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EURISOL-DS Multi-MW Target Preliminary Study of the WTF(*) Liquid Metal Proton-to-Neutron Converter

Cyril Kharoua, Yacine Kadi, Karel Samec, Roberto Rocca
and the EURISOL-DS Task#2 collaboration

Abstract

This technical note summarises the design calculations performed within Task #2 of the European Isotope Separation On-Line Radioactive Ion Beam Facility Design Study (EURISOL-DS) [1] for the WTF (Windowless Transverse Film) mercury converter.

A preliminary study was carried out in order to determine the heat deposition within the mercury and estimate the mercury velocity needed in the film. The geometry used is based on previous analysis simulated using the Monte Carlo code FLUKA [2].

The results of these calculations show the baseline parameters, which will be used for the detailed design. Particularly, with a 1 GeV proton beam with a σ ~2 mm Gaussian distribution on a 4x30x40cm long target and with a 5m/s velocity at the peak power density region seems a suitable solution.

Geneva, Switzerland
July, 2008

(*)Windowless Transverse Film

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The EURISOL Project

The EURISOL DS [1] project aims at a design study of the 'next-generation' European Isotope Separation On-Line (ISOL) Radioactive Ion Beam (RIB) facility, which will extend and amplify, beyond the year 2010, the work presently being carried out at the first generation RIB facilities in Europe and other parts of the world, in the fields of Nuclear Physics, Nuclear Astrophysics and Fundamental Interactions.

The main components of the proposed facility are: a driver accelerator, a target/ion-source assembly, and a mass-selection system. The driver accelerator investigated in this study is a 1 GeV, Multi-MW, superconducting proton linear accelerator.

Introduction

In the EURISOL DS project, and especially in the task 2 dedicated to the neutron converter, the baseline design is called Coaxial Guided Stream design (CGS). It consist of a double tube in which the mercury is flowing in though the outer annulus and do a U-turn at the window to flow back in the inner part of the tube along the beam axis. For this design the beam considered is a 25mm $\sigma_{x,y}$ of 1 GeV; the peak temperature is 190°C and the global ΔT is 120°C for the 4MW of beam. The top velocity estimated at the window for a 13L/s flow rates of mercury is 6m/s. The maximum stress calculated in the window is about 135MPa with stainless steel T91.

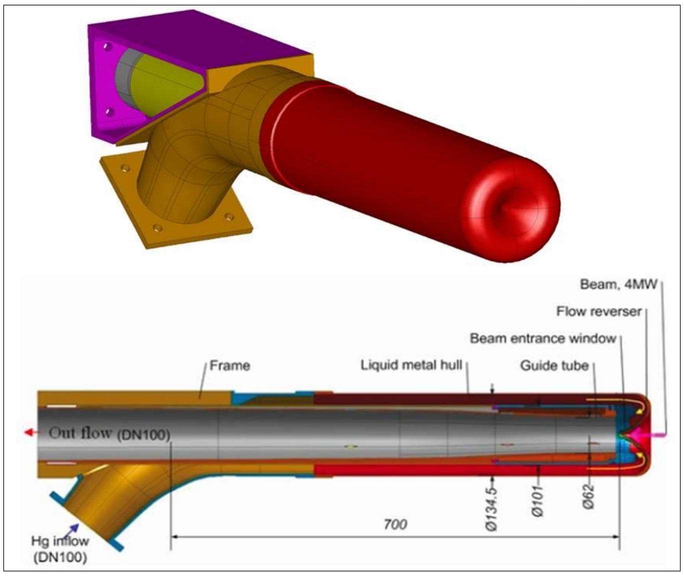


Figure 1. Description of the CGS target

It is somehow similar to the MEGAPIE target or the SNS and the JSNS target. The flow is directe towards the window where it is forced to flow backwards along the beam axis.

