PANEL II

6/14/83

CHEMICAL REACTIONS

Introduction

1. In 1957, a very serious fire occurred at a non-power reactor located at Windscale, England. 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, which permitted build-up of stored "Wigner" energy in the graphite. Release of that stored energy contributed to the cause of the fire, which resulted in extensive damage and 20,000 curies of iodine-131 being released to the environment. Milk contaminated with I-131 had to be disposed of in an area of 200 square miles around the reactor because of the accident.

2. In 1960, the UCLA Argonaut-type reactor began operation. Its Hazards Analysis did not address Wigner energy storage, and a brief paragraph dismissed the potential for fire largely based on the assertion that "none of the materials of construction of the reactor are inflammable." (p.62)

3. As the Windscale fire showed, and as shall be discussed in detail below, that assertion is dangerously untrue.* The graphite can burn; the uranium metal can burn; the magnesium can burn; even the aluminum under some circumstances will burn. And ignoring Wigner energy can likewise be dangerous.

4. It has further been asserted that the only chemical reaction of significance to be considered for the UCLA reactor is a water reaction with aluminum, and that aluminum would have to be in the form of metal filings for such a reaction to occur. That, too, is not the case.

5. Each of the destructive power excursions with aluminum-clad, plate type fuel (SPERT, BORAX, and SL-1) has apparently resulted in significant metal-water reaction. Much of the core disassembly in those three cases can be traced to a combination of steam explosion and metal-water reaction. The aluminum was in the form of fuel cladding; most assuredly, not in the form of metal filings. A destructive power excursion, thus, could result not only in fuel melting, but in explosive disassembly of the core due to explosive steam and metal-water reactions.

6. Similarly, fire suppression response, particularly if ill-prepared as in the UCLA case, can vastly worsen the situation. Metal-water reactions between the aluminum, uranium, and magnesium can be explosive and liberate considerable energy if water were poured on those substances when burning. Likewise with burning graphite. Furthermore, use of water in a fire-fighting situation could have unforeseen reactivity effects.

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* The original UCLA Hazards Analysis was apparently copied virtually verbatim from materials provided by AMF and by the University of Florida, and makes a number of serious errors. As shall be shown further, so do the new analyses UCLA has copied. This is one of the major dangers of copying analyses verbatim from others, rather than performing the analysis independently.

7. The potential for fire, Wigner energy release, and explosive or otherwise destructive chemical reactions has been examined for the case of the UCLA Argonaut-type reactor. It is concluded that the UCLA reactor is not inherently protected against serious damage from these chemical reactions, and that significant radioactive releases to the environment could ensue. Fire is a particularly dangerous hazard scenario for the UCLA reactor since it could release virtually all of the volatile fission products and could provide a powerful driving force for substantial release of particulates.

8. It is further concluded that the design characteristics of the UCLA Argonaut are most unfortunate from the point of view of inherent protection against such chemical reactions and their effects. Use of combustible materials such as magnesium, graphite, and uranium metal in an essentially dry core, without the inerting or sealing employed in modern graphite reactors, poses a substantial fire hazard. Low-temperature normal operation makes Wigner energy storage a substantial problem (Wigner energy is not stored at higher temperatures), providing the potential for significant release of heat being triggered even in an otherwise minor accident. This is further complicated by the fact that the fuel and control blades are made of very low-melting materials. The core constituent materials furthermore represent substantial potential for explosive or other destructive chemical reactions in situations such as power excursions or fire. These matters will be detailed below.

FIRE

9. The original Hazards Analysis for the UCLA reactor dismissed the probability of damage from fire resulting in the release of fission products as "very small" in part because "none of the materials of construction of the reactor are inflammable." (1960 UCLA Reactor Hazards Analysis, p. 62, "Fire"). While other factors may affect the probability of fission product release from fire, the statement that none of the materials of construction of the reactor are inflammable is simply incorrect. A number of those materials-- particularly the graphite, uranium, magnesium, and even the aluminum, among others-- are, under the right conditions, most definitely combustible.

10. The first and most obvious of the combustible materials used in the Argonaut reactor is the graphite-- used as moderator, reflector, and thermal column. Graphite will, under the right circumstances, most definitely burn, as the Hawley report correctly indicates. (Charcoal is, after all, a graphitic substance, and it will, of course, readily burn.)

