# STRIPPING FOIL TEMPERATURES IN THE EUROPEAN SPALLATION SOURCE

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## 1 INTRODUCTION

Aluminium oxide ($Al_2O_3$) and graphite have been studied as possible stripping foil materials as part of the ESS study. The ESS is a next generation neutron source and designed to use $H^-$ injection (1).This report describes the study of projected foil temperatures which has been carried out. The foil is to be rectangular, 22.1 mm wide and 13.3 mm high, supported only on two sides to reduce the number of subsequent foil transits by recirculating protons. A foil mass per unit area of 345 μg $cm^{-2}$ was chosen, corresponding to a thickness of 1.275 μm for $Al_2O_3$ and 2.247 μm for graphite. The $H^-$ beam is centred 6.4 mm from the open foil corner and has an elliptical transverse boundary with radial and vertical beam semi-axes of 2.45 and 2.10 mm respectively. Other relevant input parameters are a 1000 turn injected beam of 2.34 $10^4$ ppp at a repetition frequency of 50 Hz and with a pulse duration of 600 μs.

Injected $H^-$ ions, stripped electrons and recirculating protons scatter in the foil and large temperature rises result from atomic excitations and ionisation. The initial rate of temperature rise is inversely dependent on the foil specific heat. The temperature reaches a maximum at the end of injection and the temperature rise in the 50 Hz cycling is limited mainly by radiation, with a small additional contribution from conduction within the foil. A constant peak temperature is reached after approximately five beam pulses. Power losses due to radiation and conduction scale as the fourth and first power of the temperature difference from the surroundings, and are proportional to the foil emissivity and thermal conductivity respectively. The specific heat, emissivity and thermal conductivity are all material and temperature dependent.(2),(3).

## 2 SIMULATION

Heating and cooling of the ESS foil have been simulated in a program based on finite elements, both for time elements and transverse position co-ordinates. Radial and vertical dimensions have been scaled in the ration of 5:3 to give approximately square elements, with 50 radial elements and 30 vertical elements. The distribution of recirculating protons on the foil was based on the injection tracking studies, and the data was input to the program as the charge incident on each element per turn.This was estimated by scaling the integrated charge by the size of the recirculating beam in the ring at each time point. In reality the recirculating proton hits do not have a simple time distribution, but the use of an approximation was justified by the savings made in memory and computer time. Energy deposited in the foil is calculated using charged particle energy loss data, both for protons and stripped electrons.(4),(5). For the $H^-$ ions, one electron was assumed to strip on entry to the foil, and the other at the midpoint. High temperature estimates for specific heat have been made by scaling normalised Debye curves (6) in both dimensions to give a best fit for published data. Asymptotes used for the specific heats at high temperatures are 1289.3 and 2125 $Jkg^{-1}K^{-1}$ for $Al_2O_3$ and graphite respectively. Emissivities were kept constant at 0.4 for $Al_2O_3$ and 0.825 for graphite. Thermal conductivities were approximated by:

$4.765 + 2664470\,T^{-1.9496}$ for $Al_2O_3$.
$15 + 305958\,T^{-1.3091}$ for graphite with $T > 573$ K and
$217.9653 - 0.2233\,T$ for graphite with $T < 573$ K.

By altering independently the input parameters such as emissivity, heat capacity, the time distribution of hits by recirculating protons and the energy dumped in the foil by one proton , the variation in modelled foil temperatures caused by the uncertainties in the input conditions was calculated.The most important uncertainty is in the emissivities - this is largest for $Al_2O_3$. When all the variations due to varying input conditions are summed, the total estimated uncertainties in peak equilibrium temperatures are:
$Al_2O_3$ : + 5.3% –11.5%. Graphite : + 1.3% – 2.0%.

The peak temperature in the graphite foil is 2380 K, while that in the $Al_2O_3$ foil is 3083 K. These should be compared to melting points of 3823 K for graphite but only 2320 K for $Al_2O_3$ . The difference in temperature is due to graphite's larger emissivity and specific heat . It is possible that the emissivity of $Al_2O_3$ may rise with temperature, but even if ε approached 1.0, this would only reduce the temperature to 2745 K, still well above the melting point. The results of the simulation are shown below in Figures 1-4 for the condition just after the passage of the fifth beam pulse. The higher thermal conductivity of graphite has caused the lower contours to spread out much further in the same period., but the effect of this on the peak temperature is insignificant - (~ 0.1 K.)