An alternative and innovative windowless design was also developed, to avoid the technical difficulties related to the beam window, also presenting several advantages in terms of neutronics. The transverse mercury film would fall by gravitation,

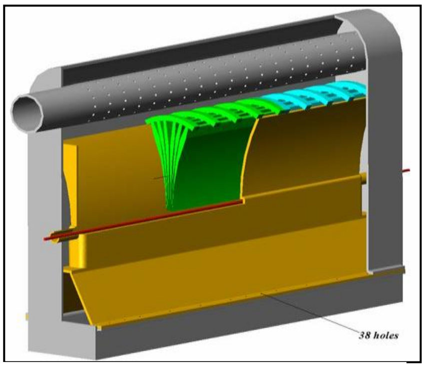


Figure 2. WTF (Windowless Transverse Film) converter

interacting with the proton beam to produce spallation neutrons and efficiently removing the beam power with reasonable flow rates. The most relevant benefit of such design is the brief exposition of the liquid metal to the proton beam, thus permitting an accurate control of the temperature increase in the liquid metal.

IPUL previous study + theoretical study!!!

Model Layout

Initially, the beam particles considered are protons with an energy of 1GeV, following a Gaussian distribution with a standard deviation of 2 mm in both x and y directions. The dimension of the target is 40 cm in length, 4 cm width and 30 cm high. Figure 3 illustrates a view of the target along the proton beam axis.

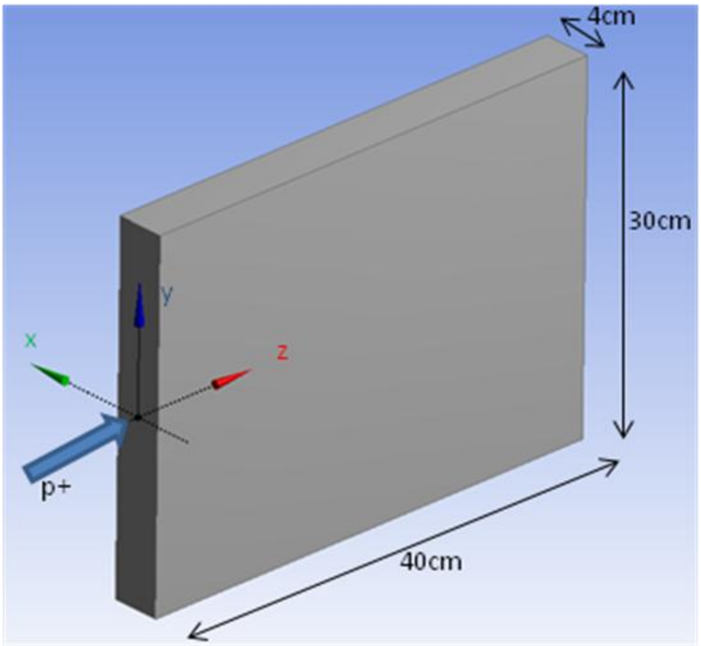


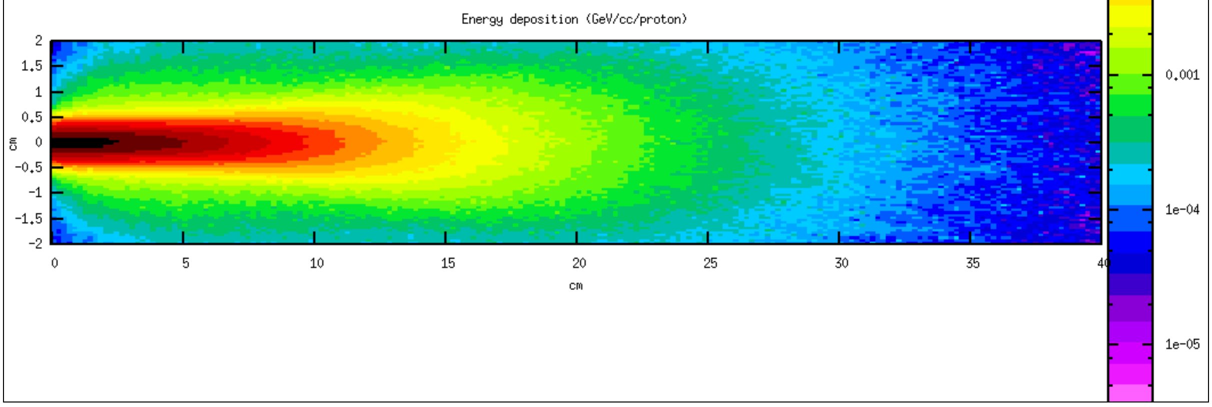
Figure 3. 3-D view of the Multi-MW EURISOL target.