11. On page 82 of the Proceedings of the 1958 Atomic Energy Commission and Contractor Safety and Fire Protection Conference (attached), held at AEC headquarters in Germantown, Maryland, June 24-25, 1958, held in part to analyze the implications for reactor safety of the Windscale accident in which the graphite moderator and the uranium fuel both caught fire, Dr. C. Rogers McCullough of the USAEC is quoted as saying:

> By the way, this is an amusing point. The belief had grown up on the part of many people in this country that graphite will not burn. This is nonsense. Graphite is carbon, and anyone knows that carbon will burn if you get it hot enough. But this glib remark, that graphite will not catch on fire, had become prevalent.

Graphite can, of course, burn in air, as the Windscale fire unfortunately so clearly demonstrated. A belief to the contrary would be neither correct nor prudent.

12. As to the matter of the ignition temperature of graphite, it is dependent upon a number of factors such as the purity and density of the graphite, the amount of air present and the velocity of the air, the particle size and surface-to-volume ratio of the graphite, and structural configuration influencing heat loss. Furthermore, there appear to be other uncertainties, as evidenced by Dr. McCullough's comments at the same page of the above-cited proceeding:

> Research work is going on; we are not satisfied that we knew the ignition point of graphite.... At any rate, research is going on to learn more about the ignition temperature. It is a tough problem to solve, and we are exploring possibilities.

Thus, there are some uncertainties as to ignition temperature of graphite, and it might be wise from the point of view of a conservative safety analysis to place or establish the magnitude of error on whatever estimate of ignition temperature is used. The Hawley report uses a figure of 650°C as the point at which graphite will burn readily if sufficient oxygen is supplied. There are some uncertainties and some error limits might be appropriate. Any temperature estimate is valid only for a fixed set of parameters (density, purity, particle size, air supply, irradiation history, etc.).

13. Once ignited, self-sustained combustion of the graphite must be assumed if the air supply is adequate. Although this depends upon configuration, and the like, Hawley assumes for purposes of his analysis that somewhere around 650°C is the critical temperature for induction of a self-sustained fire in the Argonaut reactor's graphite. This temperature is above a glowing red heat but below a white heat. The reaction is exothermic, so if some of the graphite were ignited, it could release enough heat to bring other graphite to the ignition temperature.

14. In addition to graphite, the Argonaut reactor at UCLA employs metallic uranium in a uranium-aluminum eutectic, clad with aluminum. Metallic uranium readily burns in air if ignited, and under somewhat more restrictive conditions, so can aluminum. Aluminum gives off more heat, pound for pound, than uranium metal when burned, but it is somewhat more resistant to burning. The fact that the uranium and the aluminum are in a eutectic will not affect the ability of either to burn, although burning of the eutectic will give off slightly less heat than if the materials were not in a eutectic. However, the difference is insignificant. In addition, the fact that the eutectic melts at a relatively low temperature (640°C--Hawley, p. 18), will not affect the ability of the materials to burn. The metals can burn as well in a liquid form as in a solid. In fact, molten metal can cause fresh aluminum, without the normal protective oxide layer, to be exposed to air, making burning far more likely.

15. As to ignition temperature for uranium metal, again there are some uncertainties. Charles Russell (<u>Reactor Safeguards</u>, Pergamon Press, Oxford, 1962, p. 115-116, citing W.C. Reynolds, Report NACA TN D-182, "Investigation of Ignition Temperatures of Metals") gives the ignition temperature of solid uranium metal in oxygen at 1 atmosphere as 608°F (320°C). The

United Kingdom Atomic Energy Authority, in a report on the Windscale accident (in which both the uranium and the graphite were burning) states that, "In still air uranium oxidises, i.e., the reaction is self-heating at 350°C; the corresponding temperature with carbon dioxide is 650°-700°C." (Nucleonics, Vol. 15, No. 12, December, 1957, p. 91)

16. Turnings of reactor-grade uranium have ignited when being cut using a lathe, evidently from friction. Finely divided uranium ignites in air at room temperature. Thus the ignition temperature is a variable, depending on circumstances, but in general uranium metal must be considered more combustible than graphite. The details of combustibility of the uranium-aluminum eutectic certainly merit investigation, in both solid and liquid states.

17. The control blades at the UCLA reactor are reportedly cadmium-tipped and protected by magnesium shrouds. Magnesium can also burn, and when it does so it gives off considerable energy. The ignition temperature of Mg metal is variable, depending on its particle size, etc. If one specifies a desired ignition temperature, from 25° up, one can prepare a specimen which will ignite at that temperature. One should be aware that slow oxidation occurs below ignition temperature.

