 0.055 |
| 22) Wire_2B | Moly | 127.871 | 5.01 | 0.056 |
| 23) Housing_High | AL-6061 | 166.202 | 24.21 | 0.050 |
| 24) Housing_Low | AL-6061 | 166.518 | 24.21 | 0.050 |
| 25) Housing_Mid | AL-6061 | 166.417 | 24.21 | 0.050 |
| 26) Specimen_3A_Low | SS304 | 19.799 | 19.70 | 0.143 |
| 27) Specimen_3A_TestPlane | SS304 | 19.991 | 19.91 | 0.143 |
| 28) Specimen_3A_High | SS304 | 19.970 | 19.89 | 0.143 |
| 29) Specimen_2A_Low | SS304 | 20.039 | 19.97 | 0.143 |
| 30) Specimen_2A_TestPlane | SS304 | 20.152 | 20.05 | 0.143 |
| 31) Specimen_2A_High | SS304 | 20.088 | 20.02 | 0.143 |
| 32) Specimen_1A_Low | SS304 | 20.096 | 20.03 | 0.143 |
| 33) Specimen_1A_TestPlane | SS304 | 20.160 | 20.05 | 0.143 |
| 34) Specimen_1A_High | SS304 | 20.015 | 19.94 | 0.143 |
| 35) Specimen_3B_Low | SS304 | 19.799 | 19.70 | 0.143 |
| 36) Specimen_3B_TestPlane | SS304 | 19.990 | 19.91 | 0.143 |
| 37) Specimen_3B_High | SS304 | 19.969 | 19.89 | 0.143 |
| 38) Specimen_2B_Low | SS304 | 20.038 | 19.97 | 0.143 |
| 39) Specimen_2B_TestPlane | SS304 | 20.150 | 20.05 | 0.143 |
| 40) Specimen_2B_High | SS304 | 20.086 | 20.02 | 0.143 |
| 41) Specimen_1B_Low | SS304 | 20.097 | 20.03 | 0.143 |
| 42) Specimen_1B_TestPlane | SS304 | 20.163 | 20.05 | 0.143 |
| 43) Specimen_1B_High | SS304 | 20.015 | 19.94 | 0.143 |

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STORED ENERGY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Mass (g) | Tavg (C) | Specific Heat (J/kg-C) | Stored Energy (J) |
|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 0.621 | 69. | 892. | 27. |
| 2) Holder | AL-6061 | 3.750 | 264. | 1013. | 927. |
| 3) TM_1A | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 4) TM_1B | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 5) TM_2B | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 6) TM_2A | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 7) Shim_A | SS304 | 0.241 | 359. | 392. | 32. |
| 8) Shim_B | SS304 | 0.241 | 358. | 392. | 32. |
| 9) Spring_Retainer_2 | SiC(Irr) | 0.024 | 365. | 1054. | 9. |
| 10) Spring_Retainer_1 | SiC(Irr) | 0.024 | 365. | 1054. | 9. |
| 11) Spring_TM_1A | SiC(Irr) | 0.024 | 306. | 1022. | 7. |
| 12) Spring_TM_1B | SiC(Irr) | 0.024 | 306. | 1022. | 7. |
| 13) Spring_TM_2A | SiC(Irr) | 0.024 | 306. | 1022. | 7. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 14) | Spring_TM_2B | SiC(Irr) | 0.024 | 306. | 1022. | 7. |
| 15) | Disk_3 | Moly | 0.040 | 305. | 266. | 3. |
| 16) | Disk_4 | Moly | 0.040 | 304. | 266. | 3. |
| 17) | Disk_2 | Moly | 0.040 | 277. | 265. | 3. |
| 18) | Disk_1 | Moly | 0.040 | 278. | 265. | 3. |
| 19) | Wire_2A | Moly | 0.018 | 278. | 265. | 1. |
| 20) | Wire_1A | Moly | 0.018 | 269. | 265. | 1. |
| 21) | Wire_1B | Moly | 0.019 | 273. | 265. | 1. |
| 22) | Wire_2B | Moly | 0.019 | 280. | 265. | 1. |
| 23) | Housing_High | AL-6061 | 0.164 | 56. | 881. | 5. |
| 24) | Housing_Low | AL-6061 | 0.491 | 59. | 884. | 17. |
| 25) | Housing_Mid | AL-6061 | 3.637 | 58. | 883. | 122. |
| 26) | Specimen_3A_Low | SS304 | 0.786 | 327. | 390. | 94. |
| 27) | Specimen_3A_TestPlane | SS304 | 0.014 | 341. | 391. | 2. |
| 28) | Specimen_3A_High | SS304 | 0.786 | 339. | 391. | 98. |
| 29) | Specimen_2A_Low | SS304 | 0.786 | 344. | 391. | 100. |
| 30) | Specimen_2A_TestPlane | SS304 | 0.014 | 352. | 392. | 2. |
| 31) | Specimen_2A_High | SS304 | 0.786 | 348. | 392. | 101. |
| 32) | Specimen_1A_Low | SS304 | 0.786 | 348. | 392. | 101. |
| 33) | Specimen_1A_TestPlane | SS304 | 0.014 | 353. | 392. | 2. |
| 34) | Specimen_1A_High | SS304 | 0.786 | 342. | 391. | 99. |
| 35) | Specimen_3B_Low | SS304 | 0.786 | 327. | 390. | 94. |
| 36) | Specimen_3B_TestPlane | SS304 | 0.014 | 341. | 391. | 2. |
| 37) | Specimen_3B_High | SS304 | 0.786 | 339. | 391. | 98. |
| 38) | Specimen_2B_Low | SS304 | 0.786 | 344. | 391. | 100. |
| 39) | Specimen_2B_TestPlane | SS304 | 0.014 | 352. | 392. | 2. |
| 40) | Specimen_2B_High | SS304 | 0.786 | 347. | 392. | 101. |
| 41) | Specimen_1B_Low | SS304 | 0.786 | 348. | 392. | 101. |
| 42) | Specimen_1B_TestPlane | SS304 | 0.014 | 353. | 392. | 2. |
| 43) | Specimen_1B_High | SS304 | 0.786 | 342. | 391. | 99. |
| | | | -------- | | | -------- |
| | | | 19.275 | | | 2498. |

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HOLDER TO HOUSING GAP REPORTS

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CONTACT SUMMARY FOR CONTACT ID 48: Holder To Housing_Mid

```
   Contact surface material:      AL-6061
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa
```

| | Average | Minimum | Maximum |
|---|---|---|---|
| ~~~~~~~~~~~ direct results ~~~~~~~~~~ | | | |
| Contact status | 1.000 | 1.000 | 1.000 |
| Contact temperature (C) | 264.225 | 246.287 | 280.676 |
| Target temperature (C) | 59.305 | 56.307 | 60.068 |
| Geometric gas gap (um) | 159.499 | 159.041 | 159.506 |
| Contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Gap conduction heat flux (kW/m^2) | 294.275 | 263.714 | 325.706 |
| Radiation heat flux (kW/m^2) | 0.124 | 0.104 | 0.143 |
| Contact conduction heat flux (kW/m^2 | 0.000 | 0.000 | 0.000 |
| Total heat flux (kW/m^2) | 294.400 | 263.818 | 325.849 |
| Thermal contact conductance (W/m^2-C | 1435.231 | 1359.860 | 1476.294 |
| ~~~~~~~~~~ derived results ~~~~~~~~~~ | | | |
| Effective gas gap (um) | 135.227 | 133.219 | 137.211 |
| Contact thermal jump distance (um) | 1.343 | 1.293 | 1.385 |
| Target thermal jump distance (um) | 1.204 | 1.167 | 1.234 |
| Effective contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Pressure index | 13.534 | 13.534 | 13.534 |
| Gas thermal conductivity (W/m*C) | 0.198 | 0.194 | 0.201 |
| Solid spot conductance (W/m^2*C) | 0.000 | 0.000 | 0.000 |
| Gas gap conductance (W/m^2*C) | 1434.672 | 1390.875 | 1475.613 |

Contact status codes:

----------------------------------------------

```
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking

-------------------------------------------------------------------------------
CONTACT SUMMARY FOR CONTACT ID 50: Holder To Housing_Mid
   Contact surface material:      AL-6061
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                        Average      Minimum      Maximum
                                     ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                           1.000        1.000        1.000
   Contact temperature (C)                248.554      245.550      251.574
   Target temperature (C)                  56.585       56.498       56.686
   Geometric gas gap (um)                  59.500       59.500       59.500
   Contact pressure (MPa)                   0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)      955.504      928.929      982.448
   Radiation heat flux (kW/m^2)             0.107        0.103        0.110
   Contact conduction heat flux (kW/m^2     0.000        0.000        0.000
   Total heat flux (kW/m^2)               955.610      929.033      982.559
   Thermal contact conductance (W/m^2-C  4976.472     4916.764     5036.868
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                  36.658       36.268       37.043
   Contact thermal jump distance (um)       1.299        1.291        1.306
   Target thermal jump distance (um)        1.171        1.166        1.177
   Effective contact pressure (MPa)         0.000        0.000        0.000
   Pressure index                          13.534       13.534       13.534
   Gas thermal conductivity (W/m*C)         0.195        0.194        0.195
   Solid spot conductance (W/m^2*C)         0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)         4967.410     4908.534     5026.965

   Contact status codes:
    ---------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking
```

## A-2. 9.26 mm Al Holder in TRRH3 ANSYS Summary

```
 ******************************************************************************
                            OUTPUT SUMMARY FILE
 ******************************************************************************

  ------------------------------------------------------------------------------
  INPUTS

 * Symmetry angle: 360.00 degrees
 * Housing fill gas:   100HE_0A
 * Holder material: Aluminum
 * Specimen material: SS304
 * Shim material: SS304
 * Radiative heat transfer included
 * 3D  problem geometry
 * Target temperature:  350.0 °C
 * Target dose (in SiC):  20.000 dpa
 * Irradiation facility: TRRH
 * Axial position: 3
 * Axial peaking factor above the core midplane: 30.390 cm
 * Axial peaking factor below the core midplane: 29.700 cm
 * Housing Inner Diameter:  9.519 mm
 * Holder Outer Diameter:  9.260 mm
 * Holder Tab Outer Diameter:  9.400 mm
 * Design basis
 * Nominal geometry

 ------------------------------------------------------------------------------
  BOUNDARY CONDITIONS
```

Heat generation rate scaling factor = 1.0000
Heat transfer coefficient = 47100. W/m²·°C
Bulk coolant temperature = 52.0 °C

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HEAT GENERATION

| Part | Material | Heat Gen. @Midplane (W/kg) | Heat Load @Midplane (W) | Heat Load @Location (W) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 31300. | 19.4 | 19.1 |
| 2) Holder | AL-6061 | 31300. | 121.0 | 113.8 |
| 3) TM_1A | SiC(Irr) | 31700. | 1.8 | 1.7 |
| 4) TM_1B | SiC(Irr) | 31700. | 1.8 | 1.7 |
| 5) TM_2B | SiC(Irr) | 31700. | 1.8 | 1.7 |
| 6) TM_2A | SiC(Irr) | 31700. | 1.8 | 1.7 |
| 7) Shim_A | SS304 | 38100. | 9.2 | 8.6 |
| 8) Shim_B | SS304 | 38100. | 9.2 | 8.6 |
| 9) Spring_Retainer_2 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 10) Spring_Retainer_1 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 11) Spring_TM_1A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 12) Spring_TM_1B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 13) Spring_TM_2A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 14) Spring_TM_2B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 15) Disk_3 | Moly | 42000. | 1.7 | 1.5 |
| 16) Disk_4 | Moly | 42000. | 1.7 | 1.5 |
| 17) Disk_2 | Moly | 42000. | 1.7 | 1.6 |
| 18) Disk_1 | Moly | 42000. | 1.7 | 1.6 |
| 19) Wire_2A | Moly | 42000. | 0.8 | 0.7 |
| 20) Wire_1A | Moly | 42000. | 0.8 | 0.8 |
| 21) Wire_1B | Moly | 42000. | 0.8 | 0.8 |
| 22) Wire_2B | Moly | 42000. | 0.8 | 0.7 |
| 23) Housing_High | AL-6061 | 31300. | 5.1 | 5.0 |
| 24) Housing_Low | AL-6061 | 31300. | 15.4 | 13.6 |
| 25) Housing_Mid | AL-6061 | 31300. | 113.8 | 107.1 |
| 26) Specimen_3A_Low | SS304 | 38100. | 30.0 | 27.2 |
| 27) Specimen_3A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 28) Specimen_3A_High | SS304 | 38100. | 30.0 | 27.6 |
| 29) Specimen_2A_Low | SS304 | 38100. | 30.0 | 28.0 |
| 30) Specimen_2A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 31) Specimen_2A_High | SS304 | 38100. | 30.0 | 28.4 |
| 32) Specimen_1A_Low | SS304 | 38100. | 30.0 | 28.7 |
| 33) Specimen_1A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 34) Specimen_1A_High | SS304 | 38100. | 30.0 | 29.0 |
| 35) Specimen_3B_Low | SS304 | 38100. | 30.0 | 27.2 |
| 36) Specimen_3B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 37) Specimen_3B_High | SS304 | 38100. | 30.0 | 27.6 |
| 38) Specimen_2B_Low | SS304 | 38100. | 30.0 | 28.0 |
| 39) Specimen_2B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 40) Specimen_2B_High | SS304 | 38100. | 30.0 | 28.4 |
| 41) Specimen_1B_Low | SS304 | 38100. | 30.0 | 28.7 |
| 42) Specimen_1B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 43) Specimen_1B_High | SS304 | 38100. | 30.0 | 29.0 |
| | | | 677.6 | 637.1 |

---

CAPSULE TEMPERATURE SUMMARY

| Name | Material | Tavg | Tmin | Tmax | T.025 | T.975 |
|---|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 71. | 68. | 73. | 69. | 73. |
| 2) Holder | AL-6061 | 252. | 230. | 272. | 233. | 269. |
| 3) TM_1A | SiC(Irr) | 337. | 304. | 347. | 320. | 344. |
| 4) TM_1B | SiC(Irr) | 337. | 304. | 347. | 320. | 344. |
| 5) TM_2B | SiC(Irr) | 337. | 304. | 347. | 320. | 344. |
| 6) TM_2A | SiC(Irr) | 337. | 304. | 347. | 320. | 344. |
| 7) Shim_A | SS304 | 362. | 319. | 373. | 340. | 371. |
| 8) Shim_B | SS304 | 362. | 319. | 373. | 340. | 371. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 9) | Spring_Retainer_2 | SiC(Irr) | 370. | 327. | 378. | 346. | 377. |
| 10) | Spring_Retainer_1 | SiC(Irr) | 369. | 315. | 378. | 345. | 377. |
| 11) | Spring_TM_1A | SiC(Irr) | 301. | 243. | 335. | 252. | 333. |
| 12) | Spring_TM_1B | SiC(Irr) | 301. | 243. | 335. | 252. | 332. |
| 13) | Spring_TM_2A | SiC(Irr) | 301. | 243. | 336. | 252. | 334. |
| 14) | Spring_TM_2B | SiC(Irr) | 301. | 243. | 336. | 252. | 333. |
| 15) | Disk_3 | Moly | 305. | 281. | 319. | 285. | 318. |
| 16) | Disk_4 | Moly | 304. | 290. | 314. | 293. | 313. |
| 17) | Disk_2 | Moly | 265. | 254. | 271. | 256. | 270. |
| 18) | Disk_1 | Moly | 266. | 259. | 271. | 261. | 270. |
| 19) | Wire_2A | Moly | 272. | 252. | 286. | 252. | 286. |
| 20) | Wire_1A | Moly | 255. | 239. | 267. | 240. | 267. |
| 21) | Wire_1B | Moly | 260. | 243. | 271. | 243. | 271. |
| 22) | Wire_2B | Moly | 276. | 257. | 287. | 258. | 287. |
| 23) | Housing_High | AL-6061 | 57. | 56. | 57. | 56. | 57. |
| 24) | Housing_Low | AL-6061 | 60. | 58. | 62. | 58. | 62. |
| 25) | Housing_Mid | AL-6061 | 59. | 54. | 62. | 54. | 61. |
| 26) | Specimen_3A_Low | SS304 | 331. | 284. | 360. | 297. | 355. |
| 27) | Specimen_3A_TestPlane | SS304 | 346. | 315. | 359. | 331. | 357. |
| 28) | Specimen_3A_High | SS304 | 342. | 300. | 365. | 309. | 363. |
| 29) | Specimen_2A_Low | SS304 | 346. | 303. | 370. | 312. | 366. |
| 30) | Specimen_2A_TestPlane | SS304 | 354. | 332. | 367. | 339. | 366. |
| 31) | Specimen_2A_High | SS304 | 347. | 304. | 371. | 314. | 368. |
| 32) | Specimen_1A_Low | SS304 | 346. | 303. | 369. | 312. | 367. |
| 33) | Specimen_1A_TestPlane | SS304 | 351. | 319. | 364. | 336. | 363. |
| 34) | Specimen_1A_High | SS304 | 339. | 288. | 366. | 301. | 362. |
| 35) | Specimen_3B_Low | SS304 | 331. | 284. | 360. | 297. | 355. |
| 36) | Specimen_3B_TestPlane | SS304 | 346. | 315. | 359. | 331. | 357. |
| 37) | Specimen_3B_High | SS304 | 342. | 300. | 365. | 309. | 363. |
| 38) | Specimen_2B_Low | SS304 | 346. | 303. | 369. | 312. | 366. |
| 39) | Specimen_2B_TestPlane | SS304 | 354. | 332. | 367. | 339. | 366. |
| 40) | Specimen_2B_High | SS304 | 347. | 304. | 370. | 314. | 368. |
| 41) | Specimen_1B_Low | SS304 | 346. | 303. | 369. | 312. | 367. |
| 42) | Specimen_1B_TestPlane | SS304 | 351. | 319. | 364. | 336. | 363. |
| 43) | Specimen_1B_High | SS304 | 339. | 288. | 366. | 301. | 362. |

