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FROM: Werner Stein

SUBJECT: Thermal analyses for SLC and NLC positron targets

The attached report " Thermal Analyses of the SLC Positron Target and Proposed NLC Positron Target Designs" is forwarded for your information.

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Thermal Analyses of the SLC Positron Target and Proposed NLC Positron Target Designs

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Abstract

The SLC positron target is heated by a 4.4kw electron beam and cooled by thermal conduction and convection to a pair of coolant tubes. Thermal analyses were completed showing the transient cyclical temperatures in the target. Coolant tube maximum wall temperatures of 76 C remain well below boiling temperatures and peak temperatures in the beam heated areas reach maximum values of 330 C.
Similar analyses were completed for the NLC positron target which has 23kw of beam heating. Two different designs were investigated. One design involves the use of two water coolant tubes and the other involves use of nine rectangular shaped coolant channels. Both designs show peak beam heated region temperatures of near 850 C. Maximum coolant tube/channel wall temperatures of 85 C / 72 C were reached which are well below the boiling temperature of 80 psia water.

Background

The SLC target operated successfully for three years. The target was thermally analyzed to determine coolant tube temperatures reached in the target. It was desired to design the NLC target to operate successfully and to obtain coolant tube/channel temperatures in the same range as for the SLC target.

Target description

SLC target -
The target geometry is shown in figure 1. The target consists of two coolant tubes embedded in silver material, surrounding a tungsten rhenium wheel. The electron beam impinges 1/8 inch from the tungsten and silver interface in a circular pattern with a distance of 3 mm between impinging spots. The target is rotated by a “trolling” mechanism to obtain the spot spacing. The beam consists of electrons that come in packetts of electrons every 1/120 seconds. The total heat deposisted by the beam is 4.4kw and the energy deposition rate increases as the beam travels through the tungsten/rhenium material. The coolant channels have an assumed water flow of 3 gpm in each tube with an initial water temperature of 43 C.

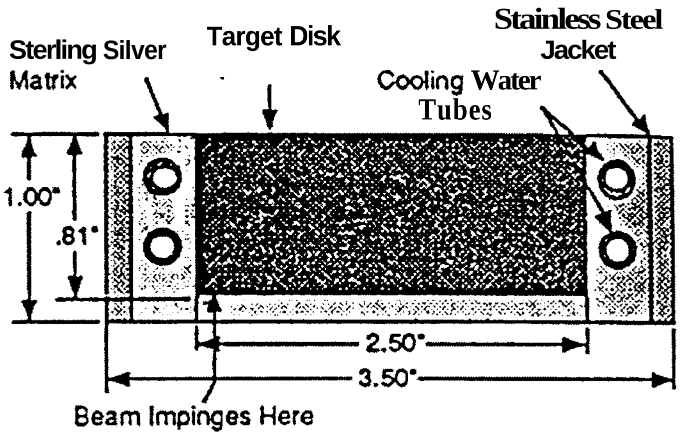

Figure **1. SLC** target schematic

NLC target -

The target geometry for the coolant tube design is shown in figure **2.** The wheel is rotated around its centerline to obtain an assumed beam spot spacing of approximately ***6.3*** mm. The **beam** power deposited in the tungsten rhenium material is **23** kw at a frequency of **120** cycles per second, with the rate of energy deposition increasing as the beam travels through the material. The target is cooled by water flowing in two tubes that are embedded in silver material at a water velocity of **29.5** ft/sec.

A slightly modified design was investigated and involved relocating the tubes slightly relative to the beam location in order to obtain a more even tube temperature distribution. Another additional design was also investigated and involved replacing the tubes with nine rectangular cross-section channels.