18. Cadmium metal is a low-melting metal with a relatively high vapor pressure. The Handbook of Chemistry and Physics reports its melting temperature as 320°C. If the control blades are made of the metal and not the oxide, it would seem prudent to analyse the reactivity and other possible consequences of an incident which resulted in the melting of the control blades. For example, an incident involving fire or other high temperature event might cause the low-melting control rods to melt out of the core region, increasing reactivity as well as making control difficult. Furthermore, the volatility of cadmium could potentially result in cadmium vapor being released in a fire or other incident involving elevated temperatures. If so, the cadmium vapor or its oxide would likely rapidly condense in air as minute particles and could cause a potential hazard for fire-fighters or others due to the toxic nature of cadmium. This, too, should probably be considered, it would seem, in designing fire-fighting plans and analyzing potential accident sequences and consequences.

19. UCLA is requesting a license for 2 curies of plutonium-239 in a plutonium-beryllium neutron source for the reactor facility. Were this Pu-Be source to become involved in fire, the consequences could verge on the catastrophic. Plutonium metal, of course, can burn, releasing minute particles into the air, dispersed by the energy of the fire. Fire-fighting would be extremely hazardous due to the presence of the plutonium oxide in the air, and the public health implications would be awful. (2 curies of Pu-239 is by no means an insignificant amount; placed near the skin, it will cause radiation burns in a few minutes; inhalation of even microgram amounts is exceedingly dangerous.) When Pu metal burns, it goes to PuO_2 in limited air, to Pu_3O_8 in excess air, just like uranium. Be is comparable to Al in its combustion, but is higher melting. Again, the chemical form of the material is important, i.e. whether in metal or oxide. BeO is volatile in steam at high temperatures.

Explosive Reactions in Fire

20. The issue of how to fight a graphite-uranium fire, leaving aside the possibility of cadmium and plutonium particles being released, has no easy answers and would require considerable prior analysis of the problems inherent and preparation in advance in the form of emergency planning. There could be great danger, in particular, in employing either water or, to a lesser degree, carbon dioxide to put out the fire. In either case, an explosion might occur, owing to the formation of combustible gases.

21. Dr. McCullough's report on the Windscale incident, in the AEC document referred to above, describes how those fighting the fire tried various methods over a couple of days to put the fire out, which involved both uranium and graphite, all to no avail, and how they had to try, as a last resort, water:

> Now they were faced with the decision either to use water or to let the fire burn up. They decided there was nothing left for them to do but put water in. There was some trepidation about this, as you can imagine, because they well knew that water on glowing uranium makes hydrogen. Water on glowing carbon makes hydrogen and CO; you have then a nice mixture of hydrogen, CO, and air, and you might have an explosion.
>
> But they had no other choice.

They, in the end, followed techniques learned during World War II in extinguishing incendiary bombs, and fortunately the gamble paid off. But they had no other choice, and rightly were extremely worried about the potential for an explosion. The fact that one did not occur at Windscale does not get one around the fact that such an explosion is clearly possible, could be quite dangerous, and that water should, if at all possible, not be used, or if used, used with the potential danger clearly thought out. As McCullough concluded:

> I think it took a great deal of courage on the part of these people to put water on this reactor. They did it with fear and trepidation, and in talking with them they will not guarantee that they could do it a second time without an explosion.

It should be noted that the steam that ensued carried with it very significant quantities of fission products into the environment.

22. The potential for metal-water or metal-steam reactions should be examined in putting together fire-fighting plans. Aluminum, uranium, magnesium, and graphite all can react in a steam environment, producing large amounts of energy, liberating hydrogen which can cause explosion dangers. Russell indicates the Al-H_2O reaction liberates more than twice the energy of nitroglycerin, in calories per gram, and five times the energy of black powder; the magnesium-water reaction just slightly less than aluminum; and the U-H_2O reaction just somewhat less than black powder. (Al + NH_4NO_3 was used as a cheap explosive in Vietnam, "Daisy Cutter.")

23. The use of CO_2 on such a fire could also be dangerous. Graphite is oxidized by CO_2, yielding carbon monoxide, which is also explosive in the presence of air.

24. Simple carbon tetrachloride extinguishers that formerly were used for lab fires have a host of problems associated with their use, notably the toxic phosgene they give off when used on fires. And even some chemical foams might have a favorable moderating effect that needs to be taken into account (this can be gotten around, perhaps, by the addition of boron-containing compounds to such foams).