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PROPERTY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | | Material | Thermal Cond. (W/m*C) | Thermal Exp. Coeff. (um/m*C) | Emis (---) |
|---|---|---|---|---|---|
| 1) | Endcap | AL-6061 | 168.011 | 24.21 | 0.050 |
| 2) | Holder | AL-6061 | 176.000 | 25.03 | 0.054 |
| 3) | TM_1A | SiC(Irr) | 6.652 | 3.37 | 0.900 |
| 4) | TM_1B | SiC(Irr) | 6.653 | 3.37 | 0.900 |
| 5) | TM_2B | SiC(Irr) | 6.657 | 3.37 | 0.900 |
| 6) | TM_2A | SiC(Irr) | 6.658 | 3.37 | 0.900 |
| 7) | Shim_A | SS304 | 20.289 | 20.01 | 0.143 |
| 8) | Shim_B | SS304 | 20.289 | 20.01 | 0.143 |
| 9) | Spring_Retainer_2 | SiC(Irr) | 7.167 | 3.46 | 0.900 |
| 10) | Spring_Retainer_1 | SiC(Irr) | 7.165 | 3.46 | 0.900 |
| 11) | Spring_TM_1A | SiC(Irr) | 6.076 | 3.27 | 0.900 |
| 12) | Spring_TM_1B | SiC(Irr) | 6.076 | 3.27 | 0.900 |
| 13) | Spring_TM_2A | SiC(Irr) | 6.080 | 3.27 | 0.900 |
| 14) | Spring_TM_2B | SiC(Irr) | 6.079 | 3.27 | 0.900 |
| 15) | Disk_3 | Moly | 126.880 | 5.03 | 0.058 |
| 16) | Disk_4 | Moly | 126.918 | 5.03 | 0.058 |
| 17) | Disk_2 | Moly | 128.495 | 5.00 | 0.054 |
| 18) | Disk_1 | Moly | 128.443 | 5.00 | 0.054 |
| 19) | Wire_2A | Moly | 128.186 | 5.01 | 0.055 |
| 20) | Wire_1A | Moly | 128.865 | 5.00 | 0.053 |
| 21) | Wire_1B | Moly | 128.678 | 5.00 | 0.054 |
| 22) | Wire_2B | Moly | 128.057 | 5.01 | 0.055 |
| 23) | Housing_High | AL-6061 | 166.259 | 24.21 | 0.050 |
| 24) | Housing_Low | AL-6061 | 166.696 | 24.21 | 0.050 |
| 25) | Housing_Mid | AL-6061 | 166.540 | 24.21 | 0.050 |
| 26) | Specimen_3A_Low | SS304 | 19.850 | 19.76 | 0.143 |
| 27) | Specimen_3A_TestPlane | SS304 | 20.062 | 19.99 | 0.143 |

| | | | | |
|---|---|---|---|---|
| 28) Specimen_3A_High | SS304 | 20.016 | 19.94 | 0.143 |
| 29) Specimen_2A_Low | SS304 | 20.062 | 19.99 | 0.143 |
| 30) Specimen_2A_TestPlane | SS304 | 20.176 | 20.04 | 0.143 |
| 31) Specimen_2A_High | SS304 | 20.084 | 20.02 | 0.143 |
| 32) Specimen_1A_Low | SS304 | 20.070 | 20.00 | 0.143 |
| 33) Specimen_1A_TestPlane | SS304 | 20.137 | 20.06 | 0.143 |
| 34) Specimen_1A_High | SS304 | 19.967 | 19.89 | 0.143 |
| 35) Specimen_3B_Low | SS304 | 19.850 | 19.76 | 0.143 |
| 36) Specimen_3B_TestPlane | SS304 | 20.060 | 19.99 | 0.143 |
| 37) Specimen_3B_High | SS304 | 20.015 | 19.94 | 0.143 |
| 38) Specimen_2B_Low | SS304 | 20.061 | 19.99 | 0.143 |
| 39) Specimen_2B_TestPlane | SS304 | 20.174 | 20.04 | 0.143 |
| 40) Specimen_2B_High | SS304 | 20.082 | 20.02 | 0.143 |
| 41) Specimen_1B_Low | SS304 | 20.072 | 20.00 | 0.143 |
| 42) Specimen_1B_TestPlane | SS304 | 20.139 | 20.06 | 0.143 |
| 43) Specimen_1B_High | SS304 | 19.967 | 19.89 | 0.143 |

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STORED ENERGY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Mass (g) | Tavg (C) | Specific Heat (J/kg-C) | Stored Energy (J) |
|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 0.621 | 71. | 893. | 28. |
| 2) Holder | AL-6061 | 3.865 | 252. | 1007. | 903. |
| 3) TM_1A | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 4) TM_1B | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 5) TM_2B | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 6) TM_2A | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 7) Shim_A | SS304 | 0.241 | 362. | 393. | 32. |
| 8) Shim_B | SS304 | 0.241 | 362. | 393. | 32. |
| 9) Spring_Retainer_2 | SiC(Irr) | 0.024 | 370. | 1057. | 9. |
| 10) Spring_Retainer_1 | SiC(Irr) | 0.024 | 369. | 1056. | 9. |
| 11) Spring_TM_1A | SiC(Irr) | 0.024 | 301. | 1019. | 7. |
| 12) Spring_TM_1B | SiC(Irr) | 0.024 | 301. | 1019. | 7. |
| 13) Spring_TM_2A | SiC(Irr) | 0.024 | 301. | 1019. | 7. |
| 14) Spring_TM_2B | SiC(Irr) | 0.024 | 301. | 1019. | 7. |
| 15) Disk_3 | Moly | 0.040 | 305. | 266. | 3. |
| 16) Disk_4 | Moly | 0.040 | 304. | 266. | 3. |
| 17) Disk_2 | Moly | 0.040 | 265. | 265. | 3. |
| 18) Disk_1 | Moly | 0.040 | 266. | 265. | 3. |
| 19) Wire_2A | Moly | 0.019 | 272. | 265. | 1. |
| 20) Wire_1A | Moly | 0.019 | 255. | 264. | 1. |
| 21) Wire_1B | Moly | 0.019 | 260. | 265. | 1. |
| 22) Wire_2B | Moly | 0.019 | 276. | 265. | 1. |
| 23) Housing_High | AL-6061 | 0.164 | 57. | 882. | 5. |
| 24) Housing_Low | AL-6061 | 0.491 | 60. | 885. | 17. |
| 25) Housing_Mid | AL-6061 | 3.637 | 59. | 884. | 125. |
| 26) Specimen_3A_Low | SS304 | 0.786 | 331. | 390. | 95. |
| 27) Specimen_3A_TestPlane | SS304 | 0.014 | 346. | 391. | 2. |
| 28) Specimen_3A_High | SS304 | 0.786 | 342. | 391. | 99. |
| 29) Specimen_2A_Low | SS304 | 0.786 | 346. | 391. | 100. |
| 30) Specimen_2A_TestPlane | SS304 | 0.014 | 354. | 392. | 2. |
| 31) Specimen_2A_High | SS304 | 0.786 | 347. | 391. | 101. |
| 32) Specimen_1A_Low | SS304 | 0.786 | 346. | 391. | 100. |
| 33) Specimen_1A_TestPlane | SS304 | 0.014 | 351. | 392. | 2. |
| 34) Specimen_1A_High | SS304 | 0.786 | 339. | 391. | 98. |
| 35) Specimen_3B_Low | SS304 | 0.786 | 331. | 390. | 95. |
| 36) Specimen_3B_TestPlane | SS304 | 0.014 | 346. | 391. | 2. |
| 37) Specimen_3B_High | SS304 | 0.786 | 342. | 391. | 99. |
| 38) Specimen_2B_Low | SS304 | 0.786 | 346. | 391. | 100. |
| 39) Specimen_2B_TestPlane | SS304 | 0.014 | 354. | 392. | 2. |
| 40) Specimen_2B_High | SS304 | 0.786 | 347. | 391. | 101. |
| 41) Specimen_1B_Low | SS304 | 0.786 | 346. | 391. | 100. |
| 42) Specimen_1B_TestPlane | SS304 | 0.014 | 351. | 392. | 2. |
| 43) Specimen_1B_High | SS304 | 0.786 | 339. | 391. | 98. |
| | | 19.391 | | | 2481. |

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HOLDER TO HOUSING GAP REPORTS

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CONTACT SUMMARY FOR CONTACT ID 48: Holder To Housing_Mid

Contact surface material: AL-6061
Target surface material: AL-6061
Interstitial gas: 100HE_0A
Effective surface roughness: 2.263 um
Effective asperity slope: 0.214 rad
Effective microhardness: 1.220 GPa

| | Average | Minimum | Maximum |
|---|---|---|---|
| ~~~~~~~~~~~ direct results ~~~~~~~~~~ | | | |
| Contact status | 1.000 | 1.000 | 1.000 |
| Contact temperature (C) | 251.928 | 230.381 | 268.753 |
| Target temperature (C) | 60.561 | 56.931 | 61.494 |
| Geometric gas gap (um) | 129.500 | 129.057 | 132.825 |
| Contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Gap conduction heat flux (kW/m^2) | 343.160 | 297.370 | 383.737 |
| Radiation heat flux (kW/m^2) | 0.110 | 0.088 | 0.129 |
| Contact conduction heat flux (kW/m^2 | 0.000 | 0.000 | 0.000 |
| Total heat flux (kW/m^2) | 343.270 | 297.458 | 383.866 |
| Thermal contact conductance (W/m^2-C | 1791.742 | 1620.721 | 1851.395 |
| ~~~~~~~~~~ derived results ~~~~~~~~~~ | | | |
| Effective gas gap (um) | 106.851 | 104.824 | 110.950 |
| Contact thermal jump distance (um) | 1.315 | 1.255 | 1.358 |
| Target thermal jump distance (um) | 1.187 | 1.142 | 1.218 |
| Effective contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Pressure index | 13.534 | 13.534 | 13.534 |
| Gas thermal conductivity (W/m*C) | 0.196 | 0.192 | 0.199 |
| Solid spot conductance (W/m^2*C) | 0.000 | 0.000 | 0.000 |
| Gas gap conductance (W/m^2*C) | 1791.632 | 1707.927 | 1851.137 |

Contact status codes:

0=open/no heat transfer, 1=near-field contact
2=closed and sliding, 3=closed and sticking

---

CONTACT SUMMARY FOR CONTACT ID 50: Holder To Housing_Mid

Contact surface material: AL-6061
Target surface material: AL-6061
Interstitial gas: 100HE_0A
Effective surface roughness: 2.263 um
Effective asperity slope: 0.214 rad
Effective microhardness: 1.220 GPa

| | Average | Minimum | Maximum |
|---|---|---|---|
| ~~~~~~~~~~~ direct results ~~~~~~~~~~ | | | |
| Contact status | 1.000 | 1.000 | 1.000 |
| Contact temperature (C) | 234.660 | 229.890 | 241.822 |
| Target temperature (C) | 57.193 | 56.908 | 57.589 |
| Geometric gas gap (um) | 59.500 | 59.499 | 59.500 |
| Contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Gap conduction heat flux (kW/m^2) | 836.176 | 798.469 | 893.346 |
| Radiation heat flux (kW/m^2) | 0.092 | 0.087 | 0.099 |
| Contact conduction heat flux (kW/m^2 | 0.000 | 0.000 | 0.000 |
| Total heat flux (kW/m^2) | 836.268 | 798.556 | 893.445 |
| Thermal contact conductance (W/m^2-C | 4708.433 | 4622.550 | 4838.430 |
| ~~~~~~~~~~ derived results ~~~~~~~~~~ | | | |
| Effective gas gap (um) | 38.483 | 37.581 | 39.080 |
| Contact thermal jump distance (um) | 1.266 | 1.254 | 1.284 |
| Target thermal jump distance (um) | 1.149 | 1.141 | 1.162 |
| Effective contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Pressure index | 13.534 | 13.534 | 13.534 |
| Gas thermal conductivity (W/m*C) | 0.192 | 0.192 | 0.194 |
| Solid spot conductance (W/m^2*C) | 0.000 | 0.000 | 0.000 |
| Gas gap conductance (W/m^2*C) | 4701.354 | 4616.013 | 4830.540 |

Contact status codes:

```
 ---------------------------------------------
 0=open/no heat transfer, 1=near-field contact
 2=closed and sliding,    3=closed and sticking
```

## A-3. 9.27 mm Al Holder in TRRH5 ANSYS Summary

```
*******************************************************************************
                            OUTPUT SUMMARY FILE
*******************************************************************************

 -------------------------------------------------------------------------------
 INPUTS

* Symmetry angle: 360.00 degrees
* Housing fill gas:   100HE_0A
* Holder material: Aluminum
* Specimen material: SS304
* Shim material: SS304
* Radiative heat transfer included
* 3D  problem geometry
* Target temperature:  350.0 °C
* Target dose (in SiC):  20.000 dpa
* Irradiation facility: TRRH
* Axial position: 5
* Axial peaking factor above the core midplane: 30.390 cm
* Axial peaking factor below the core midplane: 29.700 cm
* Housing Inner Diameter:  9.519 mm
* Holder Outer Diameter:  9.270 mm
* Holder Tab Outer Diameter:  9.400 mm
* Design basis
* Nominal geometry

-------------------------------------------------------------------------------
 BOUNDARY CONDITIONS

 Heat generation rate scaling factor = 1.0000
 Heat transfer coefficient =  47100. W/m²·°C
 Bulk coolant temperature  =    52.0 °C

-------------------------------------------------------------------------------
 HEAT GENERATION
```

| Part | Material | Heat Gen. @Midplane (W/kg) | Heat Load @Midplane (W) | Heat Load @Location (W) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 31300. | 19.4 | 17.9 |
| 2) Holder | AL-6061 | 31300. | 121.6 | 117.2 |
| 3) TM_1A | SiC(Irr) | 31700. | 1.8 | 1.8 |
| 4) TM_1B | SiC(Irr) | 31700. | 1.8 | 1.8 |
| 5) TM_2B | SiC(Irr) | 31700. | 1.8 | 1.8 |
| 6) TM_2A | SiC(Irr) | 31700. | 1.8 | 1.8 |
| 7) Shim_A | SS304 | 38100. | 9.2 | 8.8 |
| 8) Shim_B | SS304 | 38100. | 9.2 | 8.8 |
| 9) Spring_Retainer_2 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 10) Spring_Retainer_1 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 11) Spring_TM_1A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 12) Spring_TM_1B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 13) Spring_TM_2A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 14) Spring_TM_2B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 15) Disk_3 | Moly | 42000. | 1.7 | 1.7 |
| 16) Disk_4 | Moly | 42000. | 1.7 | 1.7 |
| 17) Disk_2 | Moly | 42000. | 1.7 | 1.6 |
| 18) Disk_1 | Moly | 42000. | 1.7 | 1.6 |
| 19) Wire_2A | Moly | 42000. | 0.8 | 0.8 |
| 20) Wire_1A | Moly | 42000. | 0.8 | 0.7 |
| 21) Wire_1B | Moly | 42000. | 0.8 | 0.7 |
| 22) Wire_2B | Moly | 42000. | 0.8 | 0.8 |

| | | | | |
|---|---|---|---|---|
| 23) Housing_High | AL-6061 | 31300. | 5.1 | 4.7 |
| 24) Housing_Low | AL-6061 | 31300. | 15.4 | 15.2 |
| 25) Housing_Mid | AL-6061 | 31300. | 113.8 | 109.6 |
| 26) Specimen_3A_Low | SS304 | 38100. | 30.0 | 29.5 |
| 27) Specimen_3A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 28) Specimen_3A_High | SS304 | 38100. | 30.0 | 29.3 |
| 29) Specimen_2A_Low | SS304 | 38100. | 30.0 | 29.1 |
| 30) Specimen_2A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 31) Specimen_2A_High | SS304 | 38100. | 30.0 | 28.8 |
| 32) Specimen_1A_Low | SS304 | 38100. | 30.0 | 28.5 |
| 33) Specimen_1A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 34) Specimen_1A_High | SS304 | 38100. | 30.0 | 28.2 |
| 35) Specimen_3B_Low | SS304 | 38100. | 30.0 | 29.5 |
| 36) Specimen_3B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 37) Specimen_3B_High | SS304 | 38100. | 30.0 | 29.3 |
| 38) Specimen_2B_Low | SS304 | 38100. | 30.0 | 29.1 |
| 39) Specimen_2B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 40) Specimen_2B_High | SS304 | 38100. | 30.0 | 28.8 |
| 41) Specimen_1B_Low | SS304 | 38100. | 30.0 | 28.5 |
| 42) Specimen_1B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 43) Specimen_1B_High | SS304 | 38100. | 30.0 | 28.2 |
| | | | 678.2 | 653.2 |

CAPSULE TEMPERATURE SUMMARY

| Name | Material | Tavg | Tmin | Tmax | T.025 | T.975 |
|---|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 70. | 67. | 72. | 68. | 72. |
| 2) Holder | AL-6061 | 249. | 222. | 271. | 225. | 268. |
| 3) TM_1A | SiC(Irr) | 337. | 312. | 349. | 323. | 345. |
| 4) TM_1B | SiC(Irr) | 337. | 312. | 350. | 323. | 345. |
| 5) TM_2B | SiC(Irr) | 337. | 312. | 350. | 323. | 346. |
| 6) TM_2A | SiC(Irr) | 337. | 312. | 350. | 323. | 346. |
| 7) Shim_A | SS304 | 362. | 328. | 374. | 345. | 373. |
| 8) Shim_B | SS304 | 362. | 328. | 374. | 345. | 373. |
| 9) Spring_Retainer_2 | SiC(Irr) | 371. | 337. | 380. | 354. | 379. |
| 10) Spring_Retainer_1 | SiC(Irr) | 371. | 324. | 380. | 354. | 379. |
| 11) Spring_TM_1A | SiC(Irr) | 300. | 235. | 335. | 244. | 333. |
| 12) Spring_TM_1B | SiC(Irr) | 300. | 235. | 335. | 244. | 333. |
| 13) Spring_TM_2A | SiC(Irr) | 300. | 235. | 336. | 245. | 333. |
| 14) Spring_TM_2B | SiC(Irr) | 300. | 235. | 336. | 245. | 333. |
| 15) Disk_3 | Moly | 313. | 287. | 328. | 291. | 326. |
| 16) Disk_4 | Moly | 312. | 296. | 323. | 300. | 322. |
| 17) Disk_2 | Moly | 255. | 245. | 261. | 247. | 261. |
| 18) Disk_1 | Moly | 257. | 250. | 261. | 252. | 261. |
| 19) Wire_2A | Moly | 278. | 255. | 293. | 256. | 293. |
| 20) Wire_1A | Moly | 246. | 231. | 258. | 231. | 257. |
| 21) Wire_1B | Moly | 251. | 235. | 262. | 235. | 262. |
| 22) Wire_2B | Moly | 281. | 261. | 294. | 262. | 294. |
| 23) Housing_High | AL-6061 | 56. | 56. | 57. | 56. | 57. |
| 24) Housing_Low | AL-6061 | 61. | 58. | 63. | 59. | 63. |
| 25) Housing_Mid | AL-6061 | 59. | 54. | 62. | 54. | 61. |
| 26) Specimen_3A_Low | SS304 | 339. | 290. | 370. | 304. | 365. |
| 27) Specimen_3A_TestPlane | SS304 | 354. | 322. | 367. | 338. | 366. |
| 28) Specimen_3A_High | SS304 | 348. | 304. | 372. | 314. | 370. |
| 29) Specimen_2A_Low | SS304 | 348. | 304. | 371. | 313. | 369. |
| 30) Specimen_2A_TestPlane | SS304 | 354. | 332. | 367. | 338. | 366. |
| 31) Specimen_2A_High | SS304 | 345. | 300. | 370. | 310. | 366. |
| 32) Specimen_1A_Low | SS304 | 340. | 296. | 364. | 306. | 361. |
| 33) Specimen_1A_TestPlane | SS304 | 343. | 310. | 356. | 328. | 355. |
| 34) Specimen_1A_High | SS304 | 329. | 279. | 357. | 292. | 353. |
| 35) Specimen_3B_Low | SS304 | 339. | 290. | 369. | 304. | 365. |
| 36) Specimen_3B_TestPlane | SS304 | 354. | 321. | 367. | 338. | 366. |
| 37) Specimen_3B_High | SS304 | 348. | 304. | 371. | 313. | 370. |
| 38) Specimen_2B_Low | SS304 | 348. | 304. | 371. | 313. | 369. |
| 39) Specimen_2B_TestPlane | SS304 | 354. | 322. | 367. | 338. | 366. |
| 40) Specimen_2B_High | SS304 | 345. | 300. | 370. | 310. | 366. |
| 41) Specimen_1B_Low | SS304 | 340. | 296. | 364. | 306. | 361. |
| 42) Specimen_1B_TestPlane | SS304 | 343. | 312. | 356. | 328. | 355. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 43) | Specimen_1B_High | SS304 | 329. | 279. | 358. | 292. | 353. |