Energy deposition

A critical issue for the design of a high-power spallation source is the precise definition of the energy deposition in the different elements of the target. In these preliminary calculations using a quasi pencil-like beam ($\sigma_{x,y}$~2 mm), the interest is particularly set on the estimation of the peak power densities location in order to verify the concept of the WTF converter: high power removed with reasonable rise in temperature.

For 1 GeV protons, the largest power deposition occurs in the first 10 cm after the impact point, along the beam axis, as illustrated by Figure 4 and Figure 5, with a maximum value of ~80 kW/cm^3/MW of beam power at ~0.5 cm from the impact point. Once the proton range is reached, the power densities drop sharply, to values below 500 W/cm^3/MW of beam. Large deposition gradients appear radially in the interaction region due to the narrow beam shape.

Figure 4. Power density (GeV/cm^3/primary) in a Hg target for a 1 GeV proton beam.



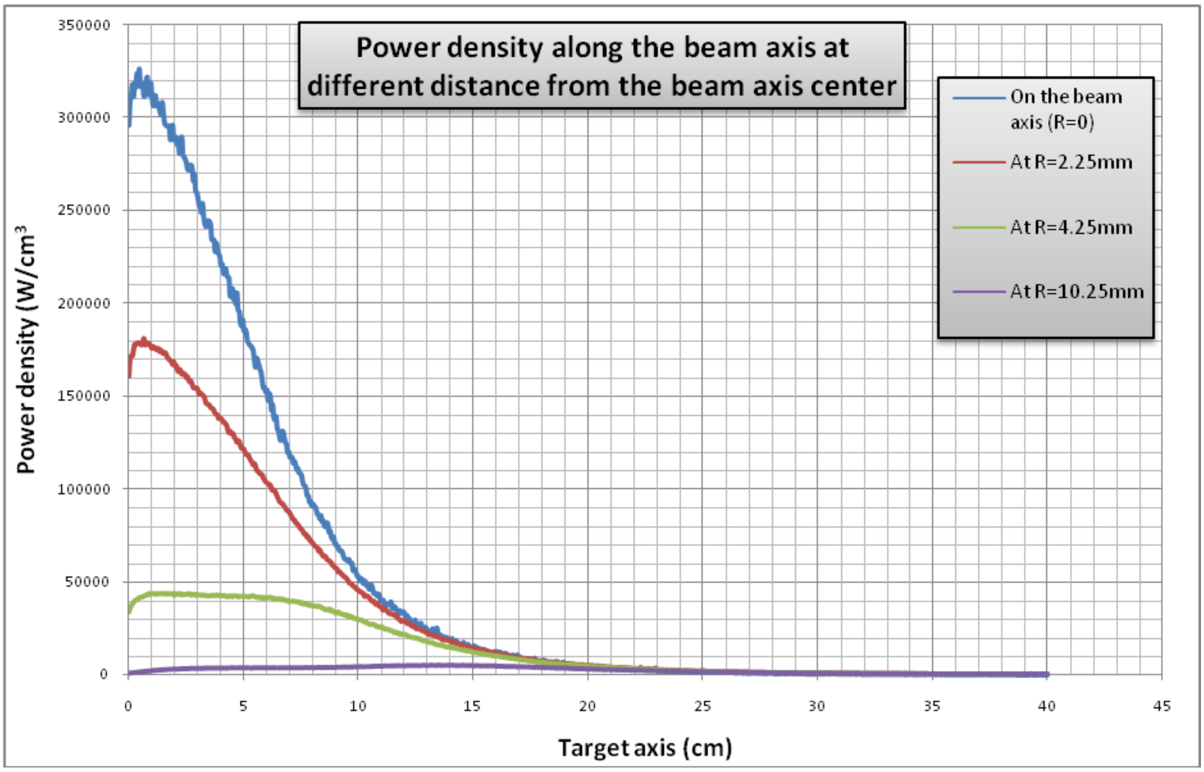


Figure 5. Power density along the beam axis at different distance from the beam axis center

