ENGINEERING DESIGN OF GALLIUM-NICKEL TARGET IN NIOBIUM CAPSULE, WITH A MAJOR FOCUS ON DETERMINING THE THERMAL PROPERTIES OF GALLIUM-NICKEL THROUGH THERMAL TESTING AND FEA, FOR IRRADIATION AT BLIP*

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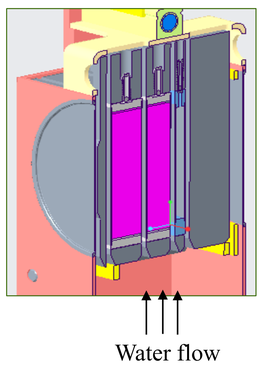
ABSTRACT

The Brookhaven Linac Isotope Producer (BLIP) produces several radioisotopes using a variable energy and current proton beam. The targets irradiated at BLIP are cooled by water and required to be isolated in a target capsule. During the design stage, thermal analysis of the target and cladding is carried out to determine the maximum beam power a target can handle during irradiation without destruction.

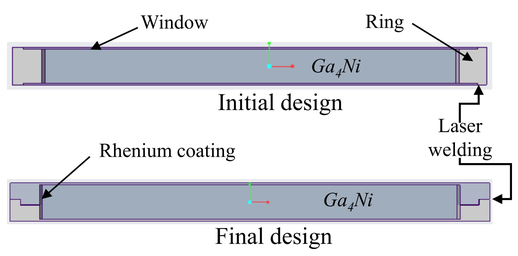
In this work we designed a capsule for Gallium-Nickel alloy target material and irradiated the target at the BLIP to produce the radioisotope *Ge-68*. Since no literature data is available on Ga_4Ni's thermal conductivity (*K*) and specific heat (*C*), measurements were carried out using thermal testing in conjunction with Finite Element Analysis (FEA). Steady-state one dimensional heat conduction method was used to determine the *K*. Transient method was used to calculate the *C*. The test setup with same methodologies can be used to assess other targets in the future. Here, we will detail these studies and discuss the improved design and fabrication of this target.

INTRODUCTION

- Radioactive isotope production by striking proton beams on different materials.
- Targets contained in a capsule are cooled by water to limit the temperature rise.
- Steady-state thermal analysis of the capsule is required to determine suitable beam power so that structural integrity of the capsule is maintained.
- To produce *Ge-68,* we designed a capsule for Ga_4Ni alloy target.
- Thermal conductivity of Ga_4Ni, a key property required for thermal analysis, is not available, so thermal testing was carried out to calculate the same.
- Using the same test and FEA, its specific heat was also estimated.



Target Holders for Irradiation



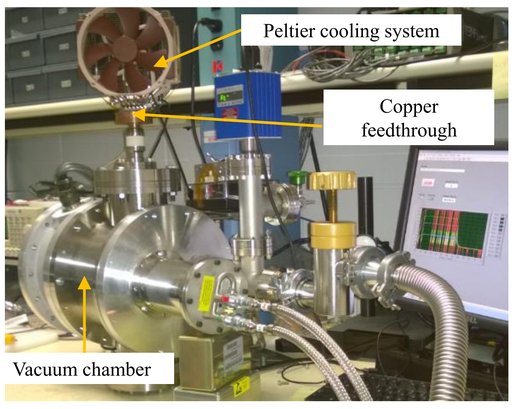
Capsule diameter and thickness = 2.750" and 0.220", window thickness = 0.012"

***Ga_4Ni* Target in Niobium Capsule**

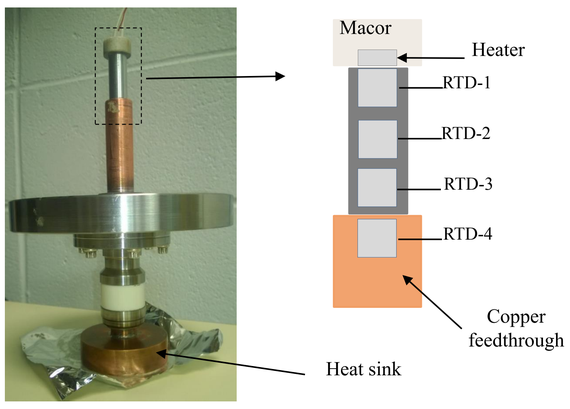
DESIGN

- Gallium (*Ga*) attacks most common metals such as Aluminium and Stainless Steel.
- Niobium which is more resistant (up to 400^0C) to *Ga* was used for making capsule.
- In the initial design, the Ga_4Ni target was enclosed by a ring and two windows.
- During test irradiation (about 33 MeV proton energy at 160 μA, i.e 5294 kW of beam power), the welding joint between the window and the ring failed.
- In the next generation design, the capsule was made of two halves where the thin window was a part of the ring rather than welded to the ring. The welding joint at the rim produces a high penetration stronger welding joint than in the initial design.
- The inner surface of capsule was Rhenium (*Re*) coated which provides good resistance to *Ga* attack up to 775^0C. Controlling *Re* coating thickness was difficult.
- The machining of such a thin niobium window in each half of the capsule was challenging as it has a tendency to gall, tear and weld to the face of the cutting tool.