25. A fire in this reactor raises other serious reactivity questions as well (e.g. power excursion implications). If water, or some other moderating substance, were used to suppress the fire, a power excursion might result. If the control blades melted out of position, the equivalent of a large positive reactivity insertion might ensue. Furthermore, the positive temperature coefficient of the graphite means that as the temperature rose in the graphite, reactivity could increase as well. All of these factors could make a fire at the reactor even more serious.

26. Firefighters would have to be prepared to deal with potentially toxic substances such as cadmium fumes in the air, and work in an environment possibly contaminated with fission products and perhaps plutonium. They would need good information as to what materials had been released into the air and in roughly what concentrations, good detectors for those materials, and ability to read and interpret that information. They would need appropriate equipment to protect themselves from inhalation of the materials and from direct exposure. They would need to know the appropriate way to fight such a fire without making it worse.

27. It is not likely that a group of firefighters arriving on the scene of a fire at the UCLA reactor would have the competence to judge whether to use water, and if so, how, etc. This is acknowledged in the Fire Department's one-page fire response plan included in UCLA's proposed emergency plan, which essentially says that the Fire Department, upon arrival at the scene, will suppress the fire if the reactor is not involved, and will "confer" if it is. Without an emergency response having been carefully considered in advance, and without stockpiling of carefully chosen, non-moderating materials that could be used to smother the fire without reacting explosively with burning core components, a fire could be made immeasurably worse. And instructions to not attempt to suppress the fire if the reactor is involved until conferring with reactor personnel and others (who might not be available, for example, at night or on weekends), while sensible in the absence of a carefully-thought-out plan for safe response, could mean substantial delay before suppression was attempted, permitting the fuel to be at greater risk.

28. Both the NRC Staff's Safety Evaluation Report (p. 9-2) and the Hawley report (p. 30-43) indicate that the UCLA reactor is not inherently protected against fire, and that protection against radiation release is dependent upon prompt and correct fire department response. The Hawley report outlines a number of scenarios that have potential for leading to such a fire, and indicates that, "depending on the length of time before discovery of the fire, the aluminum fuel boxes and fuel could be at risk for melting." (p. 43) As noted above, discovery alone would be insufficient, because of the lack of preparedness and the difficulties involved in fighting a graphite-uranium-magnesium reactor fire without causing the reactor to explode.

Fire Scenarios

29. The Hawley report presents a number of potential fire scenarios. Among them: welding torch accidentally igniting outer graphite; power excursion sufficient to ignite a flammable solvent (a common mode scenario for this event would be a power excursion caused by breakage of the sample container in which a large sample dissolved in solvent is being irradiated; removal of the neutron-absorbing material from the core could initiate the power excursion which, even though perhaps insufficient to melt the fuel itself or ignite the graphite, could ignite the solvent with its lower flash point); nuclear heating of inserted materials "to a temperature high enough to ignite various flammable substances seems well sithin the realm of possibility"; building fire; and so on. One can suggest numerous others as well, but it is sufficient to indicate that the reactor is not inherently protected against fire.* The Hawley report indicates that a number of these scenarios could put the fuel at risk,if proper and prompt response were not made to suppress the fire. The report also indicates that because graphite produces little smoke when it burns, the fire might go unnoticed for substantial periods of time. There is no procedure in the emergency plan for actually fighting a reactor fire. Given these factors, a reactor fire can occur and can put the fuel at risk. Fires are common events.

30. The NRC Staff has asserted that a graphite fire in the UCLA reactor would occur only if an experiment failed and a general building fire occurred and the reactor's graphite blocks were exposed to a free flow of air. The Staff cites pp. 41-43 of the Hawley report. We must not be reading the same report. Page 41 refers to a credible scenario in which a building fire occurred while the shield blocks were removed; there is no mention of the necessity of a failed experiment as well. Credible common-mode causation is suggested by the authors. Page 42 of Hawley describes a credible accident scenario caused by a failed experiment alone. The bottom of p. 42 continuing onto p.43 describes another credible scenario, a simple building fire while the shield blocks were removed. The Staff appears to have misread its consultants' report.