The maximum energy deposition calculated in the target is 0.08 GeV/ cm^3/proton which is equivalent to 80KW/ cm^3/MMW of beam. So in the case of a 4 MMW beam, the peak power density corresponds to 320WW/cm^3.

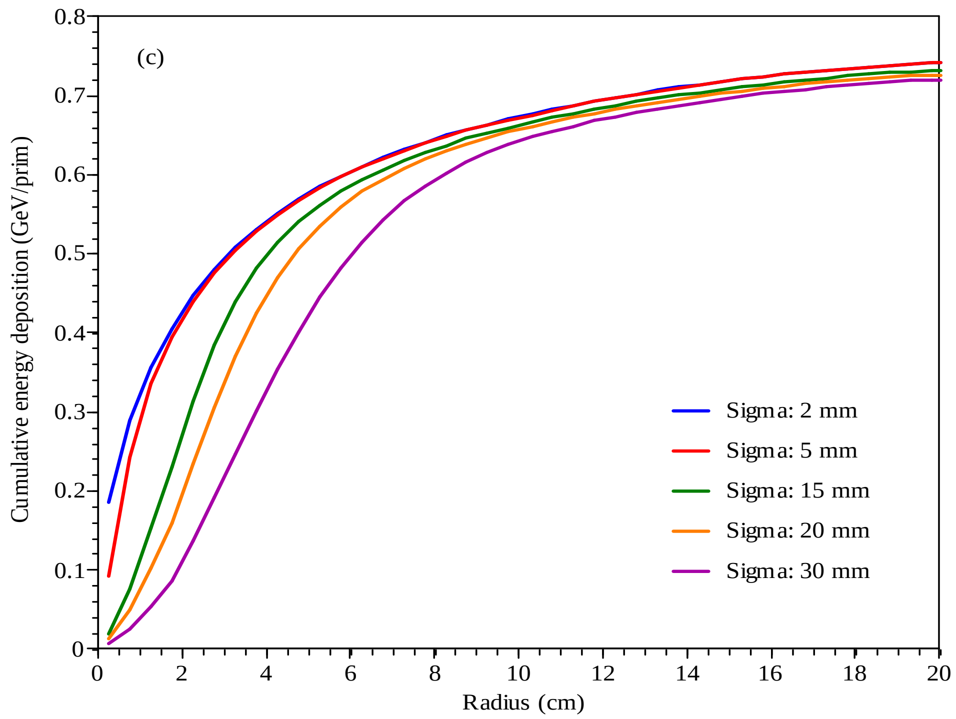


Figure 6. sum of the energy deposited along z, as a function of the radius of the target, for different σ [3]

The overall power deposited in the target is about 2.48MW for a 4 MW beam. For the simulation purpose we only considered a 4cm by 4cm by 40cm long slab. The overall power deposited in this slab is about 1.6MW. Note that this is corresponding to the 40% of power deposited given by the blue curve on the Figure 6 for a 2cm radius target with a beam of 2mm σ.

Estimation of the temperature rise in the mercury target (analytical approach)

Mercury material values	System characteristics
Cp = 140 [J/KgK]	P = 2.3 [MW] (baseline deposition)
ρ = 13'500 [J/kgK]	Q = 13 [l/s] (IPUL pump)

According to the IPUL 2008 annual report on page 7 and for the parameter listed above the bulk ΔT in the mercury is about 57.7°C. However, according to hand calculations (K. Samec), based on the same parameters, keeping such a temperature elevation necessitates 21 l/s. Or else, with the flow rate value above of 13 l/s, the temperature elevation would be 94 °C.