PROPERTY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Thermal Cond. (W/m*C) | Thermal Exp. Coeff. (um/m*C) | Emis (---) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 167.868 | 24.21 | 0.050 |
| 2) Holder | AL-6061 | 176.000 | 25.01 | 0.054 |
| 3) TM_1A | SiC(Irr) | 6.645 | 3.37 | 0.900 |
| 4) TM_1B | SiC(Irr) | 6.645 | 3.37 | 0.900 |
| 5) TM_2B | SiC(Irr) | 6.649 | 3.37 | 0.900 |
| 6) TM_2A | SiC(Irr) | 6.651 | 3.37 | 0.900 |
| 7) Shim_A | SS304 | 20.294 | 20.01 | 0.143 |
| 8) Shim_B | SS304 | 20.293 | 20.01 | 0.143 |
| 9) Spring_Retainer_2 | SiC(Irr) | 7.185 | 3.47 | 0.900 |
| 10) Spring_Retainer_1 | SiC(Irr) | 7.183 | 3.46 | 0.900 |
| 11) Spring_TM_1A | SiC(Irr) | 6.063 | 3.27 | 0.900 |
| 12) Spring_TM_1B | SiC(Irr) | 6.063 | 3.27 | 0.900 |
| 13) Spring_TM_2A | SiC(Irr) | 6.068 | 3.27 | 0.900 |
| 14) Spring_TM_2B | SiC(Irr) | 6.067 | 3.27 | 0.900 |
| 15) Disk_3 | Moly | 126.569 | 5.04 | 0.059 |
| 16) Disk_4 | Moly | 126.608 | 5.04 | 0.059 |
| 17) Disk_2 | Moly | 128.862 | 5.00 | 0.053 |
| 18) Disk_1 | Moly | 128.812 | 5.00 | 0.053 |
| 19) Wire_2A | Moly | 127.972 | 5.01 | 0.055 |
| 20) Wire_1A | Moly | 129.222 | 4.99 | 0.052 |
| 21) Wire_1B | Moly | 129.044 | 4.99 | 0.053 |
| 22) Wire_2B | Moly | 127.826 | 5.02 | 0.056 |
| 23) Housing_High | AL-6061 | 166.224 | 24.21 | 0.050 |
| 24) Housing_Low | AL-6061 | 166.811 | 24.21 | 0.050 |
| 25) Housing_Mid | AL-6061 | 166.563 | 24.21 | 0.050 |
| 26) Specimen_3A_Low | SS304 | 19.974 | 19.89 | 0.143 |
| 27) Specimen_3A_TestPlane | SS304 | 20.177 | 20.04 | 0.143 |
| 28) Specimen_3A_High | SS304 | 20.099 | 20.03 | 0.143 |
| 29) Specimen_2A_Low | SS304 | 20.091 | 20.03 | 0.143 |
| 30) Specimen_2A_TestPlane | SS304 | 20.176 | 20.04 | 0.143 |
| 31) Specimen_2A_High | SS304 | 20.050 | 19.98 | 0.143 |
| 32) Specimen_1A_Low | SS304 | 19.984 | 19.91 | 0.143 |
| 33) Specimen_1A_TestPlane | SS304 | 20.023 | 19.95 | 0.143 |
| 34) Specimen_1A_High | SS304 | 19.834 | 19.74 | 0.143 |
| 35) Specimen_3B_Low | SS304 | 19.974 | 19.89 | 0.143 |
| 36) Specimen_3B_TestPlane | SS304 | 20.175 | 20.04 | 0.143 |
| 37) Specimen_3B_High | SS304 | 20.097 | 20.03 | 0.143 |
| 38) Specimen_2B_Low | SS304 | 20.090 | 20.02 | 0.143 |
| 39) Specimen_2B_TestPlane | SS304 | 20.174 | 20.04 | 0.143 |
| 40) Specimen_2B_High | SS304 | 20.048 | 19.98 | 0.143 |
| 41) Specimen_1B_Low | SS304 | 19.985 | 19.91 | 0.143 |
| 42) Specimen_1B_TestPlane | SS304 | 20.026 | 19.95 | 0.143 |
| 43) Specimen_1B_High | SS304 | 19.835 | 19.74 | 0.143 |

STORED ENERGY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Mass (g) | Tavg (C) | Specific Heat (J/kg-C) | Stored Energy (J) |
|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 0.621 | 70. | 893. | 28. |
| 2) Holder | AL-6061 | 3.884 | 249. | 1006. | 896. |
| 3) TM_1A | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 4) TM_1B | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 5) TM_2B | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 6) TM_2A | SiC(Irr) | 0.058 | 337. | 1039. | 19. |
| 7) Shim_A | SS304 | 0.241 | 362. | 393. | 32. |
| 8) Shim_B | SS304 | 0.241 | 362. | 393. | 32. |
| 9) Spring_Retainer_2 | SiC(Irr) | 0.024 | 371. | 1057. | 9. |
| 10) Spring_Retainer_1 | SiC(Irr) | 0.024 | 371. | 1057. | 9. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11) | Spring_TM_1A | SiC(Irr) | 0.024 | 300. | 1019. | 7. |
| 12) | Spring_TM_1B | SiC(Irr) | 0.024 | 300. | 1019. | 7. |
| 13) | Spring_TM_2A | SiC(Irr) | 0.024 | 300. | 1019. | 7. |
| 14) | Spring_TM_2B | SiC(Irr) | 0.024 | 300. | 1019. | 7. |
| 15) | Disk_3 | Moly | 0.040 | 313. | 267. | 3. |
| 16) | Disk_4 | Moly | 0.040 | 312. | 267. | 3. |
| 17) | Disk_2 | Moly | 0.040 | 255. | 264. | 2. |
| 18) | Disk_1 | Moly | 0.040 | 257. | 264. | 2. |
| 19) | Wire_2A | Moly | 0.019 | 278. | 265. | 1. |
| 20) | Wire_1A | Moly | 0.019 | 246. | 264. | 1. |
| 21) | Wire_1B | Moly | 0.019 | 251. | 264. | 1. |
| 22) | Wire_2B | Moly | 0.019 | 281. | 265. | 1. |
| 23) | Housing_High | AL-6061 | 0.164 | 56. | 882. | 5. |
| 24) | Housing_Low | AL-6061 | 0.491 | 61. | 886. | 18. |
| 25) | Housing_Mid | AL-6061 | 3.637 | 59. | 884. | 126. |
| 26) | Specimen_3A_Low | SS304 | 0.786 | 339. | 391. | 98. |
| 27) | Specimen_3A_TestPlane | SS304 | 0.014 | 354. | 392. | 2. |
| 28) | Specimen_3A_High | SS304 | 0.786 | 348. | 392. | 101. |
| 29) | Specimen_2A_Low | SS304 | 0.786 | 348. | 392. | 101. |
| 30) | Specimen_2A_TestPlane | SS304 | 0.014 | 354. | 392. | 2. |
| 31) | Specimen_2A_High | SS304 | 0.786 | 345. | 391. | 100. |
| 32) | Specimen_1A_Low | SS304 | 0.786 | 340. | 391. | 98. |
| 33) | Specimen_1A_TestPlane | SS304 | 0.014 | 343. | 391. | 2. |
| 34) | Specimen_1A_High | SS304 | 0.786 | 329. | 390. | 95. |
| 35) | Specimen_3B_Low | SS304 | 0.786 | 339. | 391. | 98. |
| 36) | Specimen_3B_TestPlane | SS304 | 0.014 | 354. | 392. | 2. |
| 37) | Specimen_3B_High | SS304 | 0.786 | 348. | 392. | 101. |
| 38) | Specimen_2B_Low | SS304 | 0.786 | 348. | 392. | 101. |
| 39) | Specimen_2B_TestPlane | SS304 | 0.014 | 354. | 392. | 2. |
| 40) | Specimen_2B_High | SS304 | 0.786 | 345. | 391. | 100. |
| 41) | Specimen_1B_Low | SS304 | 0.786 | 340. | 391. | 98. |
| 42) | Specimen_1B_TestPlane | SS304 | 0.014 | 343. | 391. | 2. |
| 43) | Specimen_1B_High | SS304 | 0.786 | 329. | 390. | 95. |
| | | | 19.410 | | | 2473. |

HOLDER TO HOUSING GAP REPORTS

CONTACT SUMMARY FOR CONTACT ID 48: Holder To Housing_Mid

Contact surface material: AL-6061
Target surface material: AL-6061
Interstitial gas: 100HE_0A
Effective surface roughness: 2.263 um
Effective asperity slope: 0.214 rad
Effective microhardness: 1.220 GPa

| | Average | Minimum | Maximum |
|---|---|---|---|
| ~~~~~~~~~~~ direct results ~~~~~~~~~~ | | | |
| Contact status | 1.000 | 1.000 | 1.000 |
| Contact temperature (C) | 249.133 | 222.453 | 267.430 |
| Target temperature (C) | 60.775 | 56.778 | 61.890 |
| Geometric gas gap (um) | 124.507 | 124.070 | 125.736 |
| Contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Gap conduction heat flux (kW/m^2) | 352.146 | 291.617 | 398.160 |
| Radiation heat flux (kW/m^2) | 0.107 | 0.080 | 0.127 |
| Contact conduction heat flux (kW/m^2 | 0.000 | 0.000 | 0.000 |
| Total heat flux (kW/m^2) | 352.253 | 291.698 | 398.288 |
| Thermal contact conductance (W/m^2-C | 1867.370 | 1695.613 | 1936.621 |
| ~~~~~~~~~~ derived results ~~~~~~~~~~ | | | |
| Effective gas gap (um) | 102.221 | 100.020 | 105.638 |
| Contact thermal jump distance (um) | 1.308 | 1.235 | 1.356 |
| Target thermal jump distance (um) | 1.183 | 1.128 | 1.216 |
| Effective contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Pressure index | 13.534 | 13.534 | 13.534 |
| Gas thermal conductivity (W/m*C) | 0.196 | 0.190 | 0.199 |
| Solid spot conductance (W/m^2*C) | 0.000 | 0.000 | 0.000 |
| Gas gap conductance (W/m^2*C) | 1867.141 | 1765.259 | 1936.282 |

```
   Contact status codes:
    --------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking

--------------------------------------------------------------------------------
CONTACT SUMMARY FOR CONTACT ID 50: Holder To Housing_Mid
   Contact surface material:      AL-6061
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                          Average      Minimum      Maximum
                                        ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                              1.000        1.000        1.000
   Contact temperature (C)                   233.740      222.049      244.596
   Target temperature (C)                     57.358       56.766       58.014
   Geometric gas gap (um)                     59.500       59.499       59.500
   Contact pressure (MPa)                      0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)         830.330      741.030      914.109
   Radiation heat flux (kW/m^2)                0.091        0.080        0.102
   Contact conduction heat flux (kW/m^2        0.000        0.000        0.000
   Total heat flux (kW/m^2)                  830.421      741.109      914.211
   Thermal contact conductance (W/m^2-C     4695.545     4490.040     4887.482
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                     38.611       37.274       40.037
   Contact thermal jump distance (um)          1.264        1.234        1.292
   Target thermal jump distance (um)           1.148        1.127        1.168
   Effective contact pressure (MPa)            0.000        0.000        0.000
   Pressure index                             13.534       13.534       13.534
   Gas thermal conductivity (W/m*C)            0.192        0.190        0.194
   Solid spot conductance (W/m^2*C)            0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)            4688.659     4484.425     4879.411

   Contact status codes:
    --------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking
```

## A-4. 9.22 mm Al Holder in TRRH6 ANSYS Summary

```
 ******************************************************************************
                            OUTPUT SUMMARY FILE
 ******************************************************************************

  ------------------------------------------------------------------------------
  INPUTS

 * Symmetry angle: 360.00 degrees
 * Housing fill gas:   100HE_0A
 * Holder material: Aluminum
 * Specimen material: SS304
 * Shim material: SS304
 * Radiative heat transfer included
 * 3D  problem geometry
 * Target temperature:  350.0 °C
 * Target dose (in SiC):  20.000 dpa
 * Irradiation facility: TRRH
 * Axial position: 6
 * Axial peaking factor above the core midplane: 30.390 cm
 * Axial peaking factor below the core midplane: 29.700 cm
 * Housing Inner Diameter:  9.519 mm
 * Holder Outer Diameter:  9.220 mm
 * Holder Tab Outer Diameter:  9.400 mm
 * Design basis
 * Nominal geometry
```

BOUNDARY CONDITIONS

Heat generation rate scaling factor = 1.0000
Heat transfer coefficient = 47100. W/m²·°C
Bulk coolant temperature = 52.0 °C

HEAT GENERATION

| Part | Material | Heat Gen. @Midplane (W/kg) | Heat Load @Midplane (W) | Heat Load @Location (W) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 31300. | 19.4 | 15.1 |
| 2) Holder | AL-6061 | 31300. | 118.6 | 100.9 |
| 3) TM_1A | SiC(Irr) | 31700. | 1.8 | 1.6 |
| 4) TM_1B | SiC(Irr) | 31700. | 1.8 | 1.6 |
| 5) TM_2B | SiC(Irr) | 31700. | 1.8 | 1.6 |
| 6) TM_2A | SiC(Irr) | 31700. | 1.8 | 1.6 |
| 7) Shim_A | SS304 | 38100. | 9.2 | 7.8 |
| 8) Shim_B | SS304 | 38100. | 9.2 | 7.8 |
| 9) Spring_Retainer_2 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 10) Spring_Retainer_1 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 11) Spring_TM_1A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 12) Spring_TM_1B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 13) Spring_TM_2A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 14) Spring_TM_2B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 15) Disk_3 | Moly | 42000. | 1.7 | 1.5 |
| 16) Disk_4 | Moly | 42000. | 1.7 | 1.5 |
| 17) Disk_2 | Moly | 42000. | 1.7 | 1.3 |
| 18) Disk_1 | Moly | 42000. | 1.7 | 1.3 |
| 19) Wire_2A | Moly | 42000. | 0.8 | 0.7 |
| 20) Wire_1A | Moly | 42000. | 0.8 | 0.6 |
| 21) Wire_1B | Moly | 42000. | 0.8 | 0.6 |
| 22) Wire_2B | Moly | 42000. | 0.8 | 0.7 |
| 23) Housing_High | AL-6061 | 31300. | 5.1 | 4.0 |
| 24) Housing_Low | AL-6061 | 31300. | 15.4 | 14.0 |
| 25) Housing_Mid | AL-6061 | 31300. | 113.8 | 96.7 |
| 26) Specimen_3A_Low | SS304 | 38100. | 30.0 | 26.8 |
| 27) Specimen_3A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 28) Specimen_3A_High | SS304 | 38100. | 30.0 | 26.3 |
| 29) Specimen_2A_Low | SS304 | 38100. | 30.0 | 25.8 |
| 30) Specimen_2A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 31) Specimen_2A_High | SS304 | 38100. | 30.0 | 25.3 |
| 32) Specimen_1A_Low | SS304 | 38100. | 30.0 | 24.8 |
| 33) Specimen_1A_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 34) Specimen_1A_High | SS304 | 38100. | 30.0 | 24.3 |
| 35) Specimen_3B_Low | SS304 | 38100. | 30.0 | 26.8 |
| 36) Specimen_3B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 37) Specimen_3B_High | SS304 | 38100. | 30.0 | 26.3 |
| 38) Specimen_2B_Low | SS304 | 38100. | 30.0 | 25.8 |
| 39) Specimen_2B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 40) Specimen_2B_High | SS304 | 38100. | 30.0 | 25.3 |
| 41) Specimen_1B_Low | SS304 | 38100. | 30.0 | 24.8 |
| 42) Specimen_1B_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 43) Specimen_1B_High | SS304 | 38100. | 30.0 | 24.3 |
| | | | 675.2 | 574.4 |

CAPSULE TEMPERATURE SUMMARY

| Name | Material | Tavg | Tmin | Tmax | T.025 | T.975 |
|---|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 67. | 65. | 69. | 65. | 69. |
| 2) Holder | AL-6061 | 262. | 232. | 284. | 236. | 281. |
| 3) TM_1A | SiC(Irr) | 339. | 317. | 354. | 322. | 350. |
| 4) TM_1B | SiC(Irr) | 339. | 317. | 354. | 322. | 350. |
| 5) TM_2B | SiC(Irr) | 339. | 317. | 354. | 322. | 351. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6) | TM_2A | SiC(Irr) | 339. | 317. | 355. | 322. | 351. |
| 7) | Shim_A | SS304 | 362. | 334. | 376. | 340. | 375. |
| 8) | Shim_B | SS304 | 361. | 334. | 376. | 340. | 375. |
| 9) | Spring_Retainer_2 | SiC(Irr) | 369. | 344. | 382. | 350. | 381. |
| 10) | Spring_Retainer_1 | SiC(Irr) | 369. | 333. | 382. | 349. | 381. |
| 11) | Spring_TM_1A | SiC(Irr) | 307. | 245. | 339. | 253. | 337. |
| 12) | Spring_TM_1B | SiC(Irr) | 307. | 245. | 339. | 253. | 337. |
| 13) | Spring_TM_2A | SiC(Irr) | 307. | 245. | 339. | 253. | 337. |
| 14) | Spring_TM_2B | SiC(Irr) | 307. | 245. | 339. | 253. | 337. |
| 15) | Disk_3 | Moly | 322. | 299. | 336. | 303. | 335. |
| 16) | Disk_4 | Moly | 321. | 307. | 332. | 310. | 331. |
| 17) | Disk_2 | Moly | 261. | 252. | 266. | 254. | 266. |
| 18) | Disk_1 | Moly | 262. | 257. | 266. | 258. | 266. |
| 19) | Wire_2A | Moly | 291. | 270. | 305. | 271. | 305. |
| 20) | Wire_1A | Moly | 254. | 240. | 263. | 241. | 263. |
| 21) | Wire_1B | Moly | 257. | 243. | 267. | 244. | 266. |
| 22) | Wire_2B | Moly | 294. | 276. | 306. | 276. | 306. |
| 23) | Housing_High | AL-6061 | 56. | 55. | 56. | 56. | 56. |
| 24) | Housing_Low | AL-6061 | 61. | 58. | 62. | 58. | 62. |
| 25) | Housing_Mid | AL-6061 | 58. | 53. | 61. | 54. | 60. |
| 26) | Specimen_3A_Low | SS304 | 346. | 302. | 373. | 314. | 369. |
| 27) | Specimen_3A_TestPlane | SS304 | 359. | 329. | 371. | 345. | 370. |
| 28) | Specimen_3A_High | SS304 | 353. | 312. | 374. | 321. | 372. |
| 29) | Specimen_2A_Low | SS304 | 351. | 312. | 371. | 320. | 369. |
| 30) | Specimen_2A_TestPlane | SS304 | 355. | 335. | 366. | 341. | 365. |
| 31) | Specimen_2A_High | SS304 | 345. | 305. | 369. | 315. | 365. |
| 32) | Specimen_1A_Low | SS304 | 339. | 299. | 361. | 309. | 358. |
| 33) | Specimen_1A_TestPlane | SS304 | 340. | 311. | 351. | 326. | 350. |
| 34) | Specimen_1A_High | SS304 | 327. | 282. | 352. | 294. | 347. |
| 35) | Specimen_3B_Low | SS304 | 346. | 302. | 373. | 314. | 369. |
| 36) | Specimen_3B_TestPlane | SS304 | 359. | 329. | 371. | 345. | 370. |
| 37) | Specimen_3B_High | SS304 | 353. | 312. | 374. | 322. | 372. |
| 38) | Specimen_2B_Low | SS304 | 350. | 312. | 371. | 320. | 369. |
| 39) | Specimen_2B_TestPlane | SS304 | 355. | 335. | 366. | 341. | 365. |
| 40) | Specimen_2B_High | SS304 | 345. | 305. | 368. | 315. | 364. |
| 41) | Specimen_1B_Low | SS304 | 339. | 299. | 361. | 309. | 358. |
| 42) | Specimen_1B_TestPlane | SS304 | 340. | 312. | 352. | 327. | 350. |
| 43) | Specimen_1B_High | SS304 | 327. | 282. | 352. | 294. | 347. |