Sufficient Airflow for a Fire

31. The current Safety Analysis Report of UCLA (1982) no longer makes the mistake of its original Hazards Analysis in denying the combustibility

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* In addition to the reactor itself catching fire, significant hazards could occur through radioactive release due to other kinds of fire at the facility. For example, there could be considerable danger if the plutonium source at the facility was involved in fire. Other radioactive substances (for example, "hot" samples that had been irradiated in the core) could ignite, either in-core or outside. A fire in the "rabbit room", where the samples return after being irradiated in the core, could be quite serious. (See photos of the rabbit room, showing plastic bags containing hundreds of plastic vials containing radioactive samples, being stored.) A fuel-handling accident could likewise involve fire, were, for example, the fuel placed in a vat of solvent to clean off surfaces for inspection and were the solvent to ignite.

of the reactor's constituent materials. A new assertion is made, however, that there is insufficient air present for a fire, once started, to be sustained for extended periods. UCLA cites as basis for its assertion an asserted measured airflow out of the core extract line. In so doing, they completely miss the point.

32. First of all, UCLA contradicts itself in several places as to the actual flow rate out of the core extract line. Secondly, it is simply incorrect to assert that the air flow rate in and out of the entire core is identical to the flow rate in the small diameter core extract pipe. If that were true, one would merely have to seal off the core extract line and there would be no Argon-41 emission; the radioactive material would decay away within the core and not need to be exhausted out the reactor stack. The core is full of air, and that air passes in and out of the core through the many interstices in the graphite blocks and the cracks in the shield blocks and the numerous other passageways. A measured flowrate in a small line is irrelevant to the flowrate in and out of an unsealed core.

33. Lastly, and most importantly, the measured flowrate during non-fire situations is completely irrelevant to the flowrate that would occur during a fire. Fires are self-feeding-- they create convection currents that draw in and exhaust air. If this were not so, and the UCLA assumption were correct, no fire could ever occur unless a mechanical ventilation system were feeding the fire with air. No house with closed windows could ever catch fire inside, if the UCLA assumption were correct, because no fans were present and measured flow rate inside was low. One does not need to provide a fire with air; it provides itself.

34. Thus, even were the University correct in its estimate of flow rate during normal conditions, in which an extract line fan produces forced circulation, such a measurement is irrelevant with regards the air flow possible in case of a fire. The fire would produce convection currents, drawing air in and exhausting depleted air. After all, the airflow rate into a gas water heater is essentially zero when it is off; once the gas is ignited, however, the natural convection currents created by the released heat provide the necessary airflow. And so it would be with the UCLA reactor.

35. The airflow argument is spurious. Even if airflow were substantially restricted, that could well merely slow the rate of reaction rather than prevent it. The airflow produces two opposing effects-- it provides oxygen and removes heat. Restricted airflow will reduce heat loss, which can help to sustain the fire. There are obviously lower limits to airflow capable of sustaining the fire, but with the convection currents produced and the lack of a sealed structure, there is no evidence that those lower limits are approached for the reactor. (Furthermore, there are numerous scenarios involving the exposed graphite with a ready source of air-- insertion of experimental apparatus into the core, welding near the thermal column, etc.)

<u>Not Inherently Protected Against Fire</u>

36. The primary materials of the reactor (graphite, uranium metal *, magnesium, and so on) are combustible. The reactor is not sealed; it is

* In this respect it appears unfortunate that the fuel is not an oxide, which would be far less susceptible to burning.

essentially a pile of graphite and concrete blocks with numerous penetrations for control blades, piping, and the like. The core is diffused with air; otherwise there would be no Argon-41 problem from the activation of normal Argon in air. And the air within the core can readily be transported in and out of the core; again, if this were not the case, there would be no Argon-41 problem. Fires can occur in such graphite pile type reactors-- witness the Windscale reactor fire, which occurred with the ventilation shut down. Modern graphite reactors are generally contained inside a leak-tight vessel in an inert atmosphere to prevent fire. The UCLA reactor has no reactor vessel, isn't inerted, and has no containment. <u>The UCLA reactor is certainly not inherently protected against fire.</u>

<u>Wigner Energy</u>

32. As indicated earlier, the UCLA reactor's primary constituent material of construction is graphite, which serves both as moderator and reflector, and provides some structural support. 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 w/o 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. The control blades are also made of a very low-melting substance, cadmium, melting at 320°C.

33. 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, 0.015 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 accompany various credible accident scenarios.

34. 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 occurence.

35. 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.