This is a simple calculation and it is only valid on a systems level, once all the liquid is thoroughly mixed. In actual fact, the area where the beam intersects the liquid metal flow is the hottest part and should be considered. To estimate this peak temperature by hand the following rough calculation is proposed (K.Samec [4]).

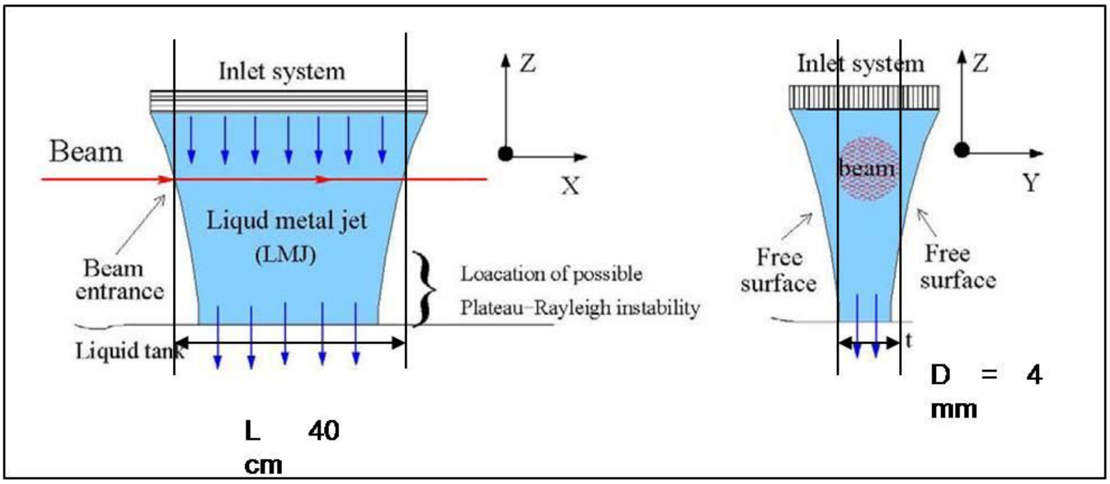


Figure 7. Layout of the mercury curtain (IPUL, [5])

The flow rate intersecting the beam and absorbing the power is approximately as:

$q = v \times D \times L$

where D and L are as in the figure above and v is the average velocity of the mercury intersecting the beam. The velocity v = 0.5 m/s according to the IPUL report page 18.

The temperature elevation in the beam centre can then be estimated according to:

$P = \rho \times q \times Cp \times \Delta T = \rho \times (v \times D \times L) \times Cp \times \Delta T$

Hence: $\Delta T = P / (\rho \times v \times D \times L \times Cp) = 2.3E6 /(13'500 \times 0.5 \times 0.004 \times 0.4 \times 140) =$ 1'521°C

Estimation of the temperature distribution in the mercury (technical approach)

The previous analysis is a very conservative calculation, therefore in order to get a more precise evaluation of the peak temperature a small CFD model has been considered using the code ANSYS CFX. It is a slab (Figure 8) representing only the fluid around the beam and on which the inlet velocity has been changed to different value in order to estimate the minimum mercury flow velocity required to minimize the peak temperature.

