UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

Docketed
USNRC
JAN 17 1983
Office of the Sec.
Branch & Serv.

In the Matter of

THE REGENTS OF THE UNIVERSITY
OF CALIFORNIA

(UCLA Research Reactor)

Docket No. 50-142

(Proposed Renewal of
Facility License)

DECLARATION OF DAVID R. DUPONT

I, David R. Dupont, declare as follows:

1. I am a chemist associated with the Southern California Federation of Scientists. A statement of professional qualifications is attached.

2. I have reviewed certain safety matters pertaining to the UCLA reactor, primarily in the area of chemical reactions associated with potential accidents.

3. This review included a site visit and an examination of a number of documents associated with the application by UCLA for renewal of its license to operate its Argonaut-type research reactor. These documents have included: the 1980 Application, and the 1982 amendments thereto; the original 1960 Hazards Analysis; Neill Ostrander's September 1, 1982, declaration; "Credible Accidents for Argonaut Reactors" by Hawley, Robkin, and Kathren; and "Fuel Temperatures in an Argonaut Core Following a Hypothetical Design Basis Accident" by G.E. Cort.

4. Based upon the above review, as well as independent calculations detailed herein, it is my conclusion that the above-mentioned analyses performed in support of the UCLA reactor are seriously flawed in their assessment of the potential for fire and other potentially destructive reactions in the UCLA reactor. In particular, the estimates of Wigner energy that may be stored in the reactor's graphite are vastly undervalued; the potential for a graphite, uranium metal, magnesium fire improperly assessed; the predictions of peak reactor temperature that can be attained in an accident are far too low; and that consequently predictions of the magnitude of fission product release in case of a maximum credible accident are severely underestimated. A discussion of these points follows.

5. The UCLA reactor's primary material of construction is graphite, which serves both as moderator/reflector and provides some structural support. The reactor is surrounded by a concrete biological shield, and the reactor's fuel plates are cooled and additionally moderated by light water. The fuel is in the form of metallic uranium alloyed with aluminum, at 13.4 wt. % U, forming the low-melting eutectic. The fuel is clad with aluminum, which also melts at a relatively low temperature; in fact, both meat and clad melt at considerably lower temperatures than the constituents of most other reactor fuels.

6. Because there is no pressure vessel, containment structure, exclusion zone, or radioactivity removal system for use in an emergency to prevent fission products from reaching the public if released from the fuel, the primary barrier against fission product release is the fuel cladding, .015 inch thick aluminum. Because of the low melting temperature of the aluminum clad and the fuel meat, considerable attention has been given in analyses related to the UCLA reactor to the maximum temperature rise within the reactor that could acompany various credible accident scenarios.

7. One of the potential sources of heat in such an accident, either singly or as one of multiple contributors to a temperature rise in moderator or fuel, is the energy stored in the graphite due to its long-term bombardment by neutrons. Such bombardment causes damage in the graphite structure itself, knocking carbon atoms out of their normal positions, and in the process storing significant amounts of energy. This is known as the "Wigner effect," after Eugene Wigner who first predicted its occurrence.

8 This stored energy can be rapidly released if the graphite is heated over a certain threshhold temperature, beginning around 170°C. It thus poses a significant accident potential, because in the process of releasing the stored energy, more of the graphite is brought to the temperature where it can release its energy, and thereby exists a potentially dangerous positive feedback mechanism. The more graphite that is heated, the more heat is released.

9. In addition to posing a simple thermal threat that could endanger the fuel's integrity, graphite is combustible. At certain temperatures (estimated in the Hawley report to be approximately 650°C), it will ignite in the presence of air, in an exothermic reaction that releases large amounts of energy. The Hawley report (p. 34) indicates that the combustion of 1 g of graphite will raise 38 g to the ignition temperature if no heat is lost, once again creating a dangerous positive feedback situation which, if started, could readily put the reactor fuel at risk of melting or of igniting. (The uranium in the fuel is also combustible. It is reported that "In still air uranium oxidises, i.e. the reaction is self-heating at 350°C." Nucleonics, Vol. 15, No. 12, December 1957.)

