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WANL-TME-561

Addendum II

January 16, 1964

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WANL Fuel Material Irradiation Program

Capsule Series T-T

(Phase I)

ADDENDUM II

D. C. Jacobs

Classification cancelled (or changed to)
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I. Introduction

WANL has modified the T-T series coolant delivery system by substituting flexible metal hose for the polyethylene coolant inlet tube. In this Addendum the modified system is described and an appropriate thermal analysis is made. Also included is an analysis of burnout during a no-flow situation.

This document is to supercede Section VI, "Thermal Analysis", of WANL-TME-561, ("WANL Fuel Material Irradiation Program-Capsule Series T-T").

II. Description of the Modified Coolant Delivery System

The modified coolant delivery system consists of 40 feet of flexible metal (stainless steel) hose with a nominal inside diameter of 0.5 inches. The system is divided into two segments; a 37 foot segment which will be reused in all irradiations, and a 3 foot segment which is permanently attached to the capsule. The 3 foot and 37 foot segments will be joined by an appropriate connector. The out-of-pile end of the 37 foot segment terminates with a quick disconnect socket. The coolant delivery hose will be connected to the GETR water supply via an appropriate flow meter.

III. Thermal Analysis

Tests performed at WANL have shown that 40 feet of the aforementioned

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flexible metal hose is capable of delivering 7.69 gpm of water when the unpiped flow rate is 20 gpm and the delivery pressure is 70 psi. On the basis of this data, a revised thermal analysis has been made (see Appendix I). The results are summarized in Table I. The calculations are based upon an unperturbed thermal neutron flux of 1.13×10^{14} n/cm² sec.

Under the aforementioned conditions, the maximum film temperature achieved is 50°C (122°F). It is, therefore, concluded that there will be no boiling in the coolant annulus during normal operation and consequently, no hazards are afforded to GETR.

IV Burnout Analysis

It is conceivable (but highly unlikely) that a complete loss of auxiliary coolant water may occur during the irradiation of a T-T series capsule. This situation was analyzed from the standpoint of burnout (see Appendix II). It was assumed that (a) the unperturbed neutron flux is 1.13×10^{14} n/cm² sec., (b) the capsule is under 30 feet of water, and (c) that a no-flow condition exists.

Under the aforementioned conditions the heat flux required to cause burnout was found to be 6.52×10^5 BTU/hr.ft². The actual heat flux developed is 3.35×10^5 BTU/hr.ft². Therefore, it is concluded that no burnout would occur if a no-flow situation arose, and consequently, no hazards would be afforded to GETR.

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Table I - Thermal Analysis of WANL Capsule Assembly

Material	Heat Generation Rate (BTU/hr. ft ³)	Heat Flow (BTU/hr)	Temperature Drop F°	Temperature	
				(°F)	(°C)
Fuel	0.988×10^8	4.51×10^4	798	5,473 ^(a) 4,675 ^(b)	3,033 ^(a) 2,590 ^(b)
Graphite	2×10^5	4.52×10^4	1,670	3,005 ^(b)	1,648 ^(b)
Gap	0	4.52×10^4	2,706		
S.S. Can	8×10^5	4.52×10^4	95.6	299 ^(c) 203 ^(b)	148 ^(c) 95 ^(b)
Film	0	4.52×10^4	80.5		
Coolant	0	4.52×10^4		122 ^(d)	50 ^(d)

(a) Centerline temperature

(b) Outer surface temperature

(c) Inner surface temperature

(d) Maximum temperature

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V. Summary and Conclusions

It has been shown that:

- (a) A coolant flow rate of 7.69 gpm is more than sufficient to prevent boiling within the water annulus of the capsule assembly.
- (b) A coolant flow rate of 7.69 gpm can be delivered by the modified coolant delivery system.
- (c) No burnout would occur if there was a complete loss of auxiliary coolant water during the irradiation of a T-T series capsule assembly.

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Appendix I - Calculations for the Thermal Analysis

A. Review of Thermal Parameters

Many of the parameters which were calculated for the thermal analysis in WANL-TME-561 are unaffected by the revised flow conditions. These are outlined below. The calculations are based on an unperturbed thermal neutron flux of 1.13×10^{14} n/cm² sec.

(a) Heat Generation Rates

1. Fission

$$Q \text{ (fission)} = 1,044 \text{ W/cm}^3 = 0.986 \times 10^8 \text{ BTU/hr.ft}^3$$

2. Gamma Heating

$$Q_{\gamma} \text{ (fuel)} = 2.03 \times 10^5 \text{ BTU/hr.ft}^3$$

$$Q_{\gamma} \text{ (graphite)} = 1.55 \times 10^5 \text{ BTU/hr.ft}^3$$

$$Q_{\gamma} \text{ (S.S.)} = 7.64 \times 10^5 \text{ BTU/hr.ft}^3$$

3. Total Heat Generation Rate

Neglecting the effects of gamma heating, the total heat generation rate in the irradiation capsule is:

$$Q'_T = (9.86 \times 10^7 \text{ BTU/hr.ft}^3 \text{ fuel}) (4.52 \times 10^{-4} \text{ ft}^3 \text{ fuel})$$

$$Q'_T = 4.46 \times 10^4 \text{ BTU/hr.}$$

(b) Heat Flow in Each Region

$$q \text{ (fuel)} = 4.51 \times 10^4 \text{ BTU/hr.}$$

$$q \text{ (graphite)} = 4.52 \times 10^4 \text{ BTU/hr.}$$

$$q \text{ (gap)} = 4.52 \times 10^4 \text{ BTU/hr.}$$

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$$q \text{ (S.S.)} = 4.52 \times 10^4 \text{ BTU/hr.}$$