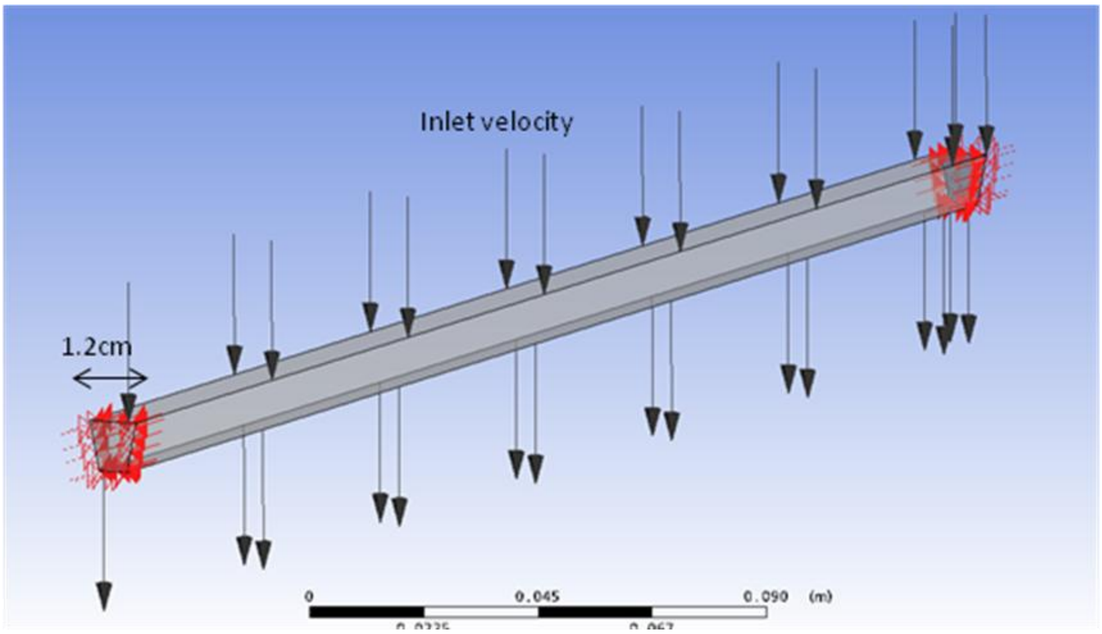


Figure 8. CFD model

The Figure 9 below represent the temperature distribution in the slab for an inlet velocity of 0.5m/s. The peak temperature estimated at 1406°C is too high for the