36. In addition to posing a simple thermal threat from Wigner release that could endanger the fuel's integrity, the graphite is, as indicated above, 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. Uranium is likewise combustible, with an apparently considerably lower ignition temperature ($\sim 350^{o}C$). This is also true of the magnesium of the control blade shrouds. So, if sufficient Wigner energy were stored in the graphite, a relatively small initial temperature rise (to about $170^{o}C$) could be sufficient to ignite or melt the core's contents.

37. The relatively low temperature required for annealing the radiation damage in graphite and releasing the stored energy points out one of the unfortunate aspects of the inherent design of the UCLA Argonaut. Whereas the low normal operating temperature of the reactor would be a favorable feature in most reactors, it has adverse effects in the Argonaut because of the graphite design. Progressively larger amounts of self-annealing occur at higher operating temperatures; conversely, larger amounts of Wigner energy are stored at lower operating temperatures, such as those found at UCLA. Thus, a low-temperature reactor such as UCLA's would be far more vulnerable to problems from Wigner energy than a high-temperature reactor, in which virtually all of the Wigner energy would be constantly annealed out of the graphite.

38. Furthermore, the small size of the UCLA reactor does not necessarily mean that the amount of Wigner energy absorbed per gram of graphite is likewise small. In fact, were a large-sized reactor and UCLA's far smaller reactor to both produce 1 MW-day of energy, all other things being equal, the amount of Wigner energy absorbed in each gram of adjacent graphite would be considerably greater in the UCLA reactor than in the larger reactor, for the simple reason that the larger reactor has far more graphite to absorb the same amount of energy, thus the energy absorption per gram of graphite is "diluted." All other things being equal, a large reactor with the same neutron flux as the UCLA reactor, run for the same length of time, would produce the same amount of energy absorbed per gram of graphite as the UCLA reactor. And it is the energy absorbed per gram of graphite that is the key to whether enough energy has been stored to bring any part of the graphite to ignition if enough air is present; given the proper configuration, one unit of graphite ignited could release enough heat to bring many additional units of graphite to the ignition point.

Assessment of Wigner Energy Storage in the UCLA Reactor

39. The 1957 Windscale accident-- in which Wigner energy release contributed to ignition of both the uranium and the graphite in the core and resulted in substantial fission product release to the environment-- 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 in reactors operating at low temperatures such as UCLA's.

40. 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.

41. 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. *

42. 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 MW-days in its first 20 years and, if relicensed, can run an additional 37 MW-days 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 to 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.

43. The Hawley report takes the value of 0.5 cal/g per MW-day/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 (attached), Nightingale states that "more accurate" values at low exposures range from 0.6 to 1.0 cal/g per MW-day/At.

44. 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. 330) for the change in the rate of energy storage with temperature, however, when graphed (see next page) produce an actual ratio of 5/6ths (inverse 1.2). This yields storage rates of 0.5 to 0.83 cal/g per MW-day/At at 50°C, as opposed to the 0.3 assumed in the Hawley report at this stage of the calculation.