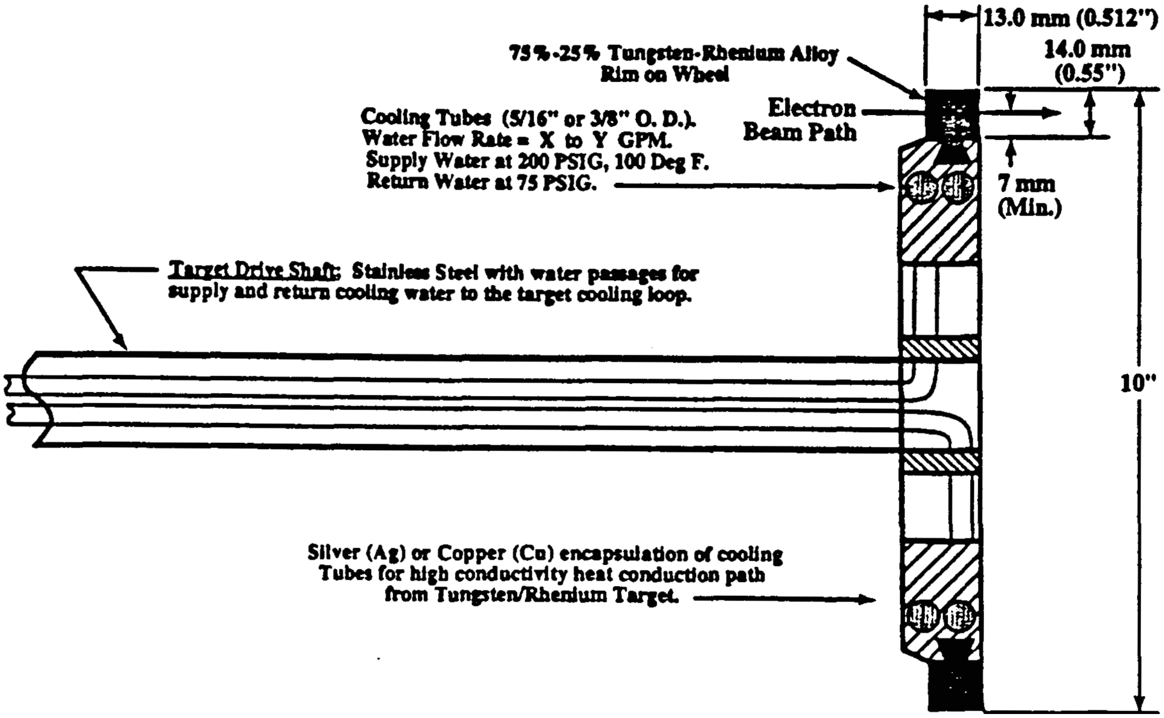

Figure **2.** NLC positron target schematic

Analyses of SLC target

The target was modeled with a two-dimensional axisymmetric model of the problem. Figure **3** shows the mesh used in the two-dimensional finite element conduction heat transfer code calculations. The beam energy deposition was modeled as an energy depositon rate per unit volume over a short pulse time of 0.002 seconds. This is a reasonable approximation for the essentially instantaneous actual energy deposition. The region into which the beam deposits energy was further divided into three regions with each region having a different power deposition rate. The power deposition rate varied from a low value as the beam first impinges on the target to a much larger value as it exits the material. An approximation to the beam power deposition was made in order to model the problem with a two-dimensional axisymmetric model. The power from one pulse of the beam is assumed to be deposited instantaneously in a circular ring, all at the same time, and then repeated every 0.5 seconds. The 0.5 seconds was calculated from the beam 120 pulses/second frequency, the beam nominal spot spacing of 0.12 inches **(3** mm) and the beam ring radius of 1.125 inches. The beam impinges in 60 spots around the target and with a beam frequency of 120 spots/second we obtain the 0.5 seconds.

The beam power deposited in the tungsten rhenium material is 4.4 kw. The energy deposition rate varies radially and axially and from this information one can determine that the hottest temperatures will occur along the centerline of the beam as it exits the material. **A** temperature rise of 207 C is calculated to result from one pulse of electrons impinging on the target in the hottest region.

The coolant water in the two tubes is assumed at an initial temperature of 43 **C** and from an energy balance the temperature increases by **3** C as the water exits the coolant tubes. In the analyses the water is therefore assumed to be at a conservatively high temperature of 46 ***C.*** The convection heat transfer from the tube walls to the water is modeled by use of a convective heat transfer coefficient to convect heat from the tube wall to the 46 C water. The convective heat transfer coefficient is obtained from experimental Nusselt number correlations. The correlation used in these analyses is for turbulent water flow and is given by :

$$Nu = 0.023\, Re^{0.8} Pr^{1/3}$$

where Re is the Reynolds number for the flow (88,000) and Pr is the Prandtl number (3.2). The Nusselt number is defined as :

