Sandia National Laboratories
Albuquerque, New Mexico 87185

January 20, 1983

Dr. T. J. Walker
U. S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
7915 Eastern Avenue
Silver Spring, MD 20912

Dear Tom:

We have completed our review of the document entitled "TMBDB Melting Scenario" which you forwarded to us. The document evaluates the consequences of a non-coolable core debris bed early in a TMBDB scenario. Using several simplifying assumptions, a combined TRUMP/CACECO analysis was used to define the consequences in terms of CRBR's thermal margins. It was concluded that containment conditions would be acceptable and there would be a maximum basemat penetration of about 5 feet at sodium boildry.

We have performed some steady state modelling to evaluate this conclusion as to the extent of the debris/concrete interaction. Our findings confirm the conclusions. Using what we feel are conservative assumptions and data from the FRAG tests, we calculate a basemat penetration of somewhat less than 4 feet at sodium boildry. We have included a discussion of these calculations in the attached material. We have also included a short discussion of the assumptions used in the study and of the possibility of synergism in a combined sodium-core debris/concrete interaction. It is not clear that a combined attack of sodium and core debris is bounded by either individual interaction. Unfortunately, the data base does not exist to determine whether the combined interaction is synergistic or mitigating.

Discussion of Assumptions Made in the Melting Scenario

The sodium/concrete interaction is assumed to proceed at an initial penetration rate of 18 cm/hr (3 mm/minute). This reaction continues for 20 minutes and results in an insulating layer of reaction products 12 cm thick. The core debris then sinks through this layer to interact with the concrete. This scenario ignores the 10 cm of insulating perlite concrete liner in CRBR which we feel should also be considered. Sodium penetrates perlite concrete quite rapidly compared to limestone concrete, and a conservative assumption would be that the perlite concrete would contribute 10 cm of

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additional debris to the insulating layer. The associated hydrogen and heat release should be added to the containment load. The results of the HEDL test LCT-9 should be helpful in determining relative penetration rates for perlite and limestone concretes. Thus, a more conservative initial condition would be a thicker insulating layer. As will be seen, however, this does not substantially affect the calculations.

Although the scenario assumes that the core debris sinks to the bottom of the reaction product layer, this is said to be unrealistic since the viscous reaciton products "would provide a measure of support for the core debris". It has been our experience with the FRAG tests, however, that the debris readily sinks through even high viscosity molten concrete. In the FRAG experiments, mild steel spheres were inductively heated in a concrete crucible. After an initial heating period of three to five hours, the concrete reached its melting point and erosion began. In each of the four FRAG tests, the molten concrete was displaced upward by the steel debris. The viscosity of the molten concrete in the FRAG tests was 14 poises for limestone/common sand concrete (FRAG tests 2 and 3) and 150 poises for basalt concrete (FRAG tests 1 and 4). This is several orders of magnitude greater than what we estimate for the sodium/concrete reaction products. Our experience in the AA/AB tests indicates that this layer of reaction products is composed of roughly 50% NaOH, 30% Na_2CO_3, and 10% each of MgO and CaO. The viscosity of this mixture is believed to be on the order of 0.01 to 0.02 poises. (Experiments are underway at Sandia to evaluate the viscosity of the reaction products.) We therefore believe that in the assumed scenario, the reaction products <u>will</u> form an insulating layer and debris will sink through this layer and may become uncoolable.

Once the insulating layer is formed, the core debris is assumed to heat up and subsequently melt the concrete. There is assumed to be no combined sodium/core debris interaction with the concrete. The two limiting cases of attack on the concrete by sodium alone and attack on concrete by core debris alone have therefore been examined. Although, as pointed out in the report being reviewed, the combined interaction may be mitigating because of coolability arguments, it may, in our opinion, possibly be synergistic because of chemistry at the interface with concrete. If sodium or sodium compounds do penetrate the debris and sodium/concrete interaction occurs, the debris represents an intense heat source at the reaction zone. In general, higher temperatures enhance the rate of chemical reactions. Thus, the experimentally observed maximum sodium/concrete penetration rates of 2-4 mm/minute. could be increased. Any limitation to the extent of sodium/concrete interactions

brought on by either slowing of the water release from concrete or occlusion of the sodium/concrete interface with precipitated products would develop more slowly if there was a high temperature heat source at the concrete interface. Sodium/ concrete interactions could be prolonged then by chemical effects.

In considering the combined interaction, one is therefore faced with chemistry considerations as well as coolability considerations. The former is synergistic; the latter is mitigating. Sufficient data to predict which will be the case are not available. We feel therefore that this remains an open issue. It is an open issue proving to be quite difficult to explore with reasonably prototypic experiments.