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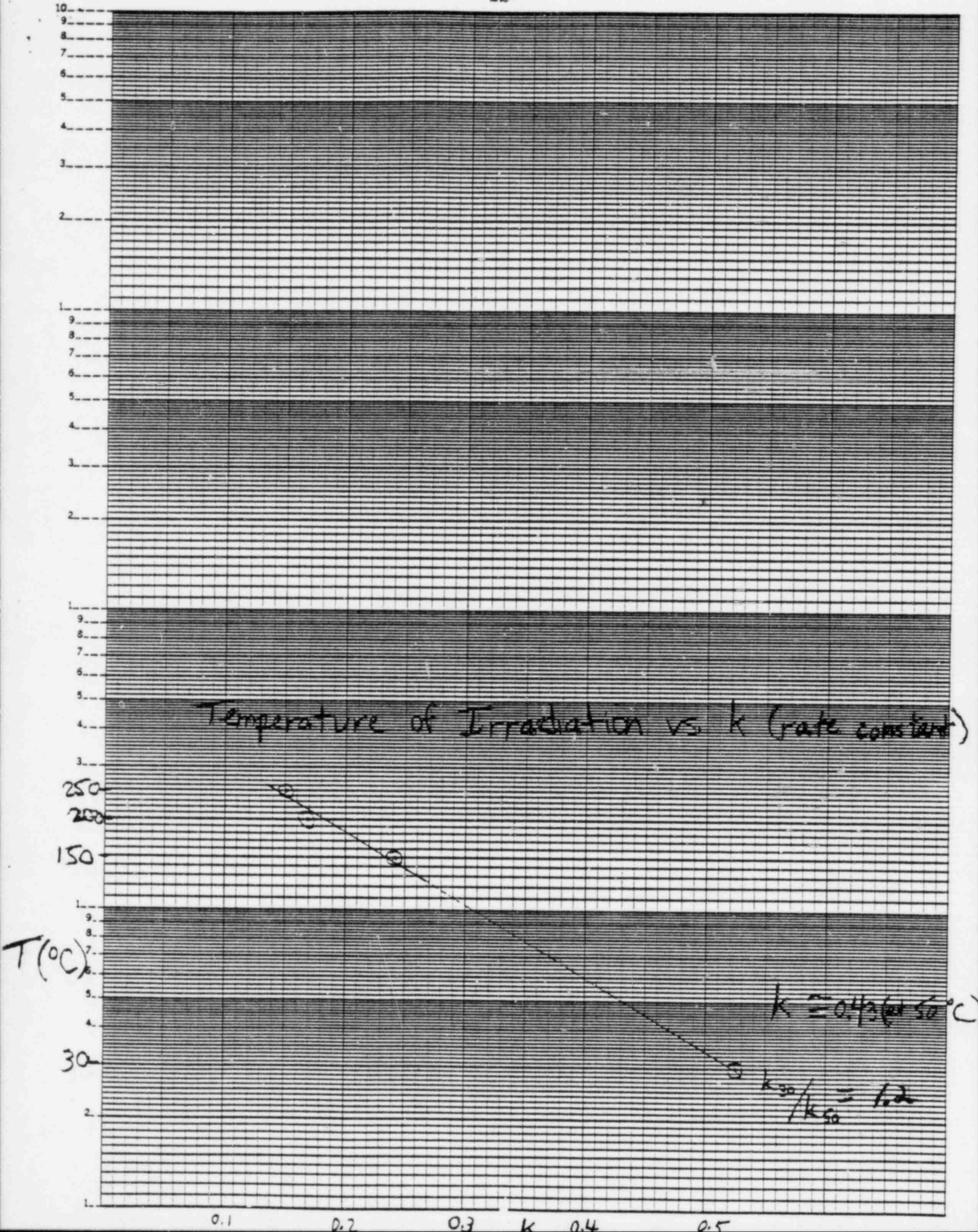
* i.e., assume an initial temperature of 50°C and some incident which raises the temperature, not 600°C to the melting point of the fuel, but rather a mere 120°C to the temperature at which Wigner energy is released. Assuming no heat loss, the released stored energy would be sufficient to raise the graphite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


Temperature of Irradiation vs. k (rate constant)
250
200
150
30
T(°C)
k ≅ 0.43 (at 50°C)
k30/k50 = 1.2
0.1
0.2
0.3
k
0.4
0.5

45. 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:

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

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}.

46. 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 1.0 x 10^{12}, whereas actual measurements made at UCLA indicate neutron flux as high as 3.3 x 10^{12}. **

47. 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 46 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 MW-days (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 MW-days, 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. ***

48. Inserting the more correct integrated thermal neutron flux into the relationship obtained from Nightingale in 45 above one gets a potential stored energy of:

$$560 \text{ full power days} \times 86{,}400 \text{ sec/day} \times 3.3 \times 10^{12} \text{n/cm}^2\text{-s} \times 7.8 \text{ to } 13\times10^{-19} \frac{\text{cal-cm}^2}{\text{g-n}}$$

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.

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* 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.

*** Furthermore, there appears to be some uncertainty as to the past irradiation history of the UCLA reactor's graphite-- whether, for example, it might have been previously used in another reactor prior to the construction of the UCLA reactor. Thus, the true maximum exposure may be greater than the 56 MW-days assumed here.

49. 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.

50. 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.

51. 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 which operate at temperatures below which significant annealing of the graphite takes place, which must worry about stored energy. And UCLA's is a low temperature reactor. Hallam was not.

The Critical Temperature for the UCLA Reactor

52. 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

* The graphite in the UCLA reactor has, by the way, apparently exhibited in the past some swelling or dimensional change, which could be physical evidence of Wigner energy storage because, in addition to storage of Wigner energy, radiation damage in graphite can cause dimensional changes in the graphite. Furthermore, the UCLA reactor is occasionally used to color diamonds. If this effect is due to changes in the diamond's crystalline structure and not to impurities in the diamond, this would be further evidence of this reactor's capability of causing radiation damage in graphite, as graphite and diamond are the two crystalline forms of carbon and would react similarly to neutron bombardment.