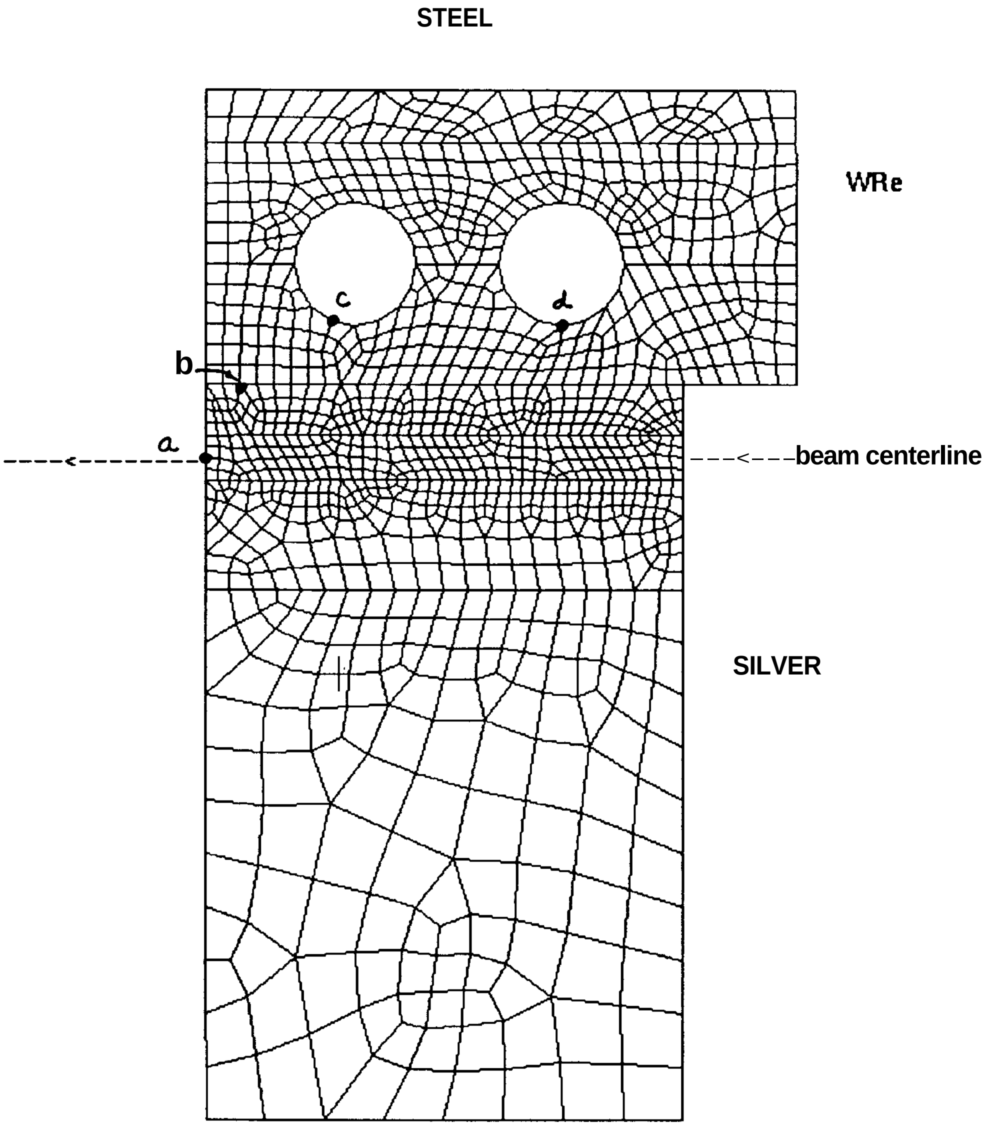

Figure 3. Schematic, calculation mesh, and temperature plot locations for the **SLC** positron target.

$$Nu = h\,d/k$$

where h is the convective heat transfer coefficient, d is the tube inside diameter **(.21** inches), and k is the water thermal conductivity **(0.38** Btu/hr-ft-F) **.** A convective heat transfer coefficient of **36** kw/m^2K was calculated.