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PROPERTY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | | Material | Thermal Cond. (W/m*C) | Thermal Exp. Coeff. (um/m*C) | Emis (---) |
|---|---|---|---|---|---|
| 1) | Endcap | AL-6061 | 167.536 | 24.21 | 0.050 |
| 2) | Holder | AL-6061 | 176.000 | 25.11 | 0.055 |
| 3) | TM_1A | SiC(Irr) | 6.677 | 3.38 | 0.900 |
| 4) | TM_1B | SiC(Irr) | 6.678 | 3.38 | 0.900 |
| 5) | TM_2B | SiC(Irr) | 6.681 | 3.38 | 0.900 |
| 6) | TM_2A | SiC(Irr) | 6.682 | 3.38 | 0.900 |
| 7) | Shim_A | SS304 | 20.283 | 20.01 | 0.143 |
| 8) | Shim_B | SS304 | 20.283 | 20.01 | 0.143 |
| 9) | Spring_Retainer_2 | SiC(Irr) | 7.165 | 3.46 | 0.900 |
| 10) | Spring_Retainer_1 | SiC(Irr) | 7.163 | 3.46 | 0.900 |
| 11) | Spring_TM_1A | SiC(Irr) | 6.167 | 3.29 | 0.900 |
| 12) | Spring_TM_1B | SiC(Irr) | 6.168 | 3.29 | 0.900 |
| 13) | Spring_TM_2A | SiC(Irr) | 6.172 | 3.29 | 0.900 |
| 14) | Spring_TM_2B | SiC(Irr) | 6.170 | 3.29 | 0.900 |
| 15) | Disk_3 | Moly | 126.188 | 5.05 | 0.060 |
| 16) | Disk_4 | Moly | 126.223 | 5.04 | 0.060 |
| 17) | Disk_2 | Moly | 128.629 | 5.00 | 0.054 |
| 18) | Disk_1 | Moly | 128.588 | 5.00 | 0.054 |
| 19) | Wire_2A | Moly | 127.450 | 5.02 | 0.057 |
| 20) | Wire_1A | Moly | 128.936 | 5.00 | 0.053 |
| 21) | Wire_1B | Moly | 128.790 | 5.00 | 0.053 |
| 22) | Wire_2B | Moly | 127.314 | 5.02 | 0.057 |
| 23) | Housing_High | AL-6061 | 166.144 | 24.21 | 0.050 |
| 24) | Housing_Low | AL-6061 | 166.724 | 24.21 | 0.050 |

| | | | | | |
|---|---|---|---|---|---|
| 25) | Housing_Mid | AL-6061 | 166.459 | 24.21 | 0.050 |
| 26) | Specimen_3A_Low | SS304 | 20.069 | 20.00 | 0.143 |
| 27) | Specimen_3A_TestPlane | SS304 | 20.243 | 20.02 | 0.143 |
| 28) | Specimen_3A_High | SS304 | 20.162 | 20.05 | 0.143 |
| 29) | Specimen_2A_Low | SS304 | 20.130 | 20.06 | 0.143 |
| 30) | Specimen_2A_TestPlane | SS304 | 20.187 | 20.04 | 0.143 |
| 31) | Specimen_2A_High | SS304 | 20.057 | 19.99 | 0.143 |
| 32) | Specimen_1A_Low | SS304 | 19.963 | 19.88 | 0.143 |
| 33) | Specimen_1A_TestPlane | SS304 | 19.976 | 19.90 | 0.143 |
| 34) | Specimen_1A_High | SS304 | 19.794 | 19.69 | 0.143 |
| 35) | Specimen_3B_Low | SS304 | 20.069 | 20.00 | 0.143 |
| 36) | Specimen_3B_TestPlane | SS304 | 20.242 | 20.02 | 0.143 |
| 37) | Specimen_3B_High | SS304 | 20.161 | 20.05 | 0.143 |
| 38) | Specimen_2B_Low | SS304 | 20.129 | 20.06 | 0.143 |
| 39) | Specimen_2B_TestPlane | SS304 | 20.185 | 20.04 | 0.143 |
| 40) | Specimen_2B_High | SS304 | 20.055 | 19.99 | 0.143 |
| 41) | Specimen_1B_Low | SS304 | 19.964 | 19.88 | 0.143 |
| 42) | Specimen_1B_TestPlane | SS304 | 19.979 | 19.90 | 0.143 |
| 43) | Specimen_1B_High | SS304 | 19.795 | 19.69 | 0.143 |

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STORED ENERGY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | | Material | Mass (g) | Tavg (C) | Specific Heat (J/kg-C) | Stored Energy (J) |
|---|---|---|---|---|---|---|
| 1) | Endcap | AL-6061 | 0.621 | 67. | 890. | 26. |
| 2) | Holder | AL-6061 | 3.788 | 262. | 1011. | 925. |
| 3) | TM_1A | SiC(Irr) | 0.058 | 339. | 1040. | 19. |
| 4) | TM_1B | SiC(Irr) | 0.058 | 339. | 1040. | 19. |
| 5) | TM_2B | SiC(Irr) | 0.058 | 339. | 1040. | 19. |
| 6) | TM_2A | SiC(Irr) | 0.058 | 339. | 1040. | 19. |
| 7) | Shim_A | SS304 | 0.241 | 362. | 393. | 32. |
| 8) | Shim_B | SS304 | 0.241 | 361. | 393. | 32. |
| 9) | Spring_Retainer_2 | SiC(Irr) | 0.024 | 369. | 1056. | 9. |
| 10) | Spring_Retainer_1 | SiC(Irr) | 0.024 | 369. | 1056. | 9. |
| 11) | Spring_TM_1A | SiC(Irr) | 0.024 | 307. | 1022. | 7. |
| 12) | Spring_TM_1B | SiC(Irr) | 0.024 | 307. | 1022. | 7. |
| 13) | Spring_TM_2A | SiC(Irr) | 0.024 | 307. | 1022. | 7. |
| 14) | Spring_TM_2B | SiC(Irr) | 0.024 | 307. | 1022. | 7. |
| 15) | Disk_3 | Moly | 0.040 | 322. | 267. | 3. |
| 16) | Disk_4 | Moly | 0.040 | 321. | 267. | 3. |
| 17) | Disk_2 | Moly | 0.040 | 261. | 265. | 3. |
| 18) | Disk_1 | Moly | 0.040 | 262. | 265. | 3. |
| 19) | Wire_2A | Moly | 0.018 | 291. | 266. | 1. |
| 20) | Wire_1A | Moly | 0.018 | 254. | 264. | 1. |
| 21) | Wire_1B | Moly | 0.019 | 257. | 264. | 1. |
| 22) | Wire_2B | Moly | 0.019 | 294. | 266. | 1. |
| 23) | Housing_High | AL-6061 | 0.164 | 56. | 881. | 5. |
| 24) | Housing_Low | AL-6061 | 0.491 | 61. | 885. | 18. |
| 25) | Housing_Mid | AL-6061 | 3.637 | 58. | 883. | 123. |
| 26) | Specimen_3A_Low | SS304 | 0.786 | 346. | 391. | 100. |
| 27) | Specimen_3A_TestPlane | SS304 | 0.014 | 359. | 392. | 2. |
| 28) | Specimen_3A_High | SS304 | 0.786 | 353. | 392. | 103. |
| 29) | Specimen_2A_Low | SS304 | 0.786 | 351. | 392. | 102. |
| 30) | Specimen_2A_TestPlane | SS304 | 0.014 | 355. | 392. | 2. |
| 31) | Specimen_2A_High | SS304 | 0.786 | 345. | 391. | 100. |
| 32) | Specimen_1A_Low | SS304 | 0.786 | 339. | 391. | 98. |
| 33) | Specimen_1A_TestPlane | SS304 | 0.014 | 340. | 391. | 2. |
| 34) | Specimen_1A_High | SS304 | 0.786 | 327. | 390. | 94. |
| 35) | Specimen_3B_Low | SS304 | 0.786 | 346. | 391. | 100. |
| 36) | Specimen_3B_TestPlane | SS304 | 0.014 | 359. | 392. | 2. |
| 37) | Specimen_3B_High | SS304 | 0.786 | 353. | 392. | 103. |
| 38) | Specimen_2B_Low | SS304 | 0.786 | 350. | 392. | 102. |
| 39) | Specimen_2B_TestPlane | SS304 | 0.014 | 355. | 392. | 2. |
| 40) | Specimen_2B_High | SS304 | 0.786 | 345. | 391. | 100. |
| 41) | Specimen_1B_Low | SS304 | 0.786 | 339. | 391. | 98. |
| 42) | Specimen_1B_TestPlane | SS304 | 0.014 | 340. | 391. | 2. |
| 43) | Specimen_1B_High | SS304 | 0.786 | 327. | 390. | 94. |
| | | | -------- | | | -------- |

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                                                19.314                2506.

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 HOLDER TO HOUSING GAP REPORTS


------------------------------------------------------------------------------
CONTACT SUMMARY FOR CONTACT ID 48: Holder To Housing_Mid
   Contact surface material:      AL-6061
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                              Average      Minimum      Maximum
                                           ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                                 1.000        1.000        1.000
   Contact temperature (C)                      261.559      232.836      280.592
   Target temperature (C)                        59.734       56.209       60.680
   Geometric gas gap (um)                       149.499      149.032      149.506
   Contact pressure (MPa)                         0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)            311.298      257.925      350.502
   Radiation heat flux (kW/m^2)                   0.121        0.090        0.143
   Contact conduction heat flux (kW/m^2           0.000        0.000        0.000
   Total heat flux (kW/m^2)                     311.419      258.015      350.645
   Thermal contact conductance (W/m^2-C        1540.657     1437.057     1593.627
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                       125.586      123.270      128.850
   Contact thermal jump distance (um)             1.337        1.260        1.386
   Target thermal jump distance (um)              1.201        1.144        1.235
   Effective contact pressure (MPa)               0.000        0.000        0.000
   Pressure index                                13.534       13.534       13.534
   Gas thermal conductivity (W/m*C)               0.197        0.192        0.201
   Solid spot conductance (W/m^2*C)               0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)               1540.172     1462.848     1592.975

   Contact status codes:
    -----------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking

------------------------------------------------------------------------------
CONTACT SUMMARY FOR CONTACT ID 50: Holder To Housing_Mid
   Contact surface material:      AL-6061
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                              Average      Minimum      Maximum
                                           ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                                 1.000        1.000        1.000
   Contact temperature (C)                      246.157      232.234      260.089
   Target temperature (C)                        56.836       56.322       57.392
   Geometric gas gap (um)                        59.500       59.500       59.500
   Contact pressure (MPa)                         0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)            938.413      821.168     1056.222
   Radiation heat flux (kW/m^2)                   0.105        0.090        0.120
   Contact conduction heat flux (kW/m^2           0.000        0.000        0.000
   Total heat flux (kW/m^2)                     938.518      821.257     1056.341
   Thermal contact conductance (W/m^2-C        4937.820     4670.517     5206.166
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                        36.984       35.261       38.700
   Contact thermal jump distance (um)             1.293        1.258        1.328
   Target thermal jump distance (um)              1.168        1.143        1.192
   Effective contact pressure (MPa)               0.000        0.000        0.000
   Pressure index                                13.534       13.534       13.534
```

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 Gas thermal conductivity (W/m*C)           0.194       0.192       0.197
 Solid spot conductance (W/m^2*C)           0.000       0.000       0.000
 Gas gap conductance (W/m^2*C)           4927.832    4663.193    5193.569

 Contact status codes:
  ----------------------------------------------
  0=open/no heat transfer, 1=near-field contact
  2=closed and sliding,    3=closed and sticking
```

## A-5. 9.18 mm Mo Holder in TRRH2 ANSYS Summary

```
*******************************************************************************
                            OUTPUT SUMMARY FILE
*******************************************************************************

 -------------------------------------------------------------------------------
 INPUTS

* Symmetry angle: 360.00 degrees
* Housing fill gas:   100HE_0A
* Holder material: Molybdenum
* Specimen material: SS304
* Shim material: SS304
* Radiative heat transfer included
* 3D  problem geometry
* Target temperature:  500.0 °C
* Target dose (in SiC):  20.000 dpa
* Irradiation facility: TRRH
* Axial position: 2
* Axial peaking factor above the core midplane: 30.390 cm
* Axial peaking factor below the core midplane: 29.700 cm
* Housing Inner Diameter:  9.519 mm
* Holder Outer Diameter:  9.180 mm
* Holder Tab Outer Diameter:  9.400 mm
* Design basis
* Nominal geometry

-------------------------------------------------------------------------------
 BOUNDARY CONDITIONS

 Heat generation rate scaling factor = 1.0000
 Heat transfer coefficient =  47100. W/m²·°C
 Bulk coolant temperature  =    52.0 °C

-------------------------------------------------------------------------------
 HEAT GENERATION

                                                    Heat Gen.   ------ Heat Load -----
                                                    @Midplane   @Midplane    @Location
  Part                                   Material    (W/kg)       (W)          (W)
----------------------------------- --------   ---------   ---------    ---------
  1) Endcap                            AL-6061      31300.       19.4         17.1
  2) Holder                            Moly         42000.      590.0        476.5
  3) TM_1A                             SiC(Irr)     31700.        1.8          1.5
  4) TM_1B                             SiC(Irr)     31700.        1.8          1.5
  5) TM_2B                             SiC(Irr)     31700.        1.8          1.5
  6) TM_2A                             SiC(Irr)     31700.        1.8          1.5
  7) Shim_A                            SS304        38100.        9.2          7.4
  8) Shim_B                            SS304        38100.        9.2          7.4
  9) Spring_Retainer_2                 SiC(Irr)     31700.        0.8          0.6
 10) Spring_Retainer_1                 SiC(Irr)     31700.        0.8          0.6
 11) Spring_TM_1A                      SiC(Irr)     31700.        0.8          0.6
 12) Spring_TM_1B                      SiC(Irr)     31700.        0.8          0.6
 13) Spring_TM_2A                      SiC(Irr)     31700.        0.8          0.6
 14) Spring_TM_2B                      SiC(Irr)     31700.        0.8          0.6
 15) Disk_3                            Moly         42000.        1.7          1.3
 16) Disk_4                            Moly         42000.        1.7          1.3
 17) Disk_2                            Moly         42000.        1.7          1.4
 18) Disk_1                            Moly         42000.        1.7          1.4
 19) Wire_2A                           Moly         42000.        0.8          0.6
```

| | | | | |
|---|---|---|---|---|
| 20) Wire_1A | Moly | 42000. | 0.8 | 0.7 |
| 21) Wire_1B | Moly | 42000. | 0.8 | 0.7 |
| 22) Wire_2B | Moly | 42000. | 0.8 | 0.6 |
| 23) Housing_High | AL-6061 | 31300. | 5.1 | 4.5 |
| 24) Housing_Low | AL-6061 | 31300. | 15.4 | 11.2 |
| 25) Housing_Mid | AL-6061 | 31300. | 113.8 | 92.0 |
| 26) Specimen_3A_Low | SS304 | 38100. | 30.0 | 22.7 |
| 27) Specimen_3A_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 28) Specimen_3A_High | SS304 | 38100. | 30.0 | 23.3 |
| 29) Specimen_2A_Low | SS304 | 38100. | 30.0 | 23.9 |
| 30) Specimen_2A_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 31) Specimen_2A_High | SS304 | 38100. | 30.0 | 24.4 |
| 32) Specimen_1A_Low | SS304 | 38100. | 30.0 | 25.0 |
| 33) Specimen_1A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 34) Specimen_1A_High | SS304 | 38100. | 30.0 | 25.5 |
| 35) Specimen_3B_Low | SS304 | 38100. | 30.0 | 22.7 |
| 36) Specimen_3B_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 37) Specimen_3B_High | SS304 | 38100. | 30.0 | 23.3 |
| 38) Specimen_2B_Low | SS304 | 38100. | 30.0 | 23.9 |
| 39) Specimen_2B_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 40) Specimen_2B_High | SS304 | 38100. | 30.0 | 24.4 |
| 41) Specimen_1B_Low | SS304 | 38100. | 30.0 | 25.0 |
| 42) Specimen_1B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 43) Specimen_1B_High | SS304 | 38100. | 30.0 | 25.5 |
| | | | 1146.7 | 925.9 |