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.

53. 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. Thus, were substantial Wigner energy stored in the graphite, an excursion not producing enough energy to melt the fuel alone may still have enough to trigger the Wigner release, which could add enough energy to bring the fuel to melting or ignition of either the graphite or fuel.

54. 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.

55. <u>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</u>. And, in a sense, the concept of stored energy means this is an accident mode present throughout the lifetime of the reactor, just awaiting the triggering incident.

56. So, the critical temperature for the UCLA reactor is about 170°C, the Wigner threshhold, not 640°C, the melting temperature of the fuel meat.

57. (Note that the Application (p. III/8-9) indicates that fission product release from aluminum/aluminum-uranium alloys is significant at temperatures of 400°C or higher. Furthermore, the Hawley study indicates the ignition temperatures 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 examines 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 cadmium metal control blades melt at around 320°C.)

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* 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 dependent upon the values used for thermal conductivity.

Conclusions as to Wigner Energy

58. 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.

Corrosion, Cladding Damage

59. As indicated at the outset, the primary barrier to fission product release at the UCLA reactor is 0.015 inch thick aluminum cladding. Severe corrosion of that cladding could produce substantial fission product release, including release of soluble, non-gaseous fission products.

60. Because of the low utilization of the reactor, fuel originally installed in the core in 1960 could remain there until the end of the proposed license period, the year 2000, due to the small burnup rate. Forty years, much of which is spent in water, could produce substantial corrosion of the thin cladding, particularly if water quality is not adequately maintained. Failure to properly calibrate or maintain the resistivity monitor for the primary coolant, and an inadequate secondary coolant monitor, could prevent discovery of substantial release until after it had occurred.

61. The University now claims that the primary coolant leak that developed after the 1971 earthquake and required major maintenance and a long shutdown were not due, as originally stated, to the earthquake but rather to corrosion of the aluminum primary coolant piping. If the far thicker aluminum piping was so substantially corroded in ten years of operation by exposure to the primary coolant, then the far thinner aluminum fuel cladding could well be at substantial risk over the forty year period being considered. (The University of Maryland converted its reactor to low-enriched TRIGA fuel in part because of its inherent safety from power excursions and its non-proliferation advantages, but also because of concern that its MTR-type fuel plates might be losing the integrity of their aluminum cladding after 11 years of use in a water-cooled reactor.)

62. Much work has been done on the attack of uranium ingots, clad in aluminum, through a pin hole. At elevated temperatures, air or water enters the pinhole, reacts, and the resulting oxide swells. This breaks more Al skin, and the process continues faster; oxidation is retarded so much the ignition temperature is not reached. Powdered uranium (from decomposition of UH_3) can react with liquid water and glow red, forming UO_2 and H_2. Massive U metal must be heated to react.

63. Numerous materials attack aluminum. Accidental insertion into the coolant of chemicals detrimental to aluminum, or experimental addition of some such material, or an attempt to remove material clogging parts of the coolant piping through addition of a flushing compound, or other acts could all result in severe and rapid degradation of the cladding and release

of fission products. Some materials react explosively with aluminum, which could be even more devastating. Note also that hydrogen is produced when aluminum corrodes, and that underwater aluminum tanks have exploded at reactors due to the explosive hydrogen-air mixture that evolved. (see Reactor Operating Experience Report 70-3, attached.)

Explosive Reactions

64. We described earlier the extreme danger of explosive reactions that could occur were water or CO_2 employed on a fire at a reactor containing graphite, uranium metal, aluminum, and magnesium, such as at UCLA.

65. Steam explosions and metal-water explosive chemical reactions are possible if a power excursion of the SPERT/BORAX/SL-1 type were to occur at UCLA. The three reactors all had their cores explosively destroyed by such reactions, the onset of which and the initiating conditions necessary for which are not fully understood. It is not even certain, due to their unpredictability, that such reactions couldn't occur even if the maximum temperatures attained in the fuel were slightly below the melting temperature.

66. Other explosive reactions could result from the explosion of NEL experimental apparatus or irradiation of explosive materials, due to improper experimental review, lack of adequate procedures or supervision, rule violations, failure to recognize the explosive nature of