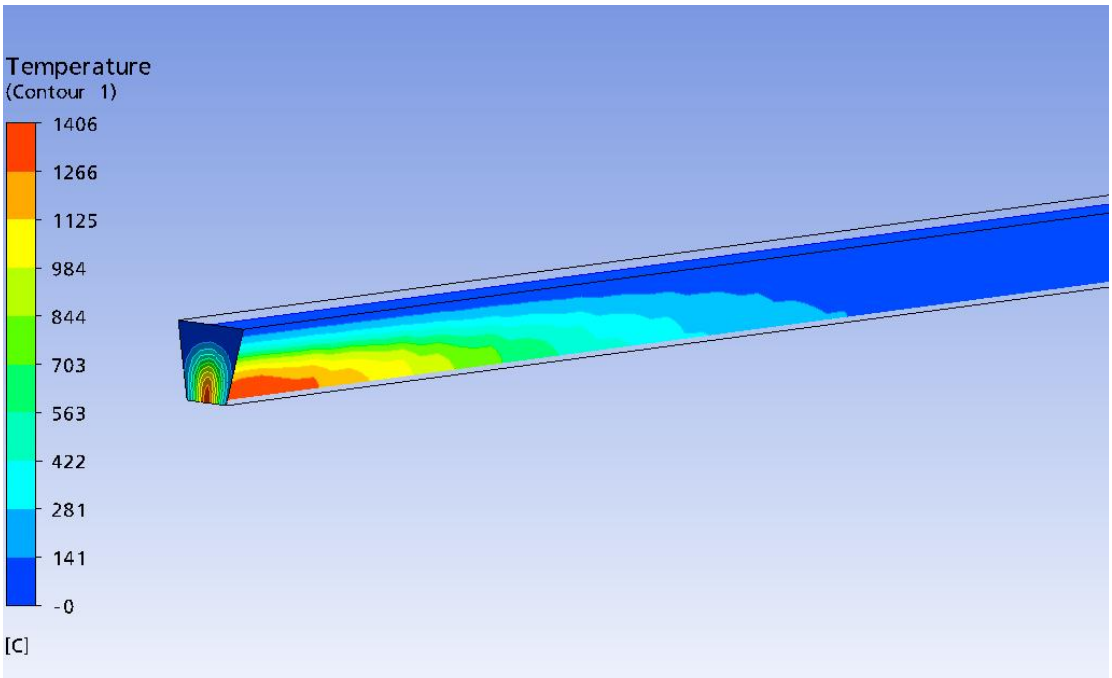


Figure 9. Temperature distribution in the Mercury flowing at 0.5m/s

Mercury which confirm the hand calculation shown above.

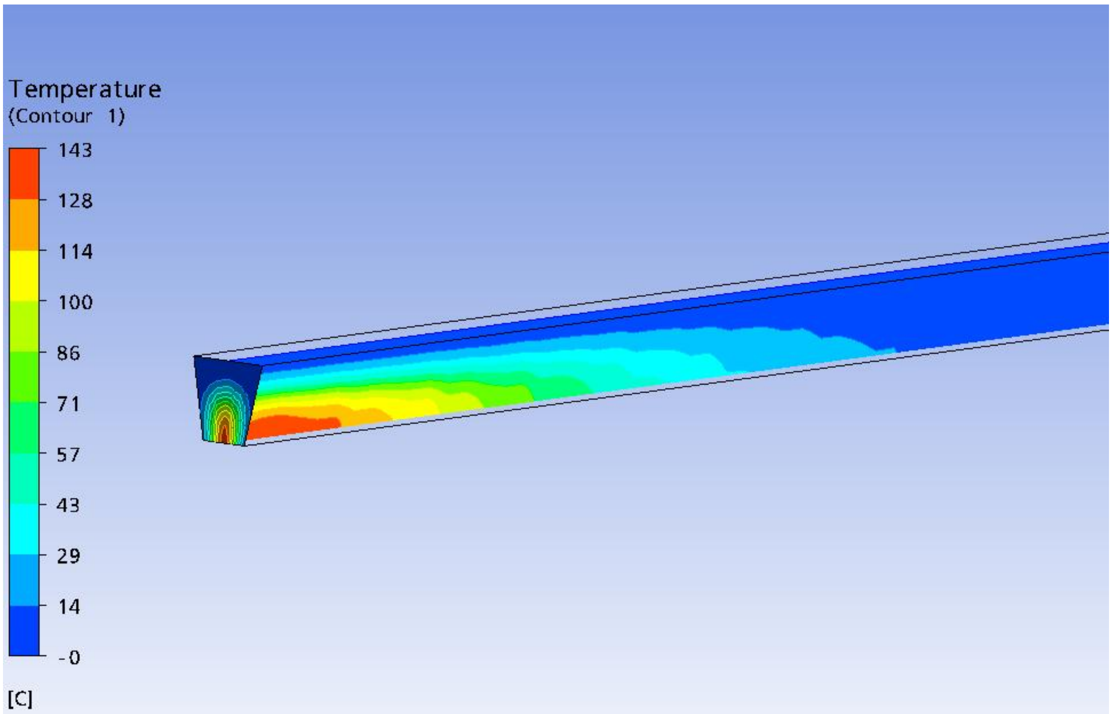


Figure 10. ature distribution in the Mercury flowing at 5m/s

The Figure 10 above illustrate the temperature distribution in the slab for an inlet velocity of 5m/s. The peak temperature is now reduced to 143°C, which is an acceptable limit for Mercury.

Conclusions

A preliminary set of calculations has been presented in this paper in order to define the basic parameters of the WTF proton-to-neutron converter for the EURISOL project.

Considering these facts, a baseline design for the WTF converter has been proposed, where a 4 cm wide, 15 cm high and 40 cm long mercury target, with a maximum flow velocity of 5m/s at the higher energy deposition region.

Acknowledgements

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