CAPSULE TEMPERATURE SUMMARY

| Name | Material | Tavg | Tmin | Tmax | T.025 | T.975 |
|---|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 69. | 66. | 71. | 67. | 71. |
| 2) Holder | Moly | 475. | 444. | 500. | 452. | 495. |
| 3) TM_1A | SiC(Irr) | 541. | 502. | 556. | 512. | 554. |
| 4) TM_1B | SiC(Irr) | 541. | 502. | 557. | 512. | 554. |
| 5) TM_2B | SiC(Irr) | 541. | 502. | 557. | 512. | 554. |
| 6) TM_2A | SiC(Irr) | 541. | 502. | 557. | 512. | 554. |
| 7) Shim_A | SS304 | 560. | 513. | 576. | 528. | 576. |
| 8) Shim_B | SS304 | 560. | 514. | 577. | 528. | 576. |
| 9) Spring_Retainer_2 | SiC(Irr) | 566. | 521. | 581. | 533. | 581. |
| 10) Spring_Retainer_1 | SiC(Irr) | 566. | 511. | 581. | 532. | 581. |
| 11) Spring_TM_1A | SiC(Irr) | 512. | 457. | 542. | 463. | 540. |
| 12) Spring_TM_1B | SiC(Irr) | 512. | 457. | 542. | 463. | 540. |
| 13) Spring_TM_2A | SiC(Irr) | 512. | 457. | 543. | 463. | 541. |
| 14) Spring_TM_2B | SiC(Irr) | 512. | 457. | 543. | 463. | 541. |
| 15) Disk_3 | Moly | 503. | 484. | 514. | 488. | 513. |
| 16) Disk_4 | Moly | 502. | 489. | 510. | 493. | 510. |
| 17) Disk_2 | Moly | 491. | 482. | 497. | 484. | 496. |
| 18) Disk_1 | Moly | 492. | 484. | 497. | 487. | 496. |
| 19) Wire_2A | Moly | 477. | 458. | 489. | 458. | 489. |
| 20) Wire_1A | Moly | 482. | 465. | 493. | 466. | 493. |
| 21) Wire_1B | Moly | 479. | 461. | 491. | 461. | 491. |
| 22) Wire_2B | Moly | 475. | 457. | 486. | 457. | 486. |
| 23) Housing_High | AL-6061 | 56. | 56. | 57. | 56. | 56. |
| 24) Housing_Low | AL-6061 | 59. | 57. | 60. | 57. | 60. |
| 25) Housing_Mid | AL-6061 | 62. | 54. | 66. | 54. | 65. |
| 26) Specimen_3A_Low | SS304 | 523. | 484. | 547. | 496. | 542. |
| 27) Specimen_3A_TestPlane | SS304 | 537. | 512. | 548. | 526. | 546. |
| 28) Specimen_3A_High | SS304 | 539. | 505. | 559. | 515. | 556. |
| 29) Specimen_2A_Low | SS304 | 548. | 513. | 568. | 523. | 565. |
| 30) Specimen_2A_TestPlane | SS304 | 557. | 540. | 567. | 546. | 566. |
| 31) Specimen_2A_High | SS304 | 555. | 522. | 573. | 530. | 571. |
| 32) Specimen_1A_Low | SS304 | 558. | 524. | 575. | 532. | 573. |
| 33) Specimen_1A_TestPlane | SS304 | 561. | 534. | 571. | 550. | 570. |
| 34) Specimen_1A_High | SS304 | 551. | 508. | 572. | 521. | 569. |
| 35) Specimen_3B_Low | SS304 | 523. | 484. | 546. | 496. | 542. |
| 36) Specimen_3B_TestPlane | SS304 | 537. | 512. | 549. | 526. | 546. |
| 37) Specimen_3B_High | SS304 | 539. | 505. | 559. | 515. | 556. |
| 38) Specimen_2B_Low | SS304 | 548. | 513. | 568. | 523. | 564. |
| 39) Specimen_2B_TestPlane | SS304 | 557. | 540. | 567. | 546. | 566. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 40) | Specimen_2B_High | SS304 | 555. | 522. | 573. | 530. | 571. |
| 41) | Specimen_1B_Low | SS304 | 558. | 525. | 575. | 532. | 573. |
| 42) | Specimen_1B_TestPlane | SS304 | 561. | 535. | 571. | 550. | 570. |
| 43) | Specimen_1B_High | SS304 | 551. | 508. | 573. | 521. | 569. |

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PROPERTY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Thermal Cond. (W/m*C) | Thermal Exp. Coeff. (um/m*C) | Emis (---) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 167.741 | 24.21 | 0.050 |
| 2) Holder | Moly | 120.088 | 5.18 | 0.075 |
| 3) TM_1A | SiC(Irr) | 10.043 | 3.84 | 0.900 |
| 4) TM_1B | SiC(Irr) | 10.043 | 3.84 | 0.900 |
| 5) TM_2B | SiC(Irr) | 10.048 | 3.84 | 0.900 |
| 6) TM_2A | SiC(Irr) | 10.049 | 3.84 | 0.900 |
| 7) Shim_A | SS304 | 22.968 | 19.27 | 0.143 |
| 8) Shim_B | SS304 | 22.968 | 19.27 | 0.143 |
| 9) Spring_Retainer_2 | SiC(Irr) | 10.597 | 3.89 | 0.900 |
| 10) Spring_Retainer_1 | SiC(Irr) | 10.594 | 3.89 | 0.900 |
| 11) Spring_TM_1A | SiC(Irr) | 9.398 | 3.79 | 0.900 |
| 12) Spring_TM_1B | SiC(Irr) | 9.398 | 3.79 | 0.900 |
| 13) Spring_TM_2A | SiC(Irr) | 9.404 | 3.79 | 0.900 |
| 14) Spring_TM_2B | SiC(Irr) | 9.403 | 3.79 | 0.900 |
| 15) Disk_3 | Moly | 118.969 | 5.20 | 0.078 |
| 16) Disk_4 | Moly | 119.000 | 5.20 | 0.078 |
| 17) Disk_2 | Moly | 119.432 | 5.19 | 0.076 |
| 18) Disk_1 | Moly | 119.396 | 5.19 | 0.077 |
| 19) Wire_2A | Moly | 119.990 | 5.18 | 0.075 |
| 20) Wire_1A | Moly | 119.797 | 5.19 | 0.075 |
| 21) Wire_1B | Moly | 119.906 | 5.18 | 0.075 |
| 22) Wire_2B | Moly | 120.072 | 5.18 | 0.075 |
| 23) Housing_High | AL-6061 | 166.204 | 24.21 | 0.050 |
| 24) Housing_Low | AL-6061 | 166.523 | 24.21 | 0.050 |
| 25) Housing_Mid | AL-6061 | 166.953 | 24.21 | 0.050 |
| 26) Specimen_3A_Low | SS304 | 22.443 | 19.36 | 0.143 |
| 27) Specimen_3A_TestPlane | SS304 | 22.645 | 19.33 | 0.143 |
| 28) Specimen_3A_High | SS304 | 22.671 | 19.32 | 0.143 |
| 29) Specimen_2A_Low | SS304 | 22.794 | 19.30 | 0.143 |
| 30) Specimen_2A_TestPlane | SS304 | 22.922 | 19.28 | 0.143 |
| 31) Specimen_2A_High | SS304 | 22.895 | 19.28 | 0.143 |
| 32) Specimen_1A_Low | SS304 | 22.929 | 19.28 | 0.143 |
| 33) Specimen_1A_TestPlane | SS304 | 22.980 | 19.27 | 0.143 |
| 34) Specimen_1A_High | SS304 | 22.830 | 19.30 | 0.143 |
| 35) Specimen_3B_Low | SS304 | 22.443 | 19.36 | 0.143 |
| 36) Specimen_3B_TestPlane | SS304 | 22.644 | 19.33 | 0.143 |
| 37) Specimen_3B_High | SS304 | 22.669 | 19.32 | 0.143 |
| 38) Specimen_2B_Low | SS304 | 22.793 | 19.30 | 0.143 |
| 39) Specimen_2B_TestPlane | SS304 | 22.920 | 19.28 | 0.143 |
| 40) Specimen_2B_High | SS304 | 22.893 | 19.28 | 0.143 |
| 41) Specimen_1B_Low | SS304 | 22.930 | 19.28 | 0.143 |
| 42) Specimen_1B_TestPlane | SS304 | 22.982 | 19.27 | 0.143 |
| 43) Specimen_1B_High | SS304 | 22.831 | 19.30 | 0.143 |

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STORED ENERGY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Mass (g) | Tavg (C) | Specific Heat (J/kg-C) | Stored Energy (J) |
|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 0.621 | 69. | 892. | 27. |
| 2) Holder | Moly | 14.048 | 475. | 274. | 1750. |
| 3) TM_1A | SiC(Irr) | 0.058 | 541. | 1131. | 34. |
| 4) TM_1B | SiC(Irr) | 0.058 | 541. | 1131. | 34. |
| 5) TM_2B | SiC(Irr) | 0.058 | 541. | 1131. | 34. |
| 6) TM_2A | SiC(Irr) | 0.058 | 541. | 1131. | 34. |
| 7) Shim_A | SS304 | 0.241 | 560. | 415. | 54. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8) | Shim_B | SS304 | 0.241 | 560. | 415. | 54. |
| 9) | Spring_Retainer_2 | SiC(Irr) | 0.024 | 566. | 1140. | 15. |
| 10) | Spring_Retainer_1 | SiC(Irr) | 0.024 | 566. | 1140. | 15. |
| 11) | Spring_TM_1A | SiC(Irr) | 0.024 | 512. | 1121. | 13. |
| 12) | Spring_TM_1B | SiC(Irr) | 0.024 | 512. | 1121. | 13. |
| 13) | Spring_TM_2A | SiC(Irr) | 0.024 | 512. | 1121. | 13. |
| 14) | Spring_TM_2B | SiC(Irr) | 0.024 | 512. | 1121. | 13. |
| 15) | Disk_3 | Moly | 0.040 | 503. | 275. | 5. |
| 16) | Disk_4 | Moly | 0.040 | 502. | 275. | 5. |
| 17) | Disk_2 | Moly | 0.040 | 491. | 275. | 5. |
| 18) | Disk_1 | Moly | 0.040 | 492. | 275. | 5. |
| 19) | Wire_2A | Moly | 0.018 | 477. | 274. | 2. |
| 20) | Wire_1A | Moly | 0.018 | 482. | 274. | 2. |
| 21) | Wire_1B | Moly | 0.019 | 479. | 274. | 2. |
| 22) | Wire_2B | Moly | 0.019 | 475. | 274. | 2. |
| 23) | Housing_High | AL-6061 | 0.164 | 56. | 881. | 5. |
| 24) | Housing_Low | AL-6061 | 0.491 | 59. | 884. | 17. |
| 25) | Housing_Mid | AL-6061 | 3.637 | 62. | 886. | 137. |
| 26) | Specimen_3A_Low | SS304 | 0.786 | 523. | 408. | 161. |
| 27) | Specimen_3A_TestPlane | SS304 | 0.014 | 537. | 410. | 3. |
| 28) | Specimen_3A_High | SS304 | 0.786 | 539. | 410. | 167. |
| 29) | Specimen_2A_Low | SS304 | 0.786 | 548. | 412. | 171. |
| 30) | Specimen_2A_TestPlane | SS304 | 0.014 | 557. | 414. | 3. |
| 31) | Specimen_2A_High | SS304 | 0.786 | 555. | 414. | 174. |
| 32) | Specimen_1A_Low | SS304 | 0.786 | 558. | 415. | 175. |
| 33) | Specimen_1A_TestPlane | SS304 | 0.014 | 561. | 415. | 3. |
| 34) | Specimen_1A_High | SS304 | 0.786 | 551. | 413. | 172. |
| 35) | Specimen_3B_Low | SS304 | 0.786 | 523. | 408. | 161. |
| 36) | Specimen_3B_TestPlane | SS304 | 0.014 | 537. | 410. | 3. |
| 37) | Specimen_3B_High | SS304 | 0.786 | 539. | 410. | 167. |
| 38) | Specimen_2B_Low | SS304 | 0.786 | 548. | 412. | 171. |
| 39) | Specimen_2B_TestPlane | SS304 | 0.014 | 557. | 414. | 3. |
| 40) | Specimen_2B_High | SS304 | 0.786 | 555. | 414. | 174. |
| 41) | Specimen_1B_Low | SS304 | 0.786 | 558. | 415. | 175. |
| 42) | Specimen_1B_TestPlane | SS304 | 0.014 | 561. | 415. | 3. |
| 43) | Specimen_1B_High | SS304 | 0.786 | 551. | 413. | 172. |
| | | | -------- | | | -------- |
| | | | 29.574 | | | 4357. |

-------------------------------------------------------------------------------

HOLDER TO HOUSING GAP REPORTS

-------------------------------------------------------------------------------

CONTACT SUMMARY FOR CONTACT ID 48: Holder To Housing_Mid

```
   Contact surface material:         Moly
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa
```

| | Average | Minimum | Maximum |
|---|---|---|---|
| ~~~~~~~~~~~ direct results ~~~~~~~~~~ | | | |
| Contact status | 1.000 | 1.000 | 1.000 |
| Contact temperature (C) | 472.526 | 445.823 | 494.074 |
| Target temperature (C) | 64.943 | 59.206 | 66.068 |
| Geometric gas gap (um) | 169.500 | 169.148 | 169.935 |
| Contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Gap conduction heat flux (kW/m^2) | 562.942 | 521.415 | 636.061 |
| Radiation heat flux (kW/m^2) | 0.635 | 0.536 | 0.724 |
| Contact conduction heat flux (kW/m^2 | 0.000 | 0.000 | 0.000 |
| Total heat flux (kW/m^2) | 563.577 | 521.952 | 636.715 |
| Thermal contact conductance (W/m^2-C | 1380.848 | 1352.599 | 1544.147 |
| ~~~~~~~~~~ derived results ~~~~~~~~~~ | | | |
| Effective gas gap (um) | 163.633 | 163.188 | 164.126 |
| Contact thermal jump distance (um) | 2.551 | 2.378 | 2.684 |
| Target thermal jump distance (um) | 1.273 | 1.222 | 1.306 |
| Effective contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Pressure index | 22.169 | 22.153 | 22.188 |

```
   Gas thermal conductivity (W/m*C)           0.231        0.226        0.235
   Solid spot conductance (W/m^2*C)           0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)           1382.486     1353.919     1405.205

   Contact status codes:
    ---------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking

--------------------------------------------------------------------------------
CONTACT SUMMARY FOR CONTACT ID 50: Holder To Housing_Mid
   Contact surface material:         Moly
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                        Average      Minimum      Maximum
                                   ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                             1.000        1.000        1.000
   Contact temperature (C)                  447.529      443.904      450.474
   Target temperature (C)                    59.800       59.491       60.165
   Geometric gas gap (um)                    59.500       59.499       59.500
   Contact pressure (MPa)                     0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)       1532.143     1512.460     1548.202
   Radiation heat flux (kW/m^2)               0.542        0.529        0.552
   Contact conduction heat flux (kW/m^2       0.000        0.000        0.000
   Total heat flux (kW/m^2)                1532.685     1512.989     1548.754
   Thermal contact conductance (W/m^2-C    3951.482     3937.351     3963.164
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                    53.634       53.542       53.731
   Contact thermal jump distance (um)         2.390        2.368        2.407
   Target thermal jump distance (um)          1.226        1.220        1.231
   Effective contact pressure (MPa)           0.000        0.000        0.000
   Pressure index                            22.187       22.185       22.189
   Gas thermal conductivity (W/m*C)           0.227        0.226        0.227
   Solid spot conductance (W/m^2*C)           0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)           3963.458     3949.466     3974.750

   Contact status codes:
    ---------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking
```

## A-6. 9.25 mm Mo Holder in TRRH3 ANSYS Summary

```
 ******************************************************************************
                            OUTPUT SUMMARY FILE
 ******************************************************************************

  -------------------------------------------------------------------------------
  INPUTS

 * Symmetry angle: 360.00 degrees
 * Housing fill gas:   100HE_0A
 * Holder material: Molybdenum
 * Specimen material: SS304
 * Shim material: SS304
 * Radiative heat transfer included
 * 3D  problem geometry
 * Target temperature:  500.0 °C
 * Target dose (in SiC):  20.000 dpa
 * Irradiation facility: TRRH
 * Axial position: 3
 * Axial peaking factor above the core midplane: 30.390 cm
 * Axial peaking factor below the core midplane: 29.700 cm
 * Housing Inner Diameter:  9.519 mm
 * Holder Outer Diameter:  9.250 mm
```

* Holder Tab Outer Diameter:  9.400 mm
* Design basis
* Nominal geometry

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BOUNDARY CONDITIONS

Heat generation rate scaling factor = 1.0000
Heat transfer coefficient =  47100. W/m²·°C
Bulk coolant temperature  =    52.0 °C

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HEAT GENERATION

| Part | Material | Heat Gen. @Midplane (W/kg) | Heat Load @Midplane (W) | Heat Load @Location (W) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 31300. | 19.4 | 19.1 |
| 2) Holder | Moly | 42000. | 611.4 | 575.0 |
| 3) TM_1A | SiC(Irr) | 31700. | 1.8 | 1.7 |
| 4) TM_1B | SiC(Irr) | 31700. | 1.8 | 1.7 |
| 5) TM_2B | SiC(Irr) | 31700. | 1.8 | 1.7 |
| 6) TM_2A | SiC(Irr) | 31700. | 1.8 | 1.7 |
| 7) Shim_A | SS304 | 38100. | 9.2 | 8.6 |
| 8) Shim_B | SS304 | 38100. | 9.2 | 8.6 |
| 9) Spring_Retainer_2 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 10) Spring_Retainer_1 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 11) Spring_TM_1A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 12) Spring_TM_1B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 13) Spring_TM_2A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 14) Spring_TM_2B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 15) Disk_3 | Moly | 42000. | 1.7 | 1.5 |
| 16) Disk_4 | Moly | 42000. | 1.7 | 1.5 |
| 17) Disk_2 | Moly | 42000. | 1.7 | 1.6 |
| 18) Disk_1 | Moly | 42000. | 1.7 | 1.6 |
| 19) Wire_2A | Moly | 42000. | 0.8 | 0.7 |
| 20) Wire_1A | Moly | 42000. | 0.8 | 0.8 |
| 21) Wire_1B | Moly | 42000. | 0.8 | 0.8 |
| 22) Wire_2B | Moly | 42000. | 0.8 | 0.7 |
| 23) Housing_High | AL-6061 | 31300. | 5.1 | 5.0 |
| 24) Housing_Low | AL-6061 | 31300. | 15.4 | 13.6 |
| 25) Housing_Mid | AL-6061 | 31300. | 113.8 | 107.1 |
| 26) Specimen_3A_Low | SS304 | 38100. | 30.0 | 27.2 |
| 27) Specimen_3A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 28) Specimen_3A_High | SS304 | 38100. | 30.0 | 27.6 |
| 29) Specimen_2A_Low | SS304 | 38100. | 30.0 | 28.0 |
| 30) Specimen_2A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 31) Specimen_2A_High | SS304 | 38100. | 30.0 | 28.4 |
| 32) Specimen_1A_Low | SS304 | 38100. | 30.0 | 28.7 |
| 33) Specimen_1A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 34) Specimen_1A_High | SS304 | 38100. | 30.0 | 29.0 |
| 35) Specimen_3B_Low | SS304 | 38100. | 30.0 | 27.2 |
| 36) Specimen_3B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 37) Specimen_3B_High | SS304 | 38100. | 30.0 | 27.6 |
| 38) Specimen_2B_Low | SS304 | 38100. | 30.0 | 28.0 |
| 39) Specimen_2B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 40) Specimen_2B_High | SS304 | 38100. | 30.0 | 28.4 |
| 41) Specimen_1B_Low | SS304 | 38100. | 30.0 | 28.7 |
| 42) Specimen_1B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 43) Specimen_1B_High | SS304 | 38100. | 30.0 | 29.0 |
| | | | 1168.0 | 1098.4 |