As the concrete is eroded by core debris, the molten concrete is displaced from the debris/concrete interface by the sinking core debris. This phenomenon has been observed in our FRAG tests. We also observed that the molten concrete rises throught the debris until a low temperature region (significantly below the concrete melting point) is reached. After a period of time, which depends on test temperatures, it solidifies to form a crust which is impermeable to liquids but allows gases to percolate through. Subsequent melting reinforces this crust. As was modeled in the TRUMP analysis, this crust thickens during the entire concrete erosion period. We therefore concur with their general assumptions as to the presence of an insulating layer.

In the TRUMP analysis, concrete erosion is assumed to proceed only in the downward direction; sideward erosion is neglected due to the presence of the wall liner anchor. Even if this structure were absent, we would not expect significant sideward erosion. As was observed in the FRAG tests, sidewall erosion proceeds at a much slower rate than downward erosion because the molten concrete at the side is not displaced from the interaction zone by the debris. It thus provides a barrier to the efficient transfer of heat between the debris and the uneroded concrete at the side.

In the FRAG tests, the initial sideward and downward erosion rates were approximately the same, but as more concrete melted, the sideware erosion rate was reduced considerably. In FRAG tests 1, 3 and 4, erosion occurred over roughly a four hour period. During this time, downward erosion was approxixmately 10 cm, whereas sideward erosion was only 3 to 4 cm. In FRAG2, the erosion period was less than two hours, and downward and sideware erosion were 5 cm and 3 cm respectively.

Our interpretation of these results is that the sidewall erosion at a particular axial location ceases once the core debris has sunk below that level because the heat source has been removed from the interaction zone. This is especially important in the TMBDB melting scenario, where the sidewall is exposed to a debris depth of only 8.6 cm. An estimate of the magnitude of the sideward erosion can be obtained as follows:

Sidewall Erosion Period = 8.6 cm/V_{ed}

Total Sidewall Erosion = V_{es} x 8.6 cm/V_{ed}

where V_{ed} and V_{es} are the downward and sideward erosion velocities. The sidewall erosion period is the total time for which a given axial sidewall location will be directly exposed to the sinking debris. Since the ratio, V_{es}/V_{ed} has always been observed to be the less than 1.0, the sideward erosion will always be less than 8.6 cm. Based on the FRAG test results, we would anticipate a total erosion of 5 cm or less in CRBR. Consequently, we agree with the essentially one-dimensional formulation of the problem used by CRBRPO in their analysis.

Discussion of the TRUMP/CACECO Analysis

In the TRUMP analysis, the insulating layer of reaction products is assumed to be composed solely of sodium carbonate. However, as noted earlier, this layer will actually be a mixture of NaOH, Na_2CO_3, CaO, and MgO. The properties in the TRUMP analysis should be modified accordingly. For example, Ref. 1 gives the thermal conductivity of NaOH as 0.53 BTU/hr ft. $^{\circ}$F, which is a factor of two less than the value used in the TRUMP analysis. Since heat conduction to the sodium coolant is directly proportional to the thermal conductivity of the intervening layer of reaction products, this change would reduce the fraction of the decay heat transferred upward to the sodium. Hence, to be conservative a reduced value for the thermal conductivity should be used in the TRUMP analysis.

The TRUMP model also assumed that the layer of eroded concrete remains molten as it increases in thickness. We would expect, however, that a significant portion of the molten concrete will solidify, especially adjacent to the layer of reaction products. This change in phase and subsequent modification of thermal properties should also be considered.

Since the ability of the CRBRP safety systems to handle th TMBDB melting scenario is directly related to the rate at which the concrete basemat erodes, a quick calculation was

done to evaluate the conservatism of the CACECO analysis. The erosion velocity can be estimated by the following simple equation:

$$V_e = \frac{q}{\int_{T_i}^{T_m} \rho C_p dT + \sum_i \rho L_i}$$

where q is the incident heat flux, T_i and T_m are the initial and upper melting range temperatures, and ρ and c_p are the concrete density and specific heat. The L_i's in the denominator are the enthalpies of decomposition and melting for the concrete. Using the available property information for limestone concrete, this equation becomes

$$V_e = \frac{q}{9500 \text{ J/cc}}$$

The incident heat flux can be estimated as follows:

$$q = \frac{fQ_D}{A}$$

where Q_D is the decay heat generated by the core (Table C.1-3 of Ref. 2), f is the fraction delivered to the concrete, and A is the concrete surface area (117 m^2).

Note that Q_D is dependent on the depth of core debris in contact with concrete. Deeper beds will supply more heat to the concrete. We have accepted the 8.6 cm value which assumes uniform distribution of the debris over the cavity floor and substantial amounts of debris retained in the reactor vessel even though we recognize that others have criticized these assumptions. Any error due to these assumptions should linearly affect erosion though it may have a non-linear effect on temperature and consequently fission product release.