EXPERIMENTAL SET UP FOR THERMAL CONDUCTIVITY AND SPECIFIC HEAT MEASUREMENTS



Experimental Test Setup



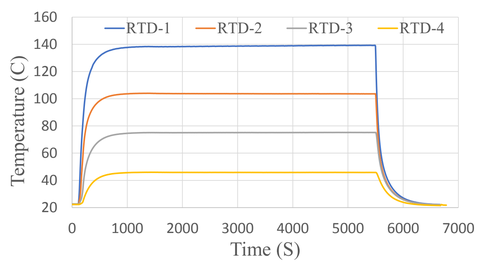
***Ga_4Ni* Test Piece Preparation for the Test**

- Test specimen size: 1/2" diameter and 1.2" long
- Heat sink temperature is always maintained at $22\ ^0$C.

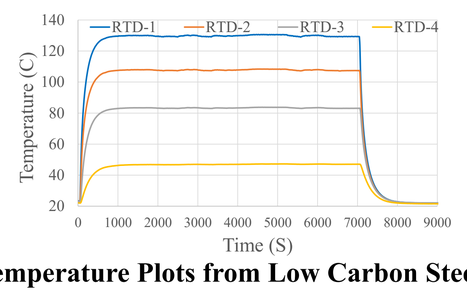
$$K = \frac{Q}{A \times \frac{\Delta T}{\Delta L}}$$

RESULTS

To estimate the radiation heat loss during the Ga_4Ni test, another identical test was carried out on low carbon steel, whose thermal conductivity is known.



Temperature Plots from *Ga_4Ni* Test



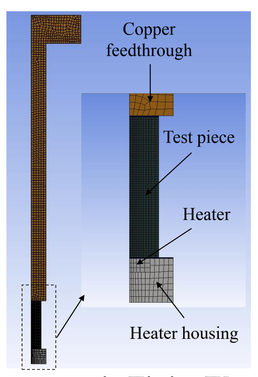
Temperature Plots from Low Carbon Steel Test

Steady state power = 18.1 watt			K of low carbon steel = 51.9 W/m-C		
RTD	RTD position from heater (m)	Temperature (C)	Heat conduction (W)	Average heat conduction (W)	Heat loss (%)
1	0.005461	129.21		15.05	**16.78**
2	0.014808	107.388	15.35		
3	0.025654	83.055	14.75		

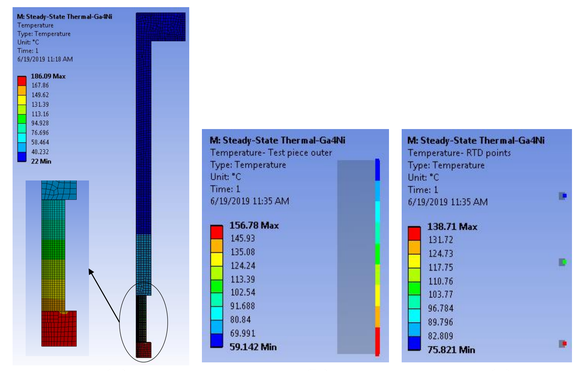
Heat Loss Calculation from Low Carbon Steel Test

Steady state power = 17.92 watt					
RTD	RTD position from heater (m)	Temperature (C)	% of heat loss from low carbon steel test	K value (W/m-C)	Average K value (W/m-C)
1	0.005486	139.24	16.78	-	**36.73**
2	0.016256	103.61		35.58	
3	0.0254	75.188		37.87	

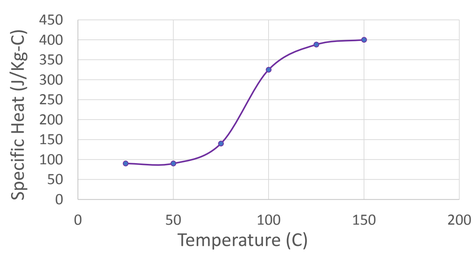
Thermal Conductivity Calculation from *Ga_4Ni* Test



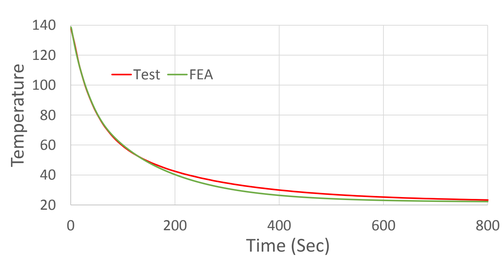
Axisymmetric Finite Element Model of the Test.



Steady State Temperature Results from FEA for *Ga_4Ni*: (a) Full Model, (b) Outer Surface, and (c) at RTD Points



Specific Heat, C of *Ga_4Ni* Obtained from the Test and FEA



Comparison of Cool Down Temperature Results Obtained from Test and FEA for RTD-1

SUMMARY

- The thermal conductivity, *K* of Ga_4Ni rod was determined to be 36.73 W/m-C.
- Specific heat values were established after several FEA runs.
- This test setup can be used to assess other targets in the future.
- The Ga_4Ni target capsule was successfully designed and fabricated.
- The *K* value obtained from this test was used to run FEA to determine the maximum beam power this target capsule can handle during irradiation without destruction.
- The target was successfully irradiated at 3147 W beam power for 11 days.

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