$$q \text{ (film)} = 4.52 \times 10^4 \text{ BTU/hr.}$$

$$q \text{ (coolant)} = 4.52 \times 10^4 \text{ BTU/hr.}$$

(c) Temperature Drops Across Each Region

$$\Delta T \text{ (S.S.)} = 95.6 \text{ F}^\circ$$

$$\Delta T \text{ (gap)} = 2,706 \text{ F}^\circ$$

$$\Delta T \text{ (graphite)} = 1670 \text{ F}^\circ$$

$$\Delta T \text{ (fuel)} = 798 \text{ F}^\circ$$

B. Temperature Rise in the Coolant

The change in temperature of the coolant as it flows through the capsule annulus is given by the expression:

$$T(x) - T_i = \frac{A}{w c_p} \int_0^x Q(x) dx$$

where: x = variable length of coolant channel

w = mass flow rate

c_p = specific heat of coolant

$Q(x)$ = heat generation rate per unit volume of the capsule

A = cross sectional area of the capsule

T_i = inlet coolant temperature

$T(x)$ = coolant temperature at x

Taking Q to be independent of position and integrating over the effective length of the coolant channel, then

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$$T_o - T_i = A \cdot Q_T / w c_p$$

where T_o is the outlet coolant temperature and Q_T is the total heat generation rate per unit volume of the capsule.

But,

$$Q_T' = (A) (1) (Q_T)$$

where $Q_T' =$ total generation rate. Consequently,

$$T_o - T_i = Q_T' / w c_p$$

If the flow rate is 7.69 gpm, the mass flow rate (w) is 3,848 lb/hr.

Taking:

$$Q_T' = 4.46 \times 10^4 \text{ BTU/hr.}$$

$$c_p = 1 \text{ BTU/hr.}$$

$$T_i = 110^\circ\text{F}$$

Then: $T_o = 121.6^\circ\text{F.}$

C. Film Coefficient

The film coefficient for water may be expressed as:

$$h(\text{BTU/hr.ft}^2 \text{ } ^\circ\text{F}) = 170 (1 + 10^{-2} T - 10^{-5} T^2) V^{0.8} / D_e^{0.2}$$

where: $T =$ film temperature ($^\circ\text{F}$)

$V =$ coolant velocity (ft/sec.)

$D_e =$ effective (hydraulic) diameter of coolant channel (inches)

If the flow is taken as 7.69 gpm ($V = 7.69 \text{ ft/sec}$), the film temperature as 180°F and using $D_e = 0.10 \text{ inch}$, then

$$h = 4.29 \times 10^3 \text{ BTU/hr.ft}^2 \text{ } ^\circ\text{F}$$

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D. Temperature Drop Across the Film

$$\Delta T (\text{film}) = q (\text{film}) / h A_h$$

$$q (\text{film}) = 4.52 \times 10^4 \text{ BTU/hr.}$$

$$h = 4.29 \times 10^3 \text{ BTU/hr.ft}^2.\text{°F}$$

$$A_h = 0.131 \text{ ft}^2$$

Therefore: $\Delta T(\text{film}) = 80.5 \text{ F}^\circ$

E. Temperature in Each Region

On the basis of the preceding calculations the temperature at various radial positions within the capsule were calculated. The results are shown in Table II.

Table II - Maximum Temperatures at Various Radial Positions Within the WANL Capsule Assembly

Position	Temperature	
	°F	°C
Coolant (outlet)	122	50
Outer Surface of Inner Can	203	95
Inner Surface of Inner Can	299	148
Outer Surface of Graphite Sleeve	3,005	1,648
Surface of Fuel Pellet	4,675	2,590
Fuel Pellet Centerline	5,473	3,033

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Appendix II - Calculations for the Burnout Analysis

According to Mirshak et. al.* the heat flux at burnout for stainless steel is given by the imperical expression:

$$(Q/A)_{BO} = 2.66 \times 10^5 (1 + 0.0365 V) (1 + 0.0091 T_s) (1 + 0.0131 p)$$

where: $(Q/A)_{BO}$ = heat flux at burnout (pcu/hr.ft²)

V = coolant velocity (ft/sec.)

T_s = subcooling, i.e., difference between saturation temperature and cooling temperature (C°)

p = pressure (psia)

It is assumed that a no-flow condition exists and that the capsule is submerged in 30 feet of water. Therefore:

$$V = 0$$

$$p = 14.7 + 12.9 = 27.6 \text{ psia}$$

It is further assumed that the water in the annulus is boiling so that:

$$T_s = 0$$

Therefore, under these conditions:

$$(Q/A)_{BO} = 3.62 \times 10^5 \text{ pcu/hr.ft}^2 = 6.52 \times 10^5 \text{ BTU/hr.ft}^2$$

Assuming that the unperturbed, thermal neutron flux is:

$1.13 \times 10^{14} \text{ n/cm}^2 \cdot \text{sec}$, the heat generation rate in the capsule will be

* S. Mirshak, W. S. Durout and R. H. Towell; DP-355, "Heat Flux at Burnout", (Feb. 1959)

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4.46×10^4 BTU/hr. Taking the effective surface area of the inner can to be 0.133 ft^2 , then:

$$Q/A = 4.46 \times 10^4 / 0.133 = 3.35 \times 10^5 \text{ BTU/hr.ft}^2$$

Therefore, it is seen that during a no-flow condition, no burnout will occur.

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