Analysis of NLC target

The target was modeled with a two-dimensional axisymmetric model of the problem. Figure **4** shows the mesh used in the two-dimensional finite element conduction heat transfer code calculations for the coolant tube design. Figure 5 shows the mesh used for the rectangular channel design. The beam energy deposition was modeled as an energy depositon rate per unit volume over a short pulse time of **0.002** seconds. This is a reasonable approximation for the essentially instantaneous actual energy deposition. The region into which the beam deposits energy was further divided into four regions with each region having a different power deposition rate. The power deposition rate varied from a low value as the beam first impinges on the target to a much larger value as it exits the material. An approximation to the beam power deposition was made in order to model the problem with a two-dimensional axisymmetric model. The power from one pulse of the beam is assumed to be deposited instantaneously in a circular ring, all at the same time, and then repeated every **1.0** seconds. The **1.0** seconds was calculated from the beam **120** pulses/second frequency, the beam nominal spacing of **0.25** inches **(6.3** mm) and the beam ring radius of 4.75 inches. The beam impinges in **120** spots around the target and with a beam frequency of **120** spots/second we obtain the **1.0** seconds.

The beam power deposited in the tungsten rhenium material is **23** kw. The energy deposition rate varies radially and axially and from this information one can determine that the hottest temperatures will occur along the centerline of the beam as it exits the material. **A** temperature rise of 505 C is calculated to result from one pulse of electrons impinging on the target in the hottest region.

The coolant water in the two tubes is assumed at an initial temperature of **38 C (100** F) and from an energy balance the temperature increases by 7 C as the water exits the coolant tubes. In the analyses the water is therefore assumed to be at a conservatively high temperature of **45** C. The convection heat transfer from the tube walls to the water is modeled by use of a convective heat transfer coefficient to convect heat from the tube wall to the **45** C water. The con-

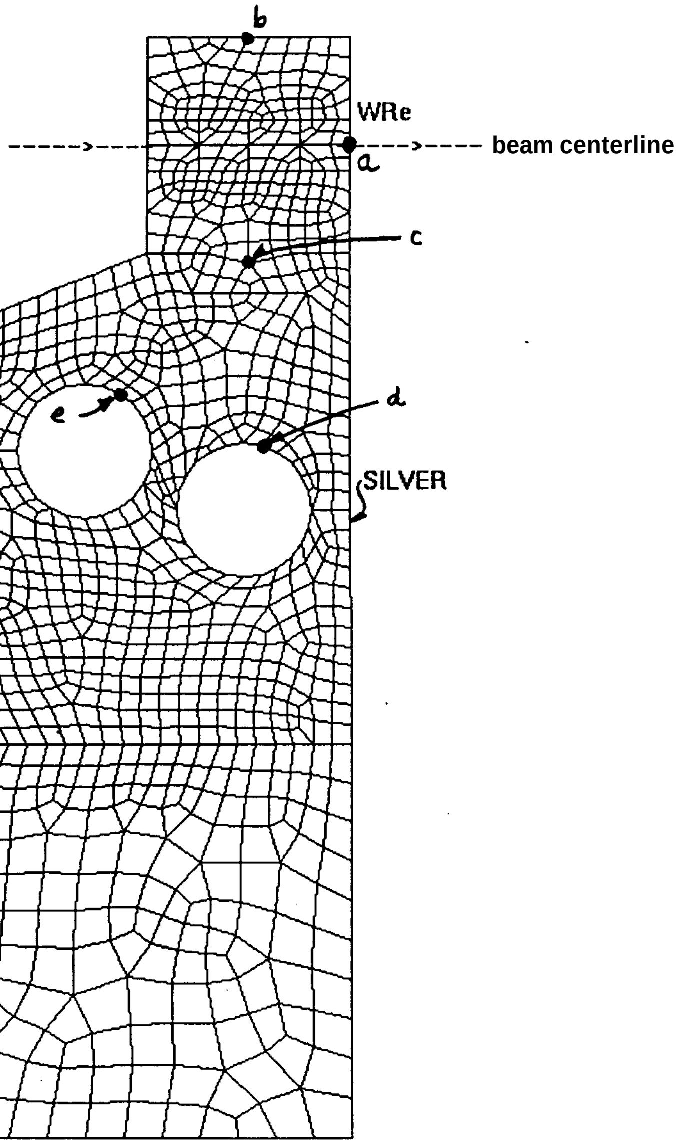

Figure **4.** Schematic, calculation mesh, and temperature plot locations for the NLC positron target.