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CAPSULE TEMPERATURE SUMMARY

| Name | Material | Tavg | Tmin | Tmax | T.025 | T.975 |
|---|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 71. | 68. | 73. | 68. | 73. |
| 2) Holder | Moly | 457. | 425. | 481. | 434. | 476. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3) TM_1A | SiC(Irr) | 534. | 499. | 546. | 512. | 544. |
| 4) TM_1B | SiC(Irr) | 534. | 499. | 546. | 512. | 544. |
| 5) TM_2B | SiC(Irr) | 534. | 499. | 546. | 512. | 544. |
| 6) TM_2A | SiC(Irr) | 534. | 499. | 546. | 512. | 544. |
| 7) Shim_A | SS304 | 557. | 513. | 569. | 530. | 568. |
| 8) Shim_B | SS304 | 557. | 513. | 569. | 530. | 568. |
| 9) Spring_Retainer_2 | SiC(Irr) | 564. | 522. | 574. | 536. | 574. |
| 10) Spring_Retainer_1 | SiC(Irr) | 564. | 511. | 574. | 535. | 574. |
| 11) Spring_TM_1A | SiC(Irr) | 501. | 446. | 534. | 453. | 532. |
| 12) Spring_TM_1B | SiC(Irr) | 501. | 446. | 534. | 453. | 532. |
| 13) Spring_TM_2A | SiC(Irr) | 501. | 446. | 535. | 453. | 533. |
| 14) Spring_TM_2B | SiC(Irr) | 501. | 446. | 535. | 453. | 533. |
| 15) Disk_3 | Moly | 500. | 478. | 514. | 482. | 512. |
| 16) Disk_4 | Moly | 500. | 485. | 510. | 488. | 509. |
| 17) Disk_2 | Moly | 470. | 459. | 476. | 461. | 475. |
| 18) Disk_1 | Moly | 471. | 462. | 475. | 465. | 475. |
| 19) Wire_2A | Moly | 470. | 446. | 485. | 447. | 485. |
| 20) Wire_1A | Moly | 459. | 440. | 471. | 441. | 471. |
| 21) Wire_1B | Moly | 457. | 436. | 470. | 437. | 470. |
| 22) Wire_2B | Moly | 468. | 447. | 482. | 448. | 481. |
| 23) Housing_High | AL-6061 | 57. | 56. | 57. | 56. | 57. |
| 24) Housing_Low | AL-6061 | 60. | 58. | 62. | 58. | 62. |
| 25) Housing_Mid | AL-6061 | 64. | 54. | 69. | 55. | 68. |
| 26) Specimen_3A_Low | SS304 | 523. | 478. | 550. | 492. | 546. |
| 27) Specimen_3A_TestPlane | SS304 | 539. | 509. | 550. | 525. | 549. |
| 28) Specimen_3A_High | SS304 | 538. | 499. | 560. | 509. | 557. |
| 29) Specimen_2A_Low | SS304 | 544. | 505. | 566. | 515. | 562. |
| 30) Specimen_2A_TestPlane | SS304 | 552. | 532. | 564. | 539. | 563. |
| 31) Specimen_2A_High | SS304 | 548. | 510. | 567. | 519. | 566. |
| 32) Specimen_1A_Low | SS304 | 547. | 508. | 567. | 518. | 565. |
| 33) Specimen_1A_TestPlane | SS304 | 550. | 519. | 562. | 537. | 561. |
| 34) Specimen_1A_High | SS304 | 537. | 489. | 563. | 503. | 558. |
| 35) Specimen_3B_Low | SS304 | 523. | 478. | 550. | 492. | 545. |
| 36) Specimen_3B_TestPlane | SS304 | 538. | 509. | 551. | 525. | 549. |
| 37) Specimen_3B_High | SS304 | 538. | 499. | 560. | 509. | 556. |
| 38) Specimen_2B_Low | SS304 | 544. | 505. | 566. | 515. | 562. |
| 39) Specimen_2B_TestPlane | SS304 | 552. | 532. | 563. | 539. | 563. |
| 40) Specimen_2B_High | SS304 | 547. | 510. | 567. | 518. | 565. |
| 41) Specimen_1B_Low | SS304 | 547. | 508. | 567. | 518. | 565. |
| 42) Specimen_1B_TestPlane | SS304 | 550. | 520. | 562. | 537. | 561. |
| 43) Specimen_1B_High | SS304 | 537. | 489. | 563. | 503. | 559. |

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PROPERTY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Thermal Cond. (W/m*C) | Thermal Exp. Coeff. (um/m*C) | Emis (---) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 167.970 | 24.21 | 0.050 |
| 2) Holder | Moly | 120.798 | 5.16 | 0.073 |
| 3) TM_1A | SiC(Irr) | 9.895 | 3.83 | 0.900 |
| 4) TM_1B | SiC(Irr) | 9.895 | 3.83 | 0.900 |
| 5) TM_2B | SiC(Irr) | 9.901 | 3.83 | 0.900 |
| 6) TM_2A | SiC(Irr) | 9.902 | 3.83 | 0.900 |
| 7) Shim_A | SS304 | 22.921 | 19.28 | 0.143 |
| 8) Shim_B | SS304 | 22.920 | 19.28 | 0.143 |
| 9) Spring_Retainer_2 | SiC(Irr) | 10.552 | 3.88 | 0.900 |
| 10) Spring_Retainer_1 | SiC(Irr) | 10.549 | 3.88 | 0.900 |
| 11) Spring_TM_1A | SiC(Irr) | 9.162 | 3.77 | 0.900 |
| 12) Spring_TM_1B | SiC(Irr) | 9.163 | 3.77 | 0.900 |
| 13) Spring_TM_2A | SiC(Irr) | 9.169 | 3.77 | 0.900 |
| 14) Spring_TM_2B | SiC(Irr) | 9.167 | 3.77 | 0.900 |
| 15) Disk_3 | Moly | 119.061 | 5.20 | 0.077 |
| 16) Disk_4 | Moly | 119.097 | 5.20 | 0.077 |
| 17) Disk_2 | Moly | 120.299 | 5.17 | 0.074 |
| 18) Disk_1 | Moly | 120.259 | 5.18 | 0.074 |
| 19) Wire_2A | Moly | 120.278 | 5.17 | 0.074 |
| 20) Wire_1A | Moly | 120.716 | 5.16 | 0.073 |
| 21) Wire_1B | Moly | 120.803 | 5.16 | 0.073 |

| | | | | | |
|---|---|---|---|---|---|
| 22) | Wire_2B | Moly | 120.341 | 5.17 | 0.074 |
| 23) | Housing_High | AL-6061 | 166.262 | 24.21 | 0.050 |
| 24) | Housing_Low | AL-6061 | 166.702 | 24.21 | 0.050 |
| 25) | Housing_Mid | AL-6061 | 167.188 | 24.21 | 0.050 |
| 26) | Specimen_3A_Low | SS304 | 22.448 | 19.36 | 0.143 |
| 27) | Specimen_3A_TestPlane | SS304 | 22.662 | 19.32 | 0.143 |
| 28) | Specimen_3A_High | SS304 | 22.657 | 19.32 | 0.143 |
| 29) | Specimen_2A_Low | SS304 | 22.739 | 19.31 | 0.143 |
| 30) | Specimen_2A_TestPlane | SS304 | 22.854 | 19.29 | 0.143 |
| 31) | Specimen_2A_High | SS304 | 22.789 | 19.30 | 0.143 |
| 32) | Specimen_1A_Low | SS304 | 22.782 | 19.30 | 0.143 |
| 33) | Specimen_1A_TestPlane | SS304 | 22.824 | 19.30 | 0.143 |
| 34) | Specimen_1A_High | SS304 | 22.642 | 19.33 | 0.143 |
| 35) | Specimen_3B_Low | SS304 | 22.448 | 19.36 | 0.143 |
| 36) | Specimen_3B_TestPlane | SS304 | 22.661 | 19.32 | 0.143 |
| 37) | Specimen_3B_High | SS304 | 22.655 | 19.32 | 0.143 |
| 38) | Specimen_2B_Low | SS304 | 22.737 | 19.31 | 0.143 |
| 39) | Specimen_2B_TestPlane | SS304 | 22.852 | 19.29 | 0.143 |
| 40) | Specimen_2B_High | SS304 | 22.787 | 19.30 | 0.143 |
| 41) | Specimen_1B_Low | SS304 | 22.783 | 19.30 | 0.143 |
| 42) | Specimen_1B_TestPlane | SS304 | 22.826 | 19.30 | 0.143 |
| 43) | Specimen_1B_High | SS304 | 22.643 | 19.33 | 0.143 |

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STORED ENERGY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Mass (g) | Tavg (C) | Specific Heat (J/kg-C) | Stored Energy (J) |
|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 0.621 | 71. | 893. | 28. |
| 2) Holder | Moly | 14.557 | 457. | 273. | 1738. |
| 3) TM_1A | SiC(Irr) | 0.058 | 534. | 1129. | 34. |
| 4) TM_1B | SiC(Irr) | 0.058 | 534. | 1129. | 34. |
| 5) TM_2B | SiC(Irr) | 0.058 | 534. | 1129. | 34. |
| 6) TM_2A | SiC(Irr) | 0.058 | 534. | 1129. | 34. |
| 7) Shim_A | SS304 | 0.241 | 557. | 414. | 54. |
| 8) Shim_B | SS304 | 0.241 | 557. | 414. | 54. |
| 9) Spring_Retainer_2 | SiC(Irr) | 0.024 | 564. | 1140. | 15. |
| 10) Spring_Retainer_1 | SiC(Irr) | 0.024 | 564. | 1139. | 15. |
| 11) Spring_TM_1A | SiC(Irr) | 0.024 | 501. | 1117. | 13. |
| 12) Spring_TM_1B | SiC(Irr) | 0.024 | 501. | 1117. | 13. |
| 13) Spring_TM_2A | SiC(Irr) | 0.024 | 501. | 1117. | 13. |
| 14) Spring_TM_2B | SiC(Irr) | 0.024 | 501. | 1117. | 13. |
| 15) Disk_3 | Moly | 0.040 | 500. | 275. | 5. |
| 16) Disk_4 | Moly | 0.040 | 500. | 275. | 5. |
| 17) Disk_2 | Moly | 0.040 | 470. | 274. | 5. |
| 18) Disk_1 | Moly | 0.040 | 471. | 274. | 5. |
| 19) Wire_2A | Moly | 0.019 | 470. | 274. | 2. |
| 20) Wire_1A | Moly | 0.019 | 459. | 273. | 2. |
| 21) Wire_1B | Moly | 0.019 | 457. | 273. | 2. |
| 22) Wire_2B | Moly | 0.019 | 468. | 274. | 2. |
| 23) Housing_High | AL-6061 | 0.164 | 57. | 882. | 5. |
| 24) Housing_Low | AL-6061 | 0.491 | 60. | 885. | 18. |
| 25) Housing_Mid | AL-6061 | 3.637 | 64. | 888. | 143. |
| 26) Specimen_3A_Low | SS304 | 0.786 | 523. | 408. | 162. |
| 27) Specimen_3A_TestPlane | SS304 | 0.014 | 539. | 410. | 3. |
| 28) Specimen_3A_High | SS304 | 0.786 | 538. | 410. | 167. |
| 29) Specimen_2A_Low | SS304 | 0.786 | 544. | 411. | 170. |
| 30) Specimen_2A_TestPlane | SS304 | 0.014 | 552. | 413. | 3. |
| 31) Specimen_2A_High | SS304 | 0.786 | 548. | 412. | 171. |
| 32) Specimen_1A_Low | SS304 | 0.786 | 547. | 412. | 171. |
| 33) Specimen_1A_TestPlane | SS304 | 0.014 | 550. | 413. | 3. |
| 34) Specimen_1A_High | SS304 | 0.786 | 537. | 410. | 167. |
| 35) Specimen_3B_Low | SS304 | 0.786 | 523. | 408. | 162. |
| 36) Specimen_3B_TestPlane | SS304 | 0.014 | 538. | 410. | 3. |
| 37) Specimen_3B_High | SS304 | 0.786 | 538. | 410. | 167. |
| 38) Specimen_2B_Low | SS304 | 0.786 | 544. | 411. | 169. |
| 39) Specimen_2B_TestPlane | SS304 | 0.014 | 552. | 413. | 3. |
| 40) Specimen_2B_High | SS304 | 0.786 | 547. | 412. | 171. |
| 41) Specimen_1B_Low | SS304 | 0.786 | 547. | 412. | 171. |

```
 42) Specimen_1B_TestPlane          SS304       0.014     550.     413.       3.
 43) Specimen_1B_High               SS304       0.786     537.     410.     167.
                                             --------                   --------
                                               30.083                      4317.

 -------------------------------------------------------------------------------
 HOLDER TO HOUSING GAP REPORTS


-------------------------------------------------------------------------------
CONTACT SUMMARY FOR CONTACT ID 48: Holder To Housing_Mid
   Contact surface material:         Moly
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                            Average      Minimum      Maximum
                                       ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                             1.000        1.000        1.000
   Contact temperature (C)                  454.350      425.869      474.298
   Target temperature (C)                    67.392       60.663       68.638
   Geometric gas gap (um)                   134.499      134.046      134.505
   Contact pressure (MPa)                     0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)        665.609      611.805      708.818
   Radiation heat flux (kW/m^2)               0.565        0.468        0.640
   Contact conduction heat flux (kW/m^2       0.000        0.000        0.000
   Total heat flux (kW/m^2)                 666.174      612.275      709.455
   Thermal contact conductance (W/m^2-C    1719.725     1682.185     1749.919
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                   129.365      128.930      129.756
   Contact thermal jump distance (um)         2.451        2.270        2.572
   Target thermal jump distance (um)          1.252        1.197        1.283
   Effective contact pressure (MPa)           0.000        0.000        0.000
   Pressure index                            22.182       22.168       22.202
   Gas thermal conductivity (W/m*C)           0.229        0.224        0.232
   Solid spot conductance (W/m^2*C)           0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)           1721.975     1684.693     1749.194

   Contact status codes:
    ---------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking

-------------------------------------------------------------------------------
CONTACT SUMMARY FOR CONTACT ID 50: Holder To Housing_Mid
   Contact surface material:         Moly
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                            Average      Minimum      Maximum
                                       ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                             1.000        1.000        1.000
   Contact temperature (C)                  428.691      424.957      431.994
   Target temperature (C)                    61.016       60.570       61.559
   Geometric gas gap (um)                    59.500       59.499       59.500
   Contact pressure (MPa)                     0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)       1423.579     1402.837     1442.769
   Radiation heat flux (kW/m^2)               0.478        0.466        0.488
   Contact conduction heat flux (kW/m^2       0.000        0.000        0.000
   Total heat flux (kW/m^2)                1424.056     1403.303     1443.256
   Thermal contact conductance (W/m^2-C    3871.717     3856.251     3886.172
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                    54.266       54.134       54.393
   Contact thermal jump distance (um)         2.286        2.264        2.306
```

```
 Target thermal jump distance (um)          1.202       1.196       1.208
 Effective contact pressure (MPa)           0.000       0.000       0.000
 Pressure index                            22.200      22.198      22.203
 Gas thermal conductivity (W/m*C)           0.224       0.224       0.225
 Solid spot conductance (W/m^2*C)           0.000       0.000       0.000
 Gas gap conductance (W/m^2*C)           3884.210    3869.041    3898.087

 Contact status codes:
  ----------------------------------------------
  0=open/no heat transfer, 1=near-field contact
  2=closed and sliding,    3=closed and sticking
```