In order to compare the concrete erosion distances calculated using these equations and the TRUMP/CACECO analysis, heat fluxes and erosion velocities were calculated using the f values given in Table 1 of the TMBDB melting scenario report. These results are given in Figure 1. Graphically integrating the erosion velocity curve with respect to time, the total erosion during the initial 71 hours (the boildry time) is estimated to be about 75 cm or 2.5 feet. This is one half the value calculated using the TRUMP/CACECO analysis.

Taking into account our reservations about the conservatism of the assumptions used in the TRUMP analysis, we recalculated the heat fluxes and erosion velocities assuming that 100% of the decay heat is transferred to the concrete. These results are also shown in Figure 1. Performing a similar integration, a total erosion of 109 cm or 3.6 feet is calculated. Once again, this value is less than that calculated by the CRBRPO. Although these calculations are not as elegant as the transient TRUMP/CACECO analysis, we have used similar analyses to successfully predict concrete erosion rates in the FRAG tests. We conclude, therefore, that the methodology used in the TRUMP/CACECO analysis is conservative.

Sincerely yours,

Erik Randich

DR Bradley

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REFERENCES

1. Thermophysical Properties of Matter, Vol. 2: Thermal Conductivity - Nonmetalic Solids, Edited by Y. S. Touloukian, R. W. Powell, C. Y. Ho, and P. G. Klemen, IFI/Plenum, New York (1970).

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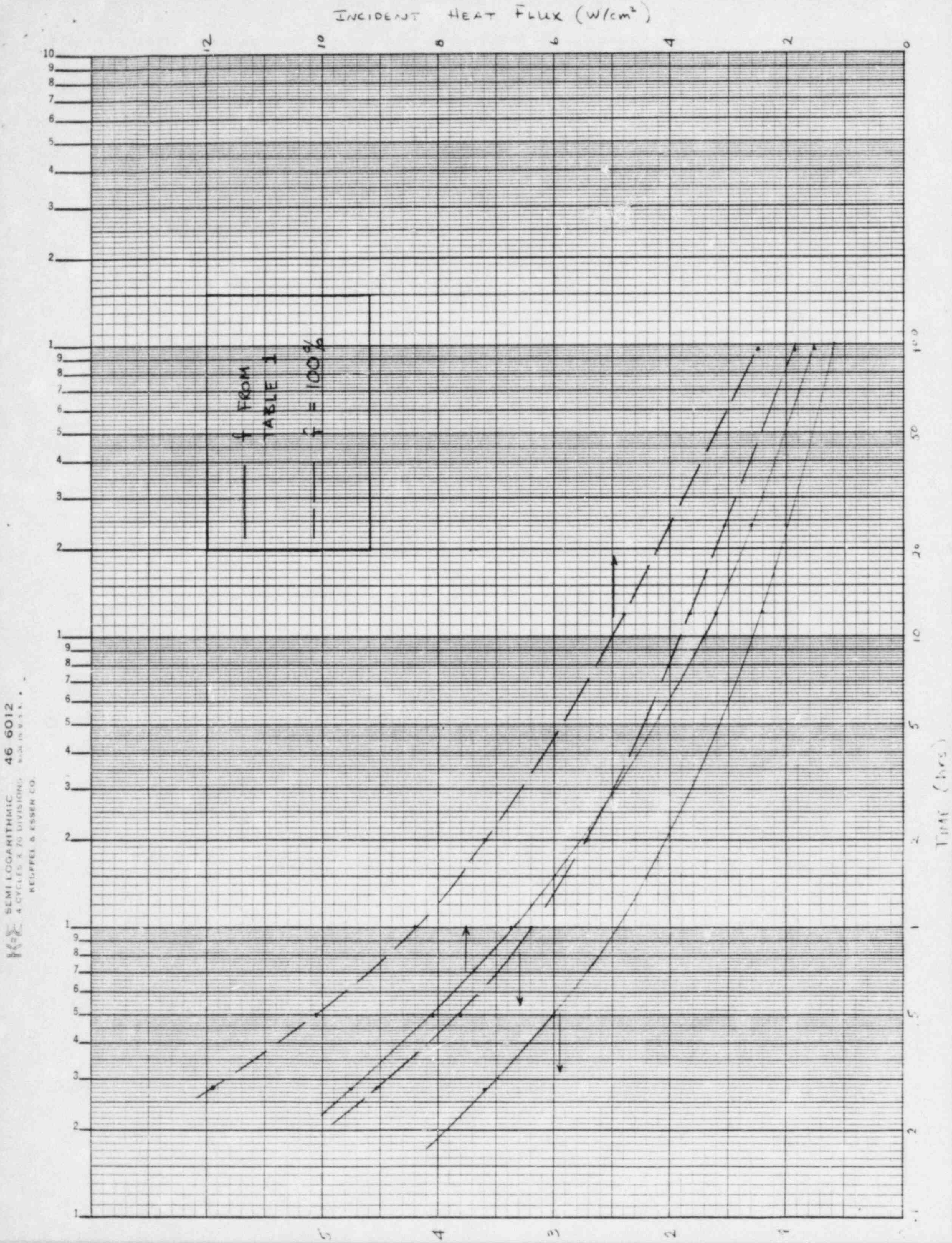
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4
2
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TIME (hrs)
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50
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10
5
2
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SEMI-LOGARITHMIC 46 6012
4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.