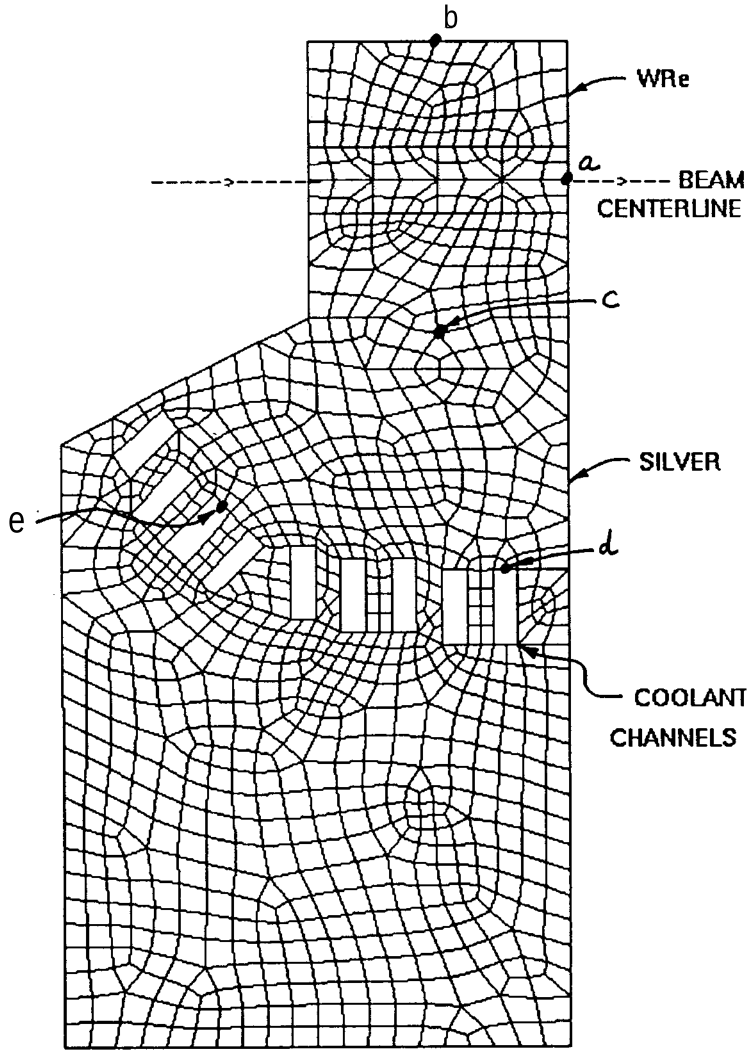

Figure 5. Schematic, calculation mesh, and temperature plot locations for the NLC positron target.

vective heat transfer coefficient is obtained from experimental Nusselt number correlations. The correlation used in these analyses is for turbulent water flow and is given by :

$$Nu = 0.023\, Re^{0.8} Pr^{1/3}$$

where Re is the Reynolds number for the flow (120,000) and Pr is the Prandtl number (3.2). The Nusselt number is defined as :

$$Nu = h\, d/k$$

where h is the convective heat transfer coefficient, d is the tube inside diameter (.34 inches), and k is the water thermal conductivity (0.38 Btu/hr-ft-F) . A convective heat transfer coefficient of 30.8 kw/m^2K was calculated for use with the coolant tubes. This value was also used for use with the rectangular channel design.

Model results for the SLC target

Figure 3 shows the geometry for the target and locations at which temperature transients are plotted in Figure 6. In the hottest region where the beam impinges the tungsten rhenium materail we see that peak temperatures of 330 C are reached. Because the pulses impinge on the same spot of the wheel every 0.5 seconds we see that the 330 C is reached every 0.5 seconds and drops down to a minimum temperature of 120 C. The maximum coolant tube wall temperature calculated is 76 C and is located on the surface of the coolant tube wall nearest to the beam downstream back wall of the tungsten rhenium material where the highest energy deposition occurs.