10. A very serious fire of the sort suggested above arose at a non-power reactor at Windscale, England, in which 20,000 curies of iodine-131 were released to the environment.* The fire--which involved both the uranium metal and the graphite--was initiated, in part, by release of the stored Wigner energy in the graphite. Although the reactor was a production reactor, it had a number of similarities to the UCLA reactor--fuel containing uranium metal, clad in aluminum, with a graphite moderator/reflector, and normal operation at relatively low temperatures. The operating temperature is very important because progressively larger amounts of self-annealing occur at higher operating temperatures; conversely, significantly larger amounts of Wigner energy are stored at the lower operating temperatures.

11. The Windscale accident in 1957 pointed to the importance of recognizing possible accident sequences involving stored energy in graphite. It is thus necessary to have an accurate idea of the amount of such energy that might be stored in a reactor subject to irradiation damage in graphite, particularly reactors operating at low temperatures.

---

* Milk contaminated with I-131 had to be disposed of in an area of 200 square miles around the reactor because of the accident.

12. The Hawley, Kathren, and Robkin review treats the Wigner matter in two brief paragraphs on page 37 of their report. They conclude that the amount of stored energy that may have accumulated in an Argonaut-type reactor like UCLA's is approximately 5 cal/g, which they indicate is insufficient, if released, to heat the graphite by more than a trivial amount.

13. The Hawley, et al, estimate, however is low by a factor of approximately 25-40. The true level of Wigner energy that may be stored in the graphite of an Argonaut-type reactor such as that at UCLA is between 125 and 210 cal/g, given the calculational assumptions employed in the Hawley report and substituting numerical values that are more correct for the UCLA case than those used by Hawley. Such a level of stored energy is sufficient, if released, to raise the graphite temperature 600 to 1000°C above the temperature which had triggered the release, assuming adiabatic conditions. In sum, an incident involving a relatively modest initial temperature rise in the graphite--of roughly 120°C--would be sufficient to trigger release of sufficient Wigner energy to ignite the graphite or otherwise put the reactor fuel at risk of igniting and/or melting.*

14. The Hawley report underestimation is caused by a series of cumulative errors. First of all, the value chosen for the rate of energy storage at 30°C is low by a factor of between 1.2 and 2. Next, the ratio of energy storage at 50°C to that at 30°C is low by about 40%. In addition, Hawley uses a thermal flux that is low by a factor of 3.3, based on empirical measurements at UCLA. And he estimates a total operating history of 12 MW-days, whereas the UCLA reactor has already run 19 MWd in its first 20 years and, if relicensed, can run an additional 37 MWd through the licensed period, given the operating restrictions at the facility. This is a further error of 4.7. The cumulative effect of these errors ($1.2 \times 1.4 \times 3.3 \times 4.7 = 26$ to $2 \times 1.4 \times 3.3 \times 4.7 = 43$), a factor of 26-43, depending on which initial value is chosen for the rate of energy storage at 30°C, is quite substantial. The errors are discussed in more detail below.

15. The Hawley report takes the value of .5 cal/g per MWd/At as the best value for the rate of energy storage in graphite irradiated at 30°C, citing Nightingale's Nuclear Graphite, p. 328. However, on page 345 of the same text, Nightingale states that "more accurate" values at low exposures range from .6 to 1.0 cal/g per MWd/At.

16. In order to correct these rates for the somewhat higher temperature found in the Argonaut's graphite, cited to be approximately 50°C, Hawley uses a correction factor of 3/5ths. Data given by Nightingale (p. 328) for the change in the rate of energy storage with temperature, however, when graphed (see attachment) produce an actual ratio of 5/6ths (inverse 1.2). This yields storage rates of .5 to .83 cal/g per MWd/At at 50°C, as opposed to the .3 assumed in the Hawley report at this stage of the calculation.

---

* i.e., assume an initial temperature of 50°C and some incident which raises the temperature, not 600°C to the melting point of the fuel, but rather a mere 120° to the temperature at which Wigner energy is released. Assuming no heat loss, the released stored energy would be sufficient to raise the graphite to 770 to 1170°C, well above the ignition temperature of the graphite or the ignition/melting temperature of the fuel.

17. Using the equation given by Nightingale relating thermal flux and MWd/At (p. 328 of Nightingale), Hawley then obtained a rate of energy storage in the UCLA reactor. The Nightingale approximation* is:

$$\frac{\text{Thermal nvt (BEPO equivalent)}}{\text{MWd/At}} = 6.4 \times 10^{17}$$

Inserting the correct values yields a rate of energy storage for graphite in the UCLA reactor of 7.8 to 13 x 10^{-19} cal-cm^2/g-n, compared to Hawley's value at this stage of 4.7 x 10^{-19}.