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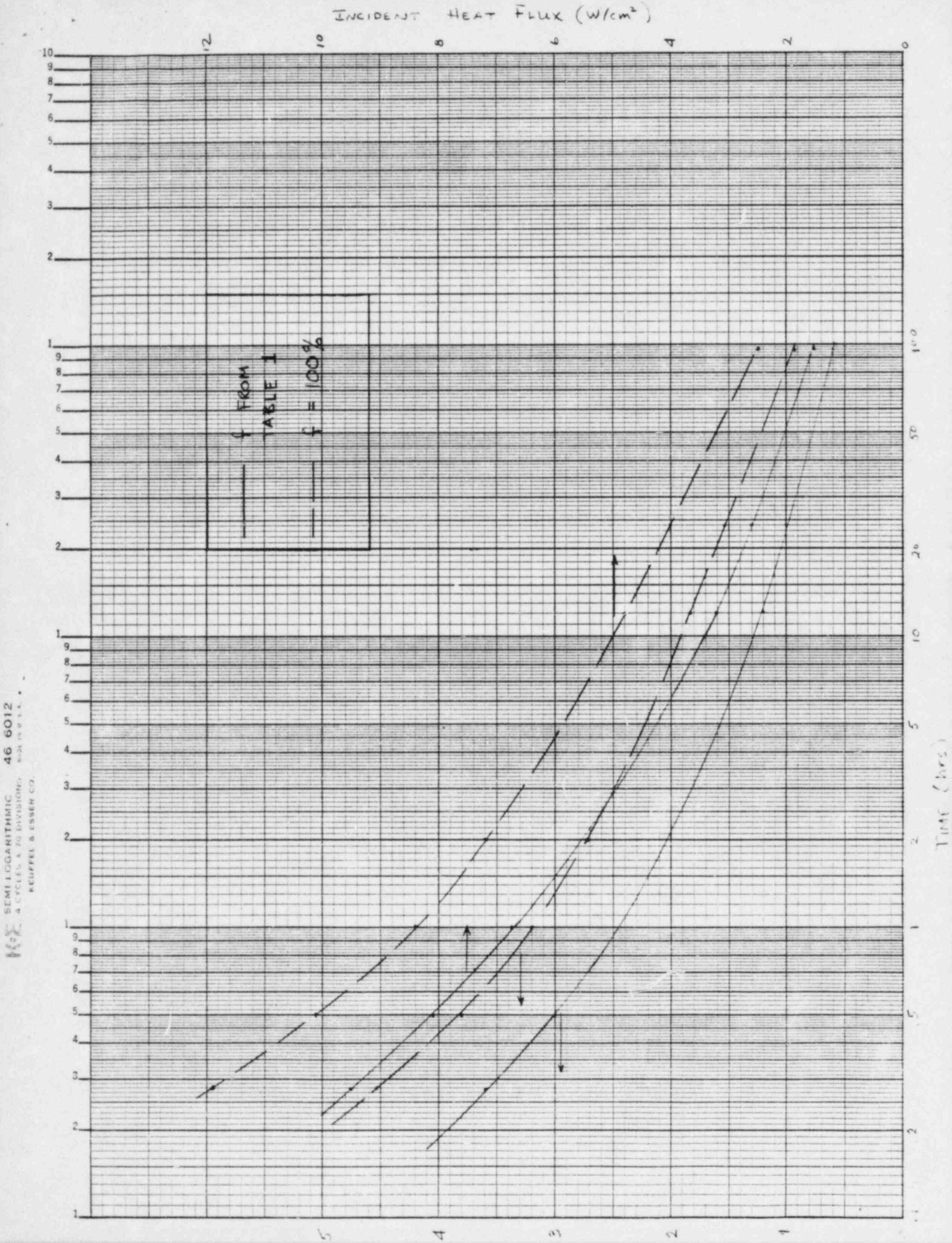
INCIDENT HEAT FLUX (W/cm²)
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4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.