Model results for the NLC target

Figure 4 shows the geometry for the target with two coolant tubes and the location of points for which temperature transients were plotted in Figure 7. In the hottest region where the beam impinges the tungsten rhenium materail we see that peak temperatures of 850 C are reached. Because the pulses impinge on the same spot of the wheel every 1.0 seconds we see that the 850 C is reached every 1.0 seconds and drops down to a minimum temperature of 350 C. The maximum coolant tube wall temperature calculated is 84 C and is located on the sur-

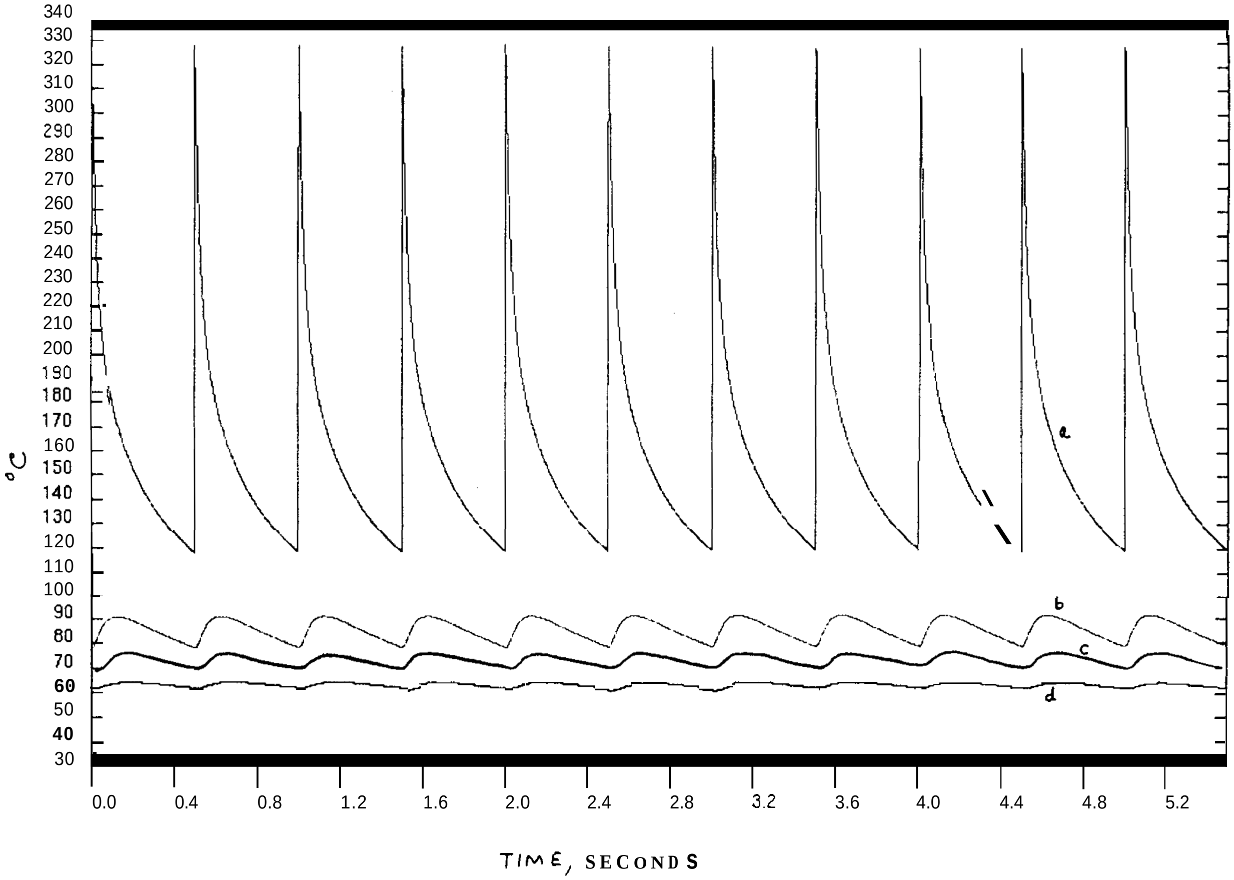

Figure *6*. Temperature (C) transients for the **SLC** target.