## A-7. 9.26 mm Mo Holder in TRRH5 ANSYS Summary

```
******************************************************************************
                            OUTPUT SUMMARY FILE
******************************************************************************

 ------------------------------------------------------------------------------
 INPUTS

* Symmetry angle: 360.00 degrees
* Housing fill gas:   100HE_0A
* Holder material: Molybdenum
* Specimen material: SS304
* Shim material: SS304
* Radiative heat transfer included
* 3D  problem geometry
* Target temperature:  500.0 °C
* Target dose (in SiC):  20.000 dpa
* Irradiation facility: TRRH
* Axial position: 5
* Axial peaking factor above the core midplane: 30.390 cm
* Axial peaking factor below the core midplane: 29.700 cm
* Housing Inner Diameter:  9.519 mm
* Holder Outer Diameter:  9.260 mm
* Holder Tab Outer Diameter:  9.400 mm
* Design basis
* Nominal geometry

------------------------------------------------------------------------------
 BOUNDARY CONDITIONS

 Heat generation rate scaling factor = 1.0000
 Heat transfer coefficient =  47100. W/m²·°C
 Bulk coolant temperature  =    52.0 °C

------------------------------------------------------------------------------
 HEAT GENERATION

                                                Heat Gen.   ------ Heat Load -----
                                                @Midplane   @Midplane    @Location
 Part                                Material    (W/kg)        (W)          (W)
-----------------------------------  --------   ---------   ---------    ---------
  1) Endcap                          AL-6061       31300.        19.4         17.9
  2) Holder                          Moly          42000.       614.4        592.1
  3) TM_1A                           SiC(Irr)      31700.         1.8          1.8
  4) TM_1B                           SiC(Irr)      31700.         1.8          1.8
  5) TM_2B                           SiC(Irr)      31700.         1.8          1.8
  6) TM_2A                           SiC(Irr)      31700.         1.8          1.8
  7) Shim_A                          SS304         38100.         9.2          8.8
  8) Shim_B                          SS304         38100.         9.2          8.8
  9) Spring_Retainer_2               SiC(Irr)      31700.         0.8          0.7
 10) Spring_Retainer_1               SiC(Irr)      31700.         0.8          0.7
 11) Spring_TM_1A                    SiC(Irr)      31700.         0.8          0.7
 12) Spring_TM_1B                    SiC(Irr)      31700.         0.8          0.7
 13) Spring_TM_2A                    SiC(Irr)      31700.         0.8          0.7
 14) Spring_TM_2B                    SiC(Irr)      31700.         0.8          0.7
 15) Disk_3                          Moly          42000.         1.7          1.7
 16) Disk_4                          Moly          42000.         1.7          1.7
 17) Disk_2                          Moly          42000.         1.7          1.6
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| | | | | |
|---|---|---|---|---|
| 18) Disk_1 | Moly | 42000. | 1.7 | 1.6 |
| 19) Wire_2A | Moly | 42000. | 0.8 | 0.8 |
| 20) Wire_1A | Moly | 42000. | 0.8 | 0.7 |
| 21) Wire_1B | Moly | 42000. | 0.8 | 0.7 |
| 22) Wire_2B | Moly | 42000. | 0.8 | 0.8 |
| 23) Housing_High | AL-6061 | 31300. | 5.1 | 4.7 |
| 24) Housing_Low | AL-6061 | 31300. | 15.4 | 15.2 |
| 25) Housing_Mid | AL-6061 | 31300. | 113.8 | 109.6 |
| 26) Specimen_3A_Low | SS304 | 38100. | 30.0 | 29.5 |
| 27) Specimen_3A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 28) Specimen_3A_High | SS304 | 38100. | 30.0 | 29.3 |
| 29) Specimen_2A_Low | SS304 | 38100. | 30.0 | 29.1 |
| 30) Specimen_2A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 31) Specimen_2A_High | SS304 | 38100. | 30.0 | 28.8 |
| 32) Specimen_1A_Low | SS304 | 38100. | 30.0 | 28.5 |
| 33) Specimen_1A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 34) Specimen_1A_High | SS304 | 38100. | 30.0 | 28.2 |
| 35) Specimen_3B_Low | SS304 | 38100. | 30.0 | 29.5 |
| 36) Specimen_3B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 37) Specimen_3B_High | SS304 | 38100. | 30.0 | 29.3 |
| 38) Specimen_2B_Low | SS304 | 38100. | 30.0 | 29.1 |
| 39) Specimen_2B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 40) Specimen_2B_High | SS304 | 38100. | 30.0 | 28.8 |
| 41) Specimen_1B_Low | SS304 | 38100. | 30.0 | 28.5 |
| 42) Specimen_1B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 43) Specimen_1B_High | SS304 | 38100. | 30.0 | 28.2 |
| | | | 1171.1 | 1128.1 |

CAPSULE TEMPERATURE SUMMARY

| Name | Material | Tavg | Tmin | Tmax | T.025 | T.975 |
|---|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 70. | 67. | 72. | 67. | 72. |
| 2) Holder | Moly | 454. | 409. | 480. | 418. | 475. |
| 3) TM_1A | SiC(Irr) | 533. | 508. | 547. | 515. | 544. |
| 4) TM_1B | SiC(Irr) | 533. | 508. | 547. | 515. | 544. |
| 5) TM_2B | SiC(Irr) | 534. | 509. | 547. | 515. | 544. |
| 6) TM_2A | SiC(Irr) | 534. | 508. | 547. | 515. | 544. |
| 7) Shim_A | SS304 | 557. | 527. | 570. | 534. | 570. |
| 8) Shim_B | SS304 | 557. | 527. | 570. | 534. | 570. |
| 9) Spring_Retainer_2 | SiC(Irr) | 565. | 539. | 575. | 544. | 575. |
| 10) Spring_Retainer_1 | SiC(Irr) | 565. | 527. | 575. | 544. | 575. |
| 11) Spring_TM_1A | SiC(Irr) | 501. | 434. | 534. | 443. | 533. |
| 12) Spring_TM_1B | SiC(Irr) | 501. | 434. | 535. | 443. | 532. |
| 13) Spring_TM_2A | SiC(Irr) | 501. | 434. | 535. | 443. | 533. |
| 14) Spring_TM_2B | SiC(Irr) | 501. | 434. | 535. | 443. | 533. |
| 15) Disk_3 | Moly | 516. | 492. | 530. | 496. | 528. |
| 16) Disk_4 | Moly | 515. | 499. | 526. | 503. | 525. |
| 17) Disk_2 | Moly | 452. | 443. | 458. | 444. | 458. |
| 18) Disk_1 | Moly | 453. | 445. | 458. | 447. | 457. |
| 19) Wire_2A | Moly | 483. | 457. | 499. | 458. | 499. |
| 20) Wire_1A | Moly | 442. | 424. | 454. | 424. | 454. |
| 21) Wire_1B | Moly | 440. | 420. | 452. | 421. | 452. |
| 22) Wire_2B | Moly | 482. | 458. | 496. | 459. | 496. |
| 23) Housing_High | AL-6061 | 56. | 56. | 57. | 56. | 57. |
| 24) Housing_Low | AL-6061 | 61. | 58. | 63. | 59. | 63. |
| 25) Housing_Mid | AL-6061 | 65. | 54. | 69. | 54. | 68. |
| 26) Specimen_3A_Low | SS304 | 538. | 492. | 566. | 506. | 561. |
| 27) Specimen_3A_TestPlane | SS304 | 552. | 521. | 564. | 538. | 563. |
| 28) Specimen_3A_High | SS304 | 548. | 509. | 568. | 518. | 567. |
| 29) Specimen_2A_Low | SS304 | 548. | 509. | 568. | 518. | 566. |
| 30) Specimen_2A_TestPlane | SS304 | 552. | 532. | 564. | 538. | 563. |
| 31) Specimen_2A_High | SS304 | 543. | 502. | 566. | 514. | 563. |
| 32) Specimen_1A_Low | SS304 | 536. | 496. | 559. | 507. | 556. |
| 33) Specimen_1A_TestPlane | SS304 | 536. | 505. | 548. | 523. | 547. |
| 34) Specimen_1A_High | SS304 | 521. | 472. | 548. | 486. | 543. |
| 35) Specimen_3B_Low | SS304 | 538. | 492. | 565. | 506. | 561. |
| 36) Specimen_3B_TestPlane | SS304 | 552. | 521. | 564. | 538. | 563. |
| 37) Specimen_3B_High | SS304 | 548. | 509. | 568. | 518. | 567. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 38) | Specimen_2B_Low | SS304 | 548. | 509. | 568. | 518. | 566. |
| 39) | Specimen_2B_TestPlane | SS304 | 552. | 522. | 564. | 538. | 563. |
| 40) | Specimen_2B_High | SS304 | 543. | 502. | 566. | 513. | 562. |
| 41) | Specimen_1B_Low | SS304 | 537. | 496. | 559. | 507. | 556. |
| 42) | Specimen_1B_TestPlane | SS304 | 536. | 507. | 548. | 523. | 547. |
| 43) | Specimen_1B_High | SS304 | 521. | 472. | 548. | 487. | 543. |

PROPERTY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | | Material | Thermal Cond. (W/m*C) | Thermal Exp. Coeff. (um/m*C) | Emis (---) |
|---|---|---|---|---|---|
| 1) | Endcap | AL-6061 | 167.830 | 24.21 | 0.050 |
| 2) | Holder | Moly | 120.914 | 5.16 | 0.073 |
| 3) | TM_1A | SiC(Irr) | 9.880 | 3.83 | 0.900 |
| 4) | TM_1B | SiC(Irr) | 9.880 | 3.83 | 0.900 |
| 5) | TM_2B | SiC(Irr) | 9.886 | 3.83 | 0.900 |
| 6) | TM_2A | SiC(Irr) | 9.888 | 3.83 | 0.900 |
| 7) | Shim_A | SS304 | 22.923 | 19.28 | 0.143 |
| 8) | Shim_B | SS304 | 22.923 | 19.28 | 0.143 |
| 9) | Spring_Retainer_2 | SiC(Irr) | 10.582 | 3.89 | 0.900 |
| 10) | Spring_Retainer_1 | SiC(Irr) | 10.578 | 3.89 | 0.900 |
| 11) | Spring_TM_1A | SiC(Irr) | 9.153 | 3.77 | 0.900 |
| 12) | Spring_TM_1B | SiC(Irr) | 9.153 | 3.77 | 0.900 |
| 13) | Spring_TM_2A | SiC(Irr) | 9.160 | 3.77 | 0.900 |
| 14) | Spring_TM_2B | SiC(Irr) | 9.158 | 3.77 | 0.900 |
| 15) | Disk_3 | Moly | 118.455 | 5.22 | 0.079 |
| 16) | Disk_4 | Moly | 118.491 | 5.22 | 0.079 |
| 17) | Disk_2 | Moly | 120.994 | 5.16 | 0.072 |
| 18) | Disk_1 | Moly | 120.956 | 5.16 | 0.072 |
| 19) | Wire_2A | Moly | 119.756 | 5.19 | 0.075 |
| 20) | Wire_1A | Moly | 121.398 | 5.15 | 0.071 |
| 21) | Wire_1B | Moly | 121.484 | 5.15 | 0.071 |
| 22) | Wire_2B | Moly | 119.807 | 5.19 | 0.075 |
| 23) | Housing_High | AL-6061 | 166.227 | 24.21 | 0.050 |
| 24) | Housing_Low | AL-6061 | 166.819 | 24.21 | 0.050 |
| 25) | Housing_Mid | AL-6061 | 167.230 | 24.21 | 0.050 |
| 26) | Specimen_3A_Low | SS304 | 22.659 | 19.32 | 0.143 |
| 27) | Specimen_3A_TestPlane | SS304 | 22.854 | 19.29 | 0.143 |
| 28) | Specimen_3A_High | SS304 | 22.799 | 19.30 | 0.143 |
| 29) | Specimen_2A_Low | SS304 | 22.791 | 19.30 | 0.143 |
| 30) | Specimen_2A_TestPlane | SS304 | 22.854 | 19.29 | 0.143 |
| 31) | Specimen_2A_High | SS304 | 22.730 | 19.31 | 0.143 |
| 32) | Specimen_1A_Low | SS304 | 22.632 | 19.33 | 0.143 |
| 33) | Specimen_1A_TestPlane | SS304 | 22.628 | 19.33 | 0.143 |
| 34) | Specimen_1A_High | SS304 | 22.420 | 19.36 | 0.143 |
| 35) | Specimen_3B_Low | SS304 | 22.659 | 19.32 | 0.143 |
| 36) | Specimen_3B_TestPlane | SS304 | 22.852 | 19.29 | 0.143 |
| 37) | Specimen_3B_High | SS304 | 22.798 | 19.30 | 0.143 |
| 38) | Specimen_2B_Low | SS304 | 22.789 | 19.30 | 0.143 |
| 39) | Specimen_2B_TestPlane | SS304 | 22.851 | 19.29 | 0.143 |
| 40) | Specimen_2B_High | SS304 | 22.728 | 19.31 | 0.143 |
| 41) | Specimen_1B_Low | SS304 | 22.633 | 19.33 | 0.143 |
| 42) | Specimen_1B_TestPlane | SS304 | 22.631 | 19.33 | 0.143 |
| 43) | Specimen_1B_High | SS304 | 22.421 | 19.36 | 0.143 |

STORED ENERGY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | | Material | Mass (g) | Tavg (C) | Specific Heat (J/kg-C) | Stored Energy (J) |
|---|---|---|---|---|---|---|
| 1) | Endcap | AL-6061 | 0.621 | 70. | 892. | 28. |
| 2) | Holder | Moly | 14.629 | 454. | 273. | 1735. |
| 3) | TM_1A | SiC(Irr) | 0.058 | 533. | 1129. | 33. |
| 4) | TM_1B | SiC(Irr) | 0.058 | 533. | 1129. | 33. |
| 5) | TM_2B | SiC(Irr) | 0.058 | 534. | 1129. | 33. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 6) | TM_2A | SiC(Irr) | 0.058 | 534. | 1129. | 34. |
| 7) | Shim_A | SS304 | 0.241 | 557. | 414. | 54. |
| 8) | Shim_B | SS304 | 0.241 | 557. | 414. | 54. |
| 9) | Spring_Retainer_2 | SiC(Irr) | 0.024 | 565. | 1140. | 15. |
| 10) | Spring_Retainer_1 | SiC(Irr) | 0.024 | 565. | 1140. | 15. |
| 11) | Spring_TM_1A | SiC(Irr) | 0.024 | 501. | 1117. | 13. |
| 12) | Spring_TM_1B | SiC(Irr) | 0.024 | 501. | 1117. | 13. |
| 13) | Spring_TM_2A | SiC(Irr) | 0.024 | 501. | 1117. | 13. |
| 14) | Spring_TM_2B | SiC(Irr) | 0.024 | 501. | 1117. | 13. |
| 15) | Disk_3 | Moly | 0.040 | 516. | 276. | 5. |
| 16) | Disk_4 | Moly | 0.040 | 515. | 276. | 5. |
| 17) | Disk_2 | Moly | 0.040 | 452. | 273. | 5. |
| 18) | Disk_1 | Moly | 0.040 | 453. | 273. | 5. |
| 19) | Wire_2A | Moly | 0.019 | 483. | 274. | 2. |
| 20) | Wire_1A | Moly | 0.019 | 442. | 273. | 2. |
| 21) | Wire_1B | Moly | 0.019 | 440. | 273. | 2. |
| 22) | Wire_2B | Moly | 0.019 | 482. | 274. | 2. |
| 23) | Housing_High | AL-6061 | 0.164 | 56. | 882. | 5. |
| 24) | Housing_Low | AL-6061 | 0.491 | 61. | 886. | 18. |
| 25) | Housing_Mid | AL-6061 | 3.637 | 65. | 888. | 145. |
| 26) | Specimen_3A_Low | SS304 | 0.786 | 538. | 410. | 167. |
| 27) | Specimen_3A_TestPlane | SS304 | 0.014 | 552. | 413. | 3. |
| 28) | Specimen_3A_High | SS304 | 0.786 | 548. | 412. | 171. |
| 29) | Specimen_2A_Low | SS304 | 0.786 | 548. | 412. | 171. |
| 30) | Specimen_2A_TestPlane | SS304 | 0.014 | 552. | 413. | 3. |
| 31) | Specimen_2A_High | SS304 | 0.786 | 543. | 411. | 169. |
| 32) | Specimen_1A_Low | SS304 | 0.786 | 536. | 410. | 166. |
| 33) | Specimen_1A_TestPlane | SS304 | 0.014 | 536. | 410. | 3. |
| 34) | Specimen_1A_High | SS304 | 0.786 | 521. | 408. | 161. |
| 35) | Specimen_3B_Low | SS304 | 0.786 | 538. | 410. | 167. |
| 36) | Specimen_3B_TestPlane | SS304 | 0.014 | 552. | 413. | 3. |
| 37) | Specimen_3B_High | SS304 | 0.786 | 548. | 412. | 171. |
| 38) | Specimen_2B_Low | SS304 | 0.786 | 548. | 412. | 171. |
| 39) | Specimen_2B_TestPlane | SS304 | 0.014 | 552. | 413. | 3. |
| 40) | Specimen_2B_High | SS304 | 0.786 | 543. | 411. | 169. |
| 41) | Specimen_1B_Low | SS304 | 0.786 | 537. | 410. | 166. |
| 42) | Specimen_1B_TestPlane | SS304 | 0.014 | 536. | 410. | 3. |
| 43) | Specimen_1B_High | SS304 | 0.786 | 521. | 408. | 161. |
| | | | -------- | | | -------- |
| | | | 30.156 | | | 4313. |

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HOLDER TO HOUSING GAP REPORTS

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CONTACT SUMMARY FOR CONTACT ID 48: Holder To Housing_Mid

```
   Contact surface material:         Moly
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa
```

| | Average | Minimum | Maximum |
|---|---|---|---|
| ~~~~~~~~~~~ direct results ~~~~~~~~~~ | | | |
| Contact status | 1.000 | 1.000 | 1.000 |
| Contact temperature (C) | 451.395 | 410.138 | 472.745 |
| Target temperature (C) | 67.830 | 60.473 | 69.166 |
| Geometric gas gap (um) | 129.500 | 129.057 | 129.508 |
| Contact pressure (MPa) | 0.000 | 0.000 | 0.000 |
| Gap conduction heat flux (kW/m^2) | 683.936 | 599.855 | 794.314 |
| Radiation heat flux (kW/m^2) | 0.555 | 0.420 | 0.634 |
| Contact conduction heat flux (kW/m^2 | 0.000 | 0.000 | 0.000 |
| Total heat flux (kW/m^2) | 684.491 | 600.283 | 794.878 |
| Thermal contact conductance (W/m^2-C | 1782.437 | 1713.927 | 2058.122 |
| ~~~~~~~~~~ derived results ~~~~~~~~~~ | | | |
| Effective gas gap (um) | 124.488 | 123.695 | 125.128 |
| Contact thermal jump distance (um) | 2.436 | 2.183 | 2.565 |
| Target thermal jump distance (um) | 1.249 | 1.175 | 1.282 |

```
   Effective contact pressure (MPa)          0.000        0.000        0.000
   Pressure index                           22.184       22.169       22.214
   Gas thermal conductivity (W/m*C)          0.229        0.221        0.232
   Solid spot conductance (W/m^2*C)          0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)          1784.783     1727.532     1815.230

   Contact status codes:
    ----------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking

-------------------------------------------------------------------------------
CONTACT SUMMARY FOR CONTACT ID 50: Holder To Housing_Mid
   Contact surface material:         Moly
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                           Average      Minimum      Maximum
                                      ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                            1.000        1.000        1.000
   Contact temperature (C)                 422.498      409.390      442.086
   Target temperature (C)                   61.166       60.403       62.248
   Geometric gas gap (um)                   59.500       59.499       59.500
   Contact pressure (MPa)                    0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)      1390.955     1323.086     1493.006
   Radiation heat flux (kW/m^2)              0.460        0.418        0.522
   Contact conduction heat flux (kW/m^2      0.000        0.000        0.000
   Total heat flux (kW/m^2)               1391.415     1323.504     1493.527
   Thermal contact conductance (W/m^2-C   3847.004     3797.206     3921.969
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                   54.442       53.943       54.771
   Contact thermal jump distance (um)        2.253        2.178        2.365
   Target thermal jump distance (um)         1.194        1.174        1.223
   Effective contact pressure (MPa)          0.000        0.000        0.000
   Pressure index                           22.205       22.191       22.214
   Gas thermal conductivity (W/m*C)          0.223        0.221        0.226
   Solid spot conductance (W/m^2*C)          0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)          3859.253     3808.603     3936.338

   Contact status codes:
    ----------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking
```

## A-8. 9.21 mm Mo Holder in TRRH6 ANSYS Summary

```
 ******************************************************************************
                            OUTPUT SUMMARY FILE
 ******************************************************************************