18. Hawley then attempted to estimate integrated thermal neutron flux (nvt, in n/cm^2) in order to convert, through the approximation provided above, into cal/g. To estimate integrated flux, Hawley assumed a flux rate of "about 10^{12} n/cm^2-sec." This order of magnitude estimate was quite crude, as Hawley assumed the flux to be <u>1.0</u> x 10^{12}, whereas actual measurements made at UCLA indicate neutron flux as high as 3.3 x 10^{12}.**

19. Hawley then assumed that the reactor had logged 120 full power days, in order to estimate integrated flux (i.e., flux in n/cm^2 per second as determined in 18 above, times number of seconds, to produce n/cm^2 integrated dose.) However, UCLA reports (Amended Application, p. III/8-7) that it had logged 19.4 MWd (or 194 full power days) in its first 20 years. In addition, Hawley failed to consider the next 20 years for which UCLA has requested the license. At a 5% operating limitation, as in the Technical Specifications, that would be approximately an additional 37 MWd, for a total of about 560 full power days to the end of the licensed period, in contrast to the 120 assumed in the Hawley report.

20. Inserting the more correct integrated thermal neutron flux into the relationship obtained from Nightingale in 17 above one gets a potential stored energy of

560 full powers days x 86,400 sec/day x 3.3 x 10^{12} n/cm^2-s x 7.8to13x 10^{-19}cal-cm^2/g-n

yielding a potential stored energy of 125 to 208 cal/g of graphite. This is in sharp contrast to the 5 cal/g estimated in the Hawley report.

21. Integrating over the applicable range of temperatures the values for the specific heat of graphite given by Nightingale on page 122, one determines that 125-208 cal/gram would correspond, if released and assuming no heat loss, to a temperature rise of approximately 600 to 1000°C.

---

* Hawley does not demonstrate that this approximation from Nightingale is universally applicable. It is used here only in following the Hawley methodology in order to demonstrate that given the methodological assumptions employed, but using more correct numerical values, a substantially different result is obtained.

** "Gamma Flux Mapping of the UCLA Training Reactor" by George B. Bradshaw, Masters Thesis, 1965, p. 53. The study measured both gamma and neutron flux at a series of locations in the graphite. The measurements were in limited locations and therefore even higher fluxes elsewhere in the core cannot be ruled out. Note also that the earlier draft of my calculations referred to in Professor Warf's affidavit were based on the assumption of a smaller flux because I had not then obtained the Bradshaw data.

22. Thus, using the Hawley methodology and more appropriate numerical inputs, it is concluded that more than sufficient energy can be stored in the UCLA reactor's graphite to produce, if released, temperatures in excess of the ignition temperature of the graphite, magnesium, and uranium, and the melting temperature of the cadmium control blades and the aluminum-uranium fuel.

23. The lack of an emergency cooling system thus becomes quite significant from a safety standpoint, as does the lack of detailed fire response plans. Furthermore, as Professor Warf has indicated in his declaration, use of water or carbon dioxide to fight such a fire could be disastrous because of the explosive chemical reactions possible. (Metal-water reactions, as Michio Kaku and Boyd Norton have indicated, can also be initiated by a power excursion at this facility.)

24. Mr. Ostrander in his September 1, 1982, declaration asserts that it would take hundreds or thousands of years of operation of the UCLA reactor to produce enough Wigner energy storage to be of concern. He bases that assertion on the experience of the Hallam reactor, which was shut down because of swelling and cracking of the graphite moderator, and asserts that such deleterious effects were observed at Hallam after a far greater integrated fast flux than could be generated in the UCLA reactor. There are a number of flaws in Mr. Ostrander's assertion (among them, that it is not at all clear that the swelling was due to neutron bombardment as opposed to thermal or other effects), but one need only examine one of the errors--the ignoring of differences in operating temperature--to dispose of the matter.

25. Mr. Ostrander cites as basis for his assertion above an answer by CBG to an interrogatory about the Hallam flux, but fails to mention the graphite operating temperature at Hallam cited by CBG in that answer. That normal temperature during operation is 600°C for the graphite, well above the annealing temperature for the graphite. Above about 200°C, virtually all of the radiation damage is constantly being annealed out of the graphite by the high operating temperatures. That is why high temperature graphite reactors have essentially no Wigner problem. It is the low temperature graphite reactors, i.e. those reactors who operate at temperatures below which significant annealing of the graphite takes place, who must worry about stored energy. And UCLA's is a low temperature reactor. Hallam was not.