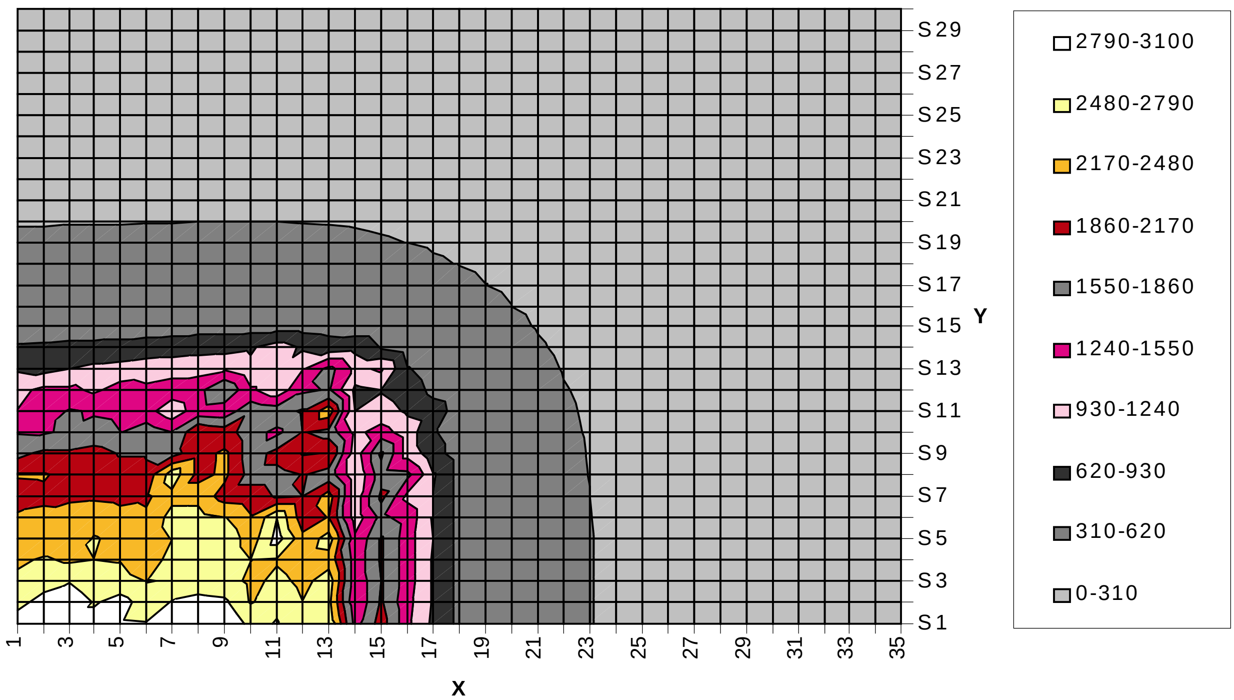


Figure 1 Contour plot of Aluminium Oxide Stripping-foil temperatures (K)

SCALE In all figures: X Division= 0.4427 mm, Y Division= 0.4435 mm

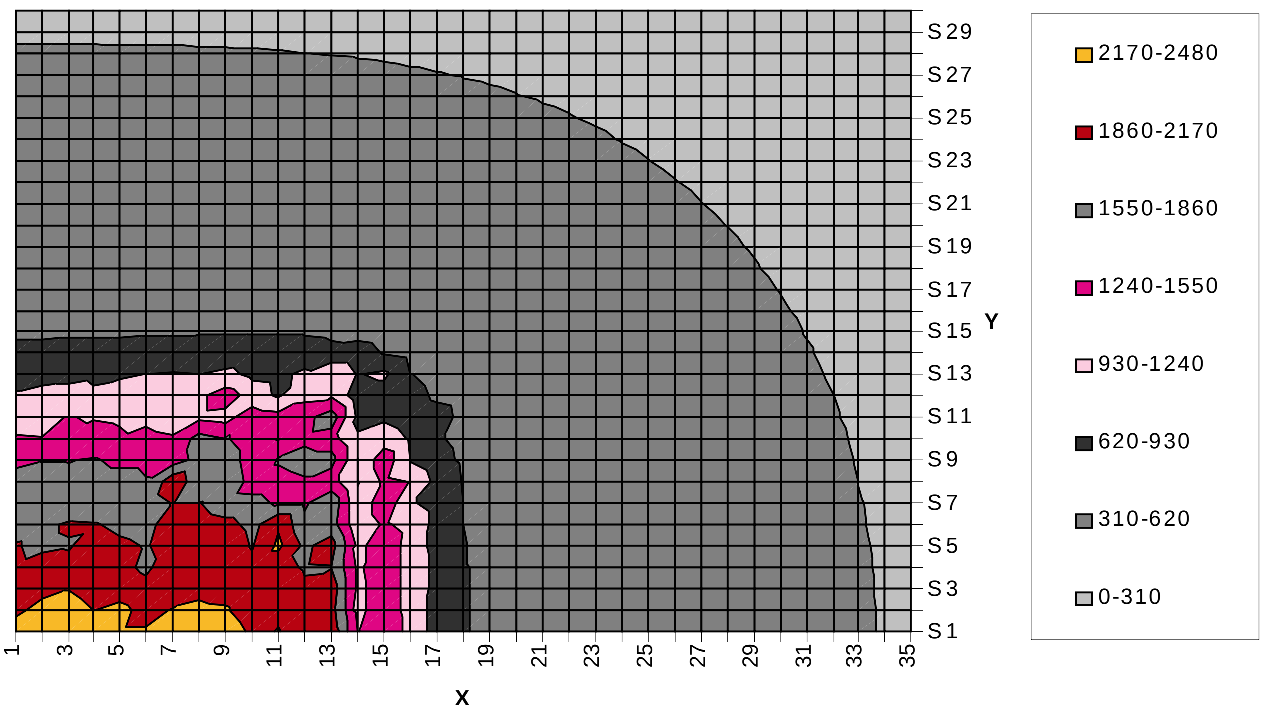


Figure 2 Contour plot of Graphite Stripping-foil temperatures (K)

## 3 CONCLUSION

It is therefore apparent that graphite is the better material for ESS foils. It is also evident that foils may set performance limits for the ESS, and that the foil performance required is at least equivalent to that achieved with the INS Carbon foils made by the'mCADAD' method (7) and tested in the Proton Storage Ring at LANL.

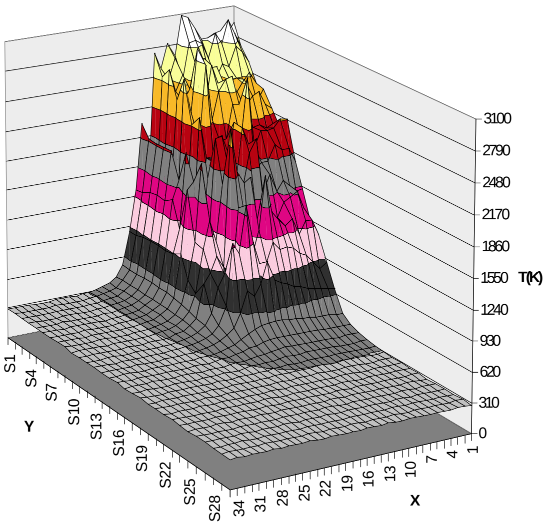


Figure 3 Aluminium Oxide Stripping-foil Temperature Profile

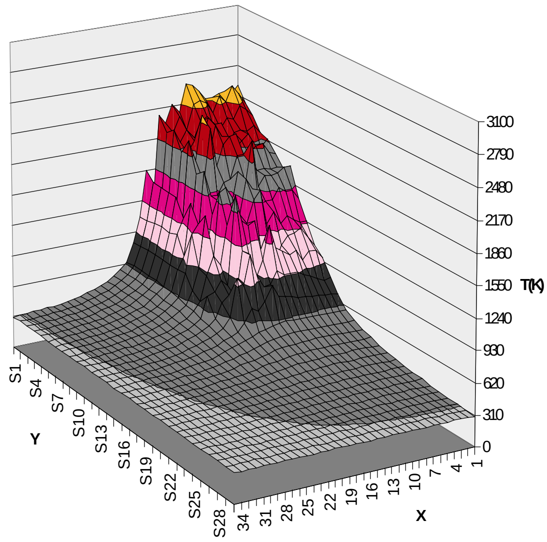


Figure 4 Graphite Stripping-foil Temperature Profile

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