  ------------------------------------------------------------------------------
  INPUTS

 * Symmetry angle: 360.00 degrees
 * Housing fill gas:   100HE_0A
 * Holder material: Molybdenum
 * Specimen material: SS304
 * Shim material: SS304
 * Radiative heat transfer included
 * 3D  problem geometry
 * Target temperature:  500.0 °C
 * Target dose (in SiC):  20.000 dpa
 * Irradiation facility: TRRH
 * Axial position: 6
 * Axial peaking factor above the core midplane: 30.390 cm
 * Axial peaking factor below the core midplane: 29.700 cm
 * Housing Inner Diameter:  9.519 mm
```

* Holder Outer Diameter: 9.210 mm
* Holder Tab Outer Diameter: 9.400 mm
* Design basis
* Nominal geometry

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BOUNDARY CONDITIONS

Heat generation rate scaling factor = 1.0000
Heat transfer coefficient = 47100. W/m²·°C
Bulk coolant temperature = 52.0 °C

---

HEAT GENERATION

| Part | Material | Heat Gen. @Midplane (W/kg) | Heat Load @Midplane (W) | Heat Load @Location (W) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 31300. | 19.4 | 15.1 |
| 2) Holder | Moly | 42000. | 599.2 | 509.9 |
| 3) TM_1A | SiC(Irr) | 31700. | 1.8 | 1.6 |
| 4) TM_1B | SiC(Irr) | 31700. | 1.8 | 1.6 |
| 5) TM_2B | SiC(Irr) | 31700. | 1.8 | 1.6 |
| 6) TM_2A | SiC(Irr) | 31700. | 1.8 | 1.6 |
| 7) Shim_A | SS304 | 38100. | 9.2 | 7.8 |
| 8) Shim_B | SS304 | 38100. | 9.2 | 7.8 |
| 9) Spring_Retainer_2 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 10) Spring_Retainer_1 | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 11) Spring_TM_1A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 12) Spring_TM_1B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 13) Spring_TM_2A | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 14) Spring_TM_2B | SiC(Irr) | 31700. | 0.8 | 0.7 |
| 15) Disk_3 | Moly | 42000. | 1.7 | 1.5 |
| 16) Disk_4 | Moly | 42000. | 1.7 | 1.5 |
| 17) Disk_2 | Moly | 42000. | 1.7 | 1.3 |
| 18) Disk_1 | Moly | 42000. | 1.7 | 1.3 |
| 19) Wire_2A | Moly | 42000. | 0.8 | 0.7 |
| 20) Wire_1A | Moly | 42000. | 0.8 | 0.6 |
| 21) Wire_1B | Moly | 42000. | 0.8 | 0.6 |
| 22) Wire_2B | Moly | 42000. | 0.8 | 0.7 |
| 23) Housing_High | AL-6061 | 31300. | 5.1 | 4.0 |
| 24) Housing_Low | AL-6061 | 31300. | 15.4 | 14.0 |
| 25) Housing_Mid | AL-6061 | 31300. | 113.8 | 96.7 |
| 26) Specimen_3A_Low | SS304 | 38100. | 30.0 | 26.8 |
| 27) Specimen_3A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 28) Specimen_3A_High | SS304 | 38100. | 30.0 | 26.3 |
| 29) Specimen_2A_Low | SS304 | 38100. | 30.0 | 25.8 |
| 30) Specimen_2A_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 31) Specimen_2A_High | SS304 | 38100. | 30.0 | 25.3 |
| 32) Specimen_1A_Low | SS304 | 38100. | 30.0 | 24.8 |
| 33) Specimen_1A_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 34) Specimen_1A_High | SS304 | 38100. | 30.0 | 24.3 |
| 35) Specimen_3B_Low | SS304 | 38100. | 30.0 | 26.8 |
| 36) Specimen_3B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 37) Specimen_3B_High | SS304 | 38100. | 30.0 | 26.3 |
| 38) Specimen_2B_Low | SS304 | 38100. | 30.0 | 25.8 |
| 39) Specimen_2B_TestPlane | SS304 | 38100. | 0.5 | 0.5 |
| 40) Specimen_2B_High | SS304 | 38100. | 30.0 | 25.3 |
| 41) Specimen_1B_Low | SS304 | 38100. | 30.0 | 24.8 |
| 42) Specimen_1B_TestPlane | SS304 | 38100. | 0.5 | 0.4 |
| 43) Specimen_1B_High | SS304 | 38100. | 30.0 | 24.3 |
| | | | 1155.8 | 983.3 |

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CAPSULE TEMPERATURE SUMMARY

| Name | Material | Tavg | Tmin | Tmax | T.025 | T.975 |
|---|---|---|---|---|---|---|
| 1) Endcap | AL-6061 | 67. | 65. | 69. | 65. | 69. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2) | Holder | Moly | 465. | 416. | 493. | 424. | 488. |
| 3) | TM_1A | SiC(Irr) | 535. | 503. | 554. | 509. | 551. |
| 4) | TM_1B | SiC(Irr) | 536. | 503. | 554. | 509. | 551. |
| 5) | TM_2B | SiC(Irr) | 536. | 503. | 555. | 509. | 551. |
| 6) | TM_2A | SiC(Irr) | 536. | 503. | 555. | 509. | 551. |
| 7) | Shim_A | SS304 | 557. | 520. | 575. | 526. | 574. |
| 8) | Shim_B | SS304 | 557. | 520. | 575. | 526. | 574. |
| 9) | Spring_Retainer_2 | SiC(Irr) | 564. | 532. | 580. | 535. | 579. |
| 10) | Spring_Retainer_1 | SiC(Irr) | 564. | 532. | 580. | 535. | 579. |
| 11) | Spring_TM_1A | SiC(Irr) | 507. | 439. | 539. | 448. | 537. |
| 12) | Spring_TM_1B | SiC(Irr) | 507. | 439. | 539. | 448. | 537. |
| 13) | Spring_TM_2A | SiC(Irr) | 507. | 439. | 539. | 448. | 537. |
| 14) | Spring_TM_2B | SiC(Irr) | 507. | 439. | 539. | 448. | 537. |
| 15) | Disk_3 | Moly | 528. | 507. | 541. | 510. | 540. |
| 16) | Disk_4 | Moly | 527. | 513. | 537. | 517. | 536. |
| 17) | Disk_2 | Moly | 454. | 445. | 459. | 447. | 458. |
| 18) | Disk_1 | Moly | 454. | 447. | 458. | 449. | 458. |
| 19) | Wire_2A | Moly | 499. | 476. | 514. | 476. | 514. |
| 20) | Wire_1A | Moly | 445. | 429. | 455. | 430. | 455. |
| 21) | Wire_1B | Moly | 442. | 425. | 453. | 426. | 453. |
| 22) | Wire_2B | Moly | 497. | 476. | 511. | 476. | 510. |
| 23) | Housing_High | AL-6061 | 56. | 55. | 56. | 56. | 56. |
| 24) | Housing_Low | AL-6061 | 61. | 58. | 62. | 58. | 62. |
| 25) | Housing_Mid | AL-6061 | 63. | 54. | 67. | 54. | 66. |
| 26) | Specimen_3A_Low | SS304 | 548. | 507. | 572. | 520. | 568. |
| 27) | Specimen_3A_TestPlane | SS304 | 560. | 532. | 570. | 547. | 569. |
| 28) | Specimen_3A_High | SS304 | 555. | 519. | 574. | 528. | 572. |
| 29) | Specimen_2A_Low | SS304 | 551. | 516. | 570. | 525. | 568. |
| 30) | Specimen_2A_TestPlane | SS304 | 553. | 535. | 564. | 541. | 563. |
| 31) | Specimen_2A_High | SS304 | 543. | 505. | 565. | 516. | 561. |
| 32) | Specimen_1A_Low | SS304 | 533. | 496. | 555. | 507. | 551. |
| 33) | Specimen_1A_TestPlane | SS304 | 530. | 503. | 541. | 519. | 540. |
| 34) | Specimen_1A_High | SS304 | 515. | 471. | 540. | 485. | 535. |
| 35) | Specimen_3B_Low | SS304 | 548. | 507. | 572. | 520. | 568. |
| 36) | Specimen_3B_TestPlane | SS304 | 560. | 532. | 570. | 547. | 569. |
| 37) | Specimen_3B_High | SS304 | 555. | 519. | 573. | 528. | 571. |
| 38) | Specimen_2B_Low | SS304 | 551. | 516. | 570. | 525. | 568. |
| 39) | Specimen_2B_TestPlane | SS304 | 553. | 526. | 563. | 541. | 562. |
| 40) | Specimen_2B_High | SS304 | 543. | 505. | 565. | 516. | 561. |
| 41) | Specimen_1B_Low | SS304 | 533. | 496. | 555. | 507. | 551. |
| 42) | Specimen_1B_TestPlane | SS304 | 531. | 505. | 542. | 519. | 540. |
| 43) | Specimen_1B_High | SS304 | 515. | 471. | 540. | 485. | 535. |

--------------------------------------------------------------------------------

PROPERTY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | Material | Thermal Cond. (W/m*C) | Thermal Exp. Coeff. (um/m*C) | Emis (---) |
|---|---|---|---|---|
| 1) Endcap | AL-6061 | 167.504 | 24.21 | 0.050 |
| 2) Holder | Moly | 120.468 | 5.17 | 0.074 |
| 3) TM_1A | SiC(Irr) | 9.927 | 3.83 | 0.900 |
| 4) TM_1B | SiC(Irr) | 9.927 | 3.83 | 0.900 |
| 5) TM_2B | SiC(Irr) | 9.933 | 3.83 | 0.900 |
| 6) TM_2A | SiC(Irr) | 9.934 | 3.83 | 0.900 |
| 7) Shim_A | SS304 | 22.918 | 19.28 | 0.143 |
| 8) Shim_B | SS304 | 22.917 | 19.28 | 0.143 |
| 9) Spring_Retainer_2 | SiC(Irr) | 10.567 | 3.89 | 0.900 |
| 10) Spring_Retainer_1 | SiC(Irr) | 10.564 | 3.89 | 0.900 |
| 11) Spring_TM_1A | SiC(Irr) | 9.295 | 3.78 | 0.900 |
| 12) Spring_TM_1B | SiC(Irr) | 9.295 | 3.78 | 0.900 |
| 13) Spring_TM_2A | SiC(Irr) | 9.301 | 3.78 | 0.900 |
| 14) Spring_TM_2B | SiC(Irr) | 9.300 | 3.78 | 0.900 |
| 15) Disk_3 | Moly | 117.965 | 5.23 | 0.081 |
| 16) Disk_4 | Moly | 117.988 | 5.23 | 0.081 |
| 17) Disk_2 | Moly | 120.939 | 5.16 | 0.073 |
| 18) Disk_1 | Moly | 120.908 | 5.16 | 0.073 |
| 19) Wire_2A | Moly | 119.121 | 5.20 | 0.077 |
| 20) Wire_1A | Moly | 121.285 | 5.15 | 0.072 |

| | | | | | |
|---|---|---|---|---|---|
| 21) | Wire_1B | Moly | 121.387 | 5.15 | 0.071 |
| 22) | Wire_2B | Moly | 119.184 | 5.20 | 0.077 |
| 23) | Housing_High | AL-6061 | 166.145 | 24.21 | 0.050 |
| 24) | Housing_Low | AL-6061 | 166.730 | 24.21 | 0.050 |
| 25) | Housing_Mid | AL-6061 | 167.033 | 24.21 | 0.050 |
| 26) | Specimen_3A_Low | SS304 | 22.798 | 19.30 | 0.143 |
| 27) | Specimen_3A_TestPlane | SS304 | 22.960 | 19.27 | 0.143 |
| 28) | Specimen_3A_High | SS304 | 22.892 | 19.29 | 0.143 |
| 29) | Specimen_2A_Low | SS304 | 22.840 | 19.29 | 0.143 |
| 30) | Specimen_2A_TestPlane | SS304 | 22.866 | 19.29 | 0.143 |
| 31) | Specimen_2A_High | SS304 | 22.725 | 19.31 | 0.143 |
| 32) | Specimen_1A_Low | SS304 | 22.584 | 19.34 | 0.143 |
| 33) | Specimen_1A_TestPlane | SS304 | 22.549 | 19.34 | 0.143 |
| 34) | Specimen_1A_High | SS304 | 22.348 | 19.38 | 0.143 |
| 35) | Specimen_3B_Low | SS304 | 22.798 | 19.30 | 0.143 |
| 36) | Specimen_3B_TestPlane | SS304 | 22.959 | 19.27 | 0.143 |
| 37) | Specimen_3B_High | SS304 | 22.890 | 19.29 | 0.143 |
| 38) | Specimen_2B_Low | SS304 | 22.839 | 19.29 | 0.143 |
| 39) | Specimen_2B_TestPlane | SS304 | 22.863 | 19.29 | 0.143 |
| 40) | Specimen_2B_High | SS304 | 22.724 | 19.31 | 0.143 |
| 41) | Specimen_1B_Low | SS304 | 22.585 | 19.33 | 0.143 |
| 42) | Specimen_1B_TestPlane | SS304 | 22.550 | 19.34 | 0.143 |
| 43) | Specimen_1B_High | SS304 | 22.348 | 19.38 | 0.143 |

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STORED ENERGY SUMMARY AT THE AVERAGE PART TEMPERATURE

| Name | | Material | Mass (g) | Tavg (C) | Specific Heat (J/kg-C) | Stored Energy (J) |
|---|---|---|---|---|---|---|
| 1) | Endcap | AL-6061 | 0.621 | 67. | 890. | 26. |
| 2) | Holder | Moly | 14.266 | 465. | 274. | 1738. |
| 3) | TM_1A | SiC(Irr) | 0.058 | 535. | 1129. | 34. |
| 4) | TM_1B | SiC(Irr) | 0.058 | 536. | 1129. | 34. |
| 5) | TM_2B | SiC(Irr) | 0.058 | 536. | 1129. | 34. |
| 6) | TM_2A | SiC(Irr) | 0.058 | 536. | 1129. | 34. |
| 7) | Shim_A | SS304 | 0.241 | 557. | 414. | 54. |
| 8) | Shim_B | SS304 | 0.241 | 557. | 414. | 54. |
| 9) | Spring_Retainer_2 | SiC(Irr) | 0.024 | 564. | 1140. | 15. |
| 10) | Spring_Retainer_1 | SiC(Irr) | 0.024 | 564. | 1140. | 15. |
| 11) | Spring_TM_1A | SiC(Irr) | 0.024 | 507. | 1119. | 13. |
| 12) | Spring_TM_1B | SiC(Irr) | 0.024 | 507. | 1119. | 13. |
| 13) | Spring_TM_2A | SiC(Irr) | 0.024 | 507. | 1119. | 13. |
| 14) | Spring_TM_2B | SiC(Irr) | 0.024 | 507. | 1119. | 13. |
| 15) | Disk_3 | Moly | 0.040 | 528. | 276. | 6. |
| 16) | Disk_4 | Moly | 0.040 | 527. | 276. | 6. |
| 17) | Disk_2 | Moly | 0.040 | 454. | 273. | 5. |
| 18) | Disk_1 | Moly | 0.040 | 454. | 273. | 5. |
| 19) | Wire_2A | Moly | 0.018 | 499. | 275. | 2. |
| 20) | Wire_1A | Moly | 0.018 | 445. | 273. | 2. |
| 21) | Wire_1B | Moly | 0.019 | 442. | 273. | 2. |
| 22) | Wire_2B | Moly | 0.019 | 497. | 275. | 2. |
| 23) | Housing_High | AL-6061 | 0.164 | 56. | 881. | 5. |
| 24) | Housing_Low | AL-6061 | 0.491 | 61. | 885. | 18. |
| 25) | Housing_Mid | AL-6061 | 3.637 | 63. | 887. | 139. |
| 26) | Specimen_3A_Low | SS304 | 0.786 | 548. | 412. | 171. |
| 27) | Specimen_3A_TestPlane | SS304 | 0.014 | 560. | 415. | 3. |
| 28) | Specimen_3A_High | SS304 | 0.786 | 555. | 414. | 174. |
| 29) | Specimen_2A_Low | SS304 | 0.786 | 551. | 413. | 173. |
| 30) | Specimen_2A_TestPlane | SS304 | 0.014 | 553. | 413. | 3. |
| 31) | Specimen_2A_High | SS304 | 0.786 | 543. | 411. | 169. |
| 32) | Specimen_1A_Low | SS304 | 0.786 | 533. | 409. | 165. |
| 33) | Specimen_1A_TestPlane | SS304 | 0.014 | 530. | 409. | 3. |
| 34) | Specimen_1A_High | SS304 | 0.786 | 515. | 407. | 159. |
| 35) | Specimen_3B_Low | SS304 | 0.786 | 548. | 412. | 171. |
| 36) | Specimen_3B_TestPlane | SS304 | 0.014 | 560. | 415. | 3. |
| 37) | Specimen_3B_High | SS304 | 0.786 | 555. | 414. | 174. |
| 38) | Specimen_2B_Low | SS304 | 0.786 | 551. | 413. | 173. |
| 39) | Specimen_2B_TestPlane | SS304 | 0.014 | 553. | 413. | 3. |
| 40) | Specimen_2B_High | SS304 | 0.786 | 543. | 411. | 169. |

```
  41) Specimen_1B_Low              SS304       0.786     533.     409.     165.
  42) Specimen_1B_TestPlane        SS304       0.014     531.     409.       3.
  43) Specimen_1B_High             SS304       0.786     515.     407.     159.
                                            --------                   --------
                                              29.792                      4321.

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 HOLDER TO HOUSING GAP REPORTS


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CONTACT SUMMARY FOR CONTACT ID 48: Holder To Housing_Mid
   Contact surface material:         Moly
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                              Average      Minimum      Maximum
                                         ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                               1.000        1.000        1.000
   Contact temperature (C)                    462.915      417.016      487.108
   Target temperature (C)                      65.787       59.308       67.086
   Geometric gas gap (um)                     154.499      154.044      154.505
   Contact pressure (MPa)                       0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)          598.097      517.737      644.130
   Radiation heat flux (kW/m^2)                 0.599        0.441        0.694
   Contact conduction heat flux (kW/m^2         0.000        0.000        0.000
   Total heat flux (kW/m^2)                   598.696      518.179      644.824
   Thermal contact conductance (W/m^2-C      1505.269     1451.764     1548.160
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                     148.970      148.146      149.757
   Contact thermal jump distance (um)           2.497        2.217        2.645
   Target thermal jump distance (um)            1.261        1.182        1.298
   Effective contact pressure (MPa)             0.000        0.000        0.000
   Pressure index                              22.176       22.158       22.209
   Gas thermal conductivity (W/m*C)             0.230        0.222        0.234
   Solid spot conductance (W/m^2*C)             0.000        0.000        0.000
   Gas gap conductance (W/m^2*C)             1507.184     1452.913     1535.616

   Contact status codes:
    ---------------------------------------------
    0=open/no heat transfer, 1=near-field contact
    2=closed and sliding,    3=closed and sticking

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CONTACT SUMMARY FOR CONTACT ID 50: Holder To Housing_Mid
   Contact surface material:         Moly
   Target surface material:       AL-6061
   Interstitial gas:             100HE_0A
   Effective surface roughness:     2.263 um
   Effective asperity slope:        0.214 rad
   Effective microhardness:         1.220 GPa

                                              Average      Minimum      Maximum
                                         ------------ ------------ ------------
   ~~~~~~~~~~~ direct results ~~~~~~~~~~
   Contact status                               1.000        1.000        1.000
   Contact temperature (C)                    438.198      415.878      460.501
   Target temperature (C)                      60.245       59.493       61.063
   Geometric gas gap (um)                      59.500       59.500       59.500
   Contact pressure (MPa)                       0.000        0.000        0.000
   Gap conduction heat flux (kW/m^2)         1481.031     1363.782     1598.089
   Radiation heat flux (kW/m^2)                 0.513        0.438        0.589
   Contact conduction heat flux (kW/m^2         0.000        0.000        0.000
   Total heat flux (kW/m^2)                  1481.544     1364.220     1598.678
   Thermal contact conductance (W/m^2-C      3913.837     3828.699     3997.436
   ~~~~~~~~~~ derived results ~~~~~~~~~~
   Effective gas gap (um)                      53.927       53.395       54.450
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Contact thermal jump distance (um)          2.339        2.211        2.468
Target thermal jump distance (um)           1.214        1.181        1.247
Effective contact pressure (MPa)            0.000        0.000        0.000
Pressure index                             22.193       22.178       22.209
Gas thermal conductivity (W/m*C)            0.225        0.222        0.229
Solid spot conductance (W/m^2*C)            0.000        0.000        0.000
Gas gap conductance (W/m^2*C)            3924.500     3837.217     4012.194

Contact status codes:
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 0=open/no heat transfer, 1=near-field contact
 2=closed and sliding,    3=closed and sticking
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