The Critical Temperature for the UCLA Reactor

26. The Cort and Hawley analyses, as well as the Staff and UCLA reiterations thereof, are based on the premise that essentially no fission product release can occur should reactor temperatures remain in an accident below about 640°C, the melting temperature of the fuel meat. They therefore conclude that if, in the case of Cort, airflow in the fuel boxes were cut off in a seismic event, the reactor would not be at risk because the maximum temperatures attained would be below that critical temperature; likewise in the Hawley report, which indicates temperatures just below the melting temperature in case of power excursion, and concludes that no fission product release would occur.

27. However, all of these analyses ignore the crucial additional energy that could be added to the incident from release of stored Wigner energy in the graphite. Whereas Hawley indicates a power excursion could produce fuel temperatures of 590°C, just below that of the melting temperature, a graphite temperature rise of only about 120°C is sufficient to release what appears to be enough Wigner energy to push the reactor far over the threshhold temperature for ignition and melting. The same is true with the Cort analysis. Even accepting all of Cort's other assumptions*, peak temperatures of about 360°C are predicted. While insufficient in and of itself to melt the fuel, such temperatures would not necessarily be insufficient to push the graphite over the Wigner threshhold, releasing sufficient energy to melt the fuel or ignite the core. Similarly, heat sources deemed in the Hawley study insufficient to ignite the graphite by themselves may not be insufficient to cause release of the Wigner energy, which could then bring about such ignition. Thus, a common-mode accident involving an incident insufficient in itself to bring about ignition or melting could well trigger release of sufficient stored energy to bring about that result. And, in a sense, the concept of <u>stored</u> energy means this is an accident mode present throughout the lifetime of the reactor, just awaiting the triggering incident.

28. Thus, the critical temperature for the UCLA reactor is about 170°C, the Wigner threshhold, not 640°C, the melting temperature of the fuel meat. I note that the Application (p. III/8-9) indicates that fission fragment release from aluminum/aluminum-uranium alloys is significant at temperatures of 400°C or higher. Furthermore, the Hawley study indicates the ignition temperature of materials that may be placed in-core are substantially lower than the maximum temperatures Hawley assumes for a power excursion. And none of the analyses examine the effects of cladding softening and volumetric expansion that can occur at temperatures substantially below that of the eutectic melting temperature. Even were there no Wigner potential, the critical temperature for this reactor would thus be considerably below the melting temperature of the fuel or the ignition temperature of the graphite. (Note also, as indicated earlier, that uranium may ignite in air at temperatures well below that of the U-Al melting temperature, and that, as Professor Warf indicates in his declaration, cadmium metal control blades melt at around 320°C).

<u>Conclusions</u>

29. Accepting the Hawley methodology and substituting numerical values more accurate for the UCLA case indicates substantial Wigner energy can be stored in the graphite of the UCLA reactor during the license period. This energy, if released, could raise temperatures well above ignition and melting temperatures. The energy release can be triggered by a relatively small initial temperature rise; thereafter the reaction is self-heating. Thus, a number of scenarios of credible accidents which result in temperatures asserted to be below the melting temperature of the fuel could actually result in putting the fuel at risk, due to release of the stored energy, through fire or melting, or both.