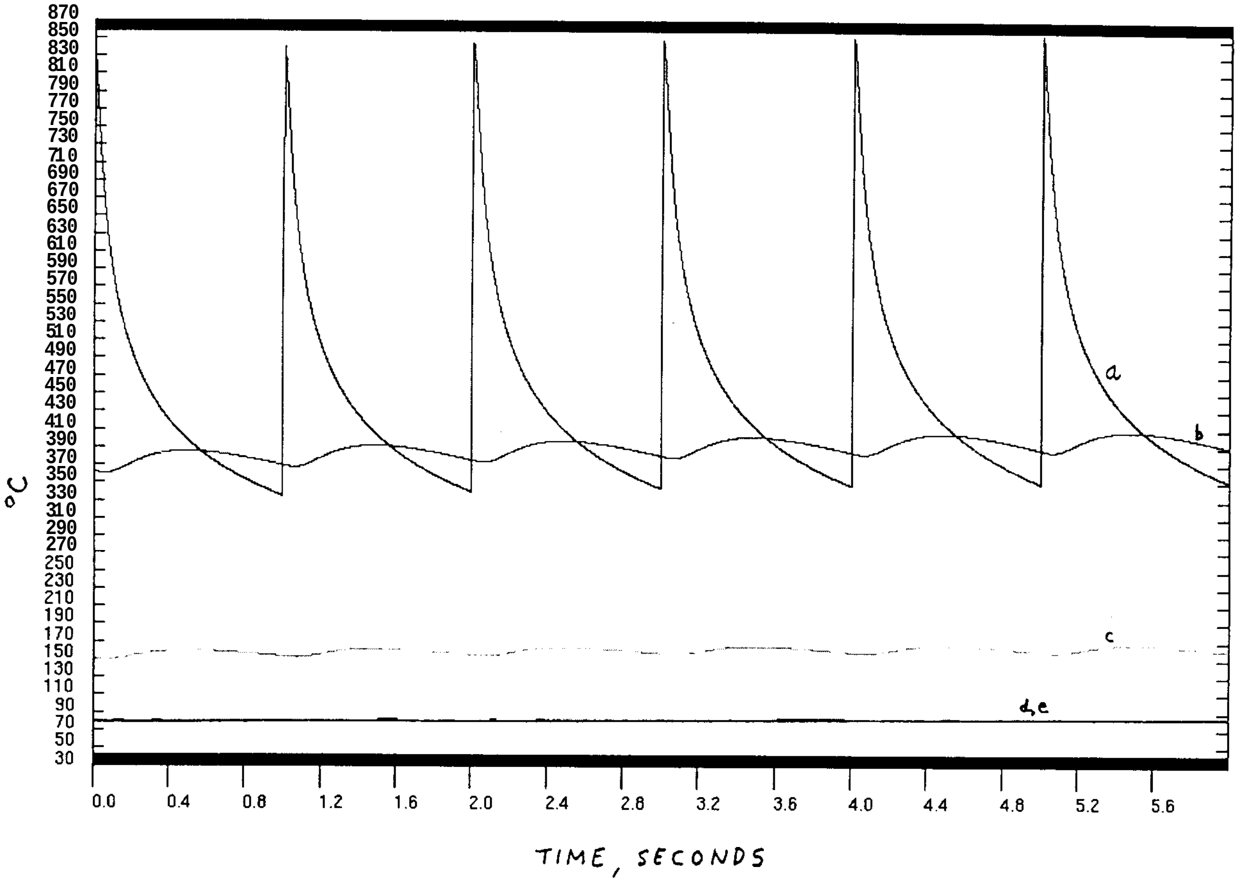

Figure 7. Temperature (C) transients for the NLC target.

face of the coolant tube wall nearest to the beam downstream back wall of the tungsten rhenium material where the highest energy deposition occurs.

For the case with the rectangular channel cooling, Figure 5 shows the geometry and the location of points for which temperature transients were plotted in Figure 8. In the hottest region where the beam impinges the tungsten rhenium materail we see that peak temperatures of 840 C are reached. Because the pulses impinge on the same spot of the wheel every 1.0 seconds we see that the 840 C is reached every 1.0 seconds and drops down to a minimum temperature of 340 C. The maximum coolant tube wall temperature calculated is 72 C and is located on the surface of the coolant tube wall nearest to the beam downstream back wall of the tungsten rhenium material where the highest energy deposition occurs.