---

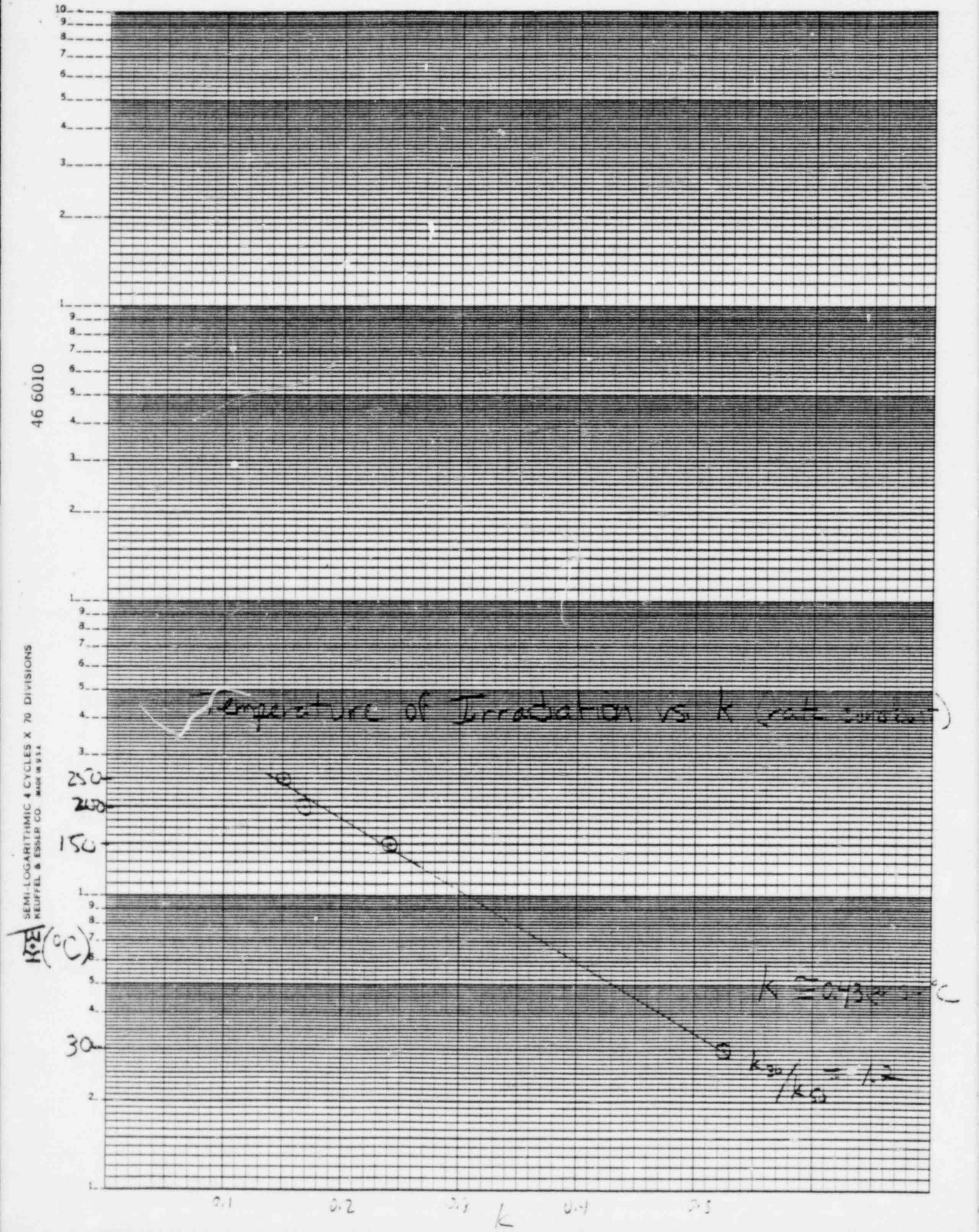
* Note that Mr. Cort assumes no effect on thermal conductivity of either the fuel or the graphite due to irradiation effects. This erroneous assumption invalidates the final results, as they are highly dependent upon the values used for thermal conductivity.

I declare under penalty of perjury that the foregoing is true and correct to the best of my knowledge and belief.

David R. Dupont

David R. Dupont

Dated this 23rd day of December, 1982, at Ben Lomond, California



Temperature of Irradiation vs k (rate constant)

Professional Qualifications

DAVID R. DUPONT

My name is David R. Dupont. I am a chemist associated with the Southern California Federation of Scientists (SCFS).

I worked, in cooperation with Professor James Warf, a colleague at SCFS, on an assessment of chemical reactions that might affect reactor safety at UCLA. This included assessment of the potential for combustion of the reactor's graphite, magnesium, and/or uranium constituents; the potential for explosive reactions with steam, water, or carbon dioxide should such a fire occur or elevated temperatures otherwise result; Wigner energy storage and other effects of radiation upon the chemical and physical properties of the reactor materials; and the chemistry of fission product release at temperatures above and below the melting point of the fuel meat.

I received a Bachelor of Science Degree in Chemistry from the State University of New York at Albany in 1977. From 1980-1982 I was a Research Associate in the Biological Chemistry Department at the University of California at Los Angeles.

UCLA MISCELLANEOUS "FACTS"

36. See response to UCLA fact 17, under contention XIX

37. See response to NRC fact 3 under contention VII