Summary

The thermal analyses for the two targets show that the coolant water only increases in temperature by a few degrees C as it flow through the coolant tubes/channels. The tube/channel wall temperatures are all well below boiling temperature. Since the water pressure on the downstream side of the coolant channels is above 80 psia the water boiling temperature is above 155 C and the coolant wall temperatures are well below the boiling temperature.

The calculational results are very much dependent on the convective heat transfer coefficient calculated from the correlations. **A** possible uncertainty of 30 % in this coefficient would result in tube or channel wall temperatures rising by 8 C to 12 C but temperatures would still be well below boiling temperatures.

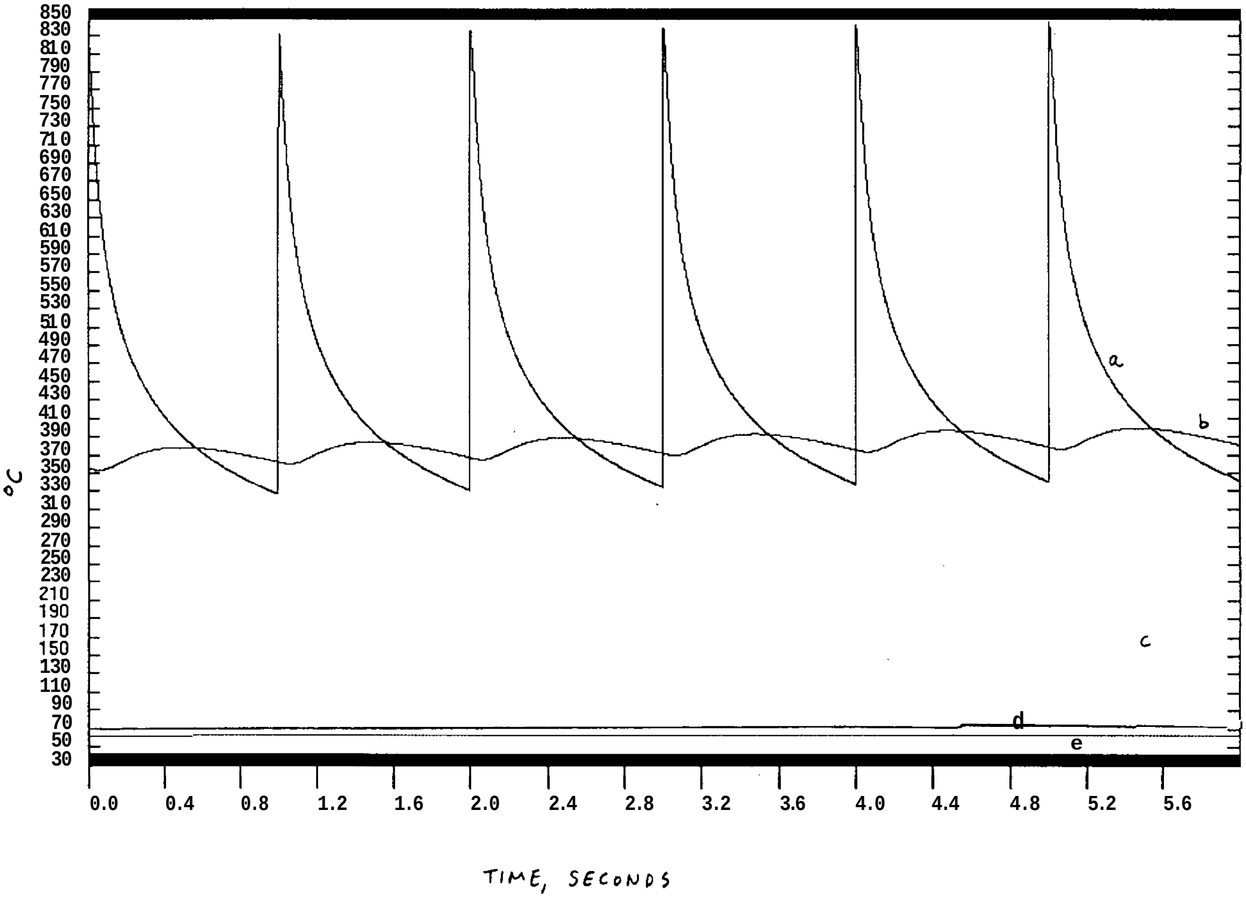

Figure 8. Temperature (C) transients for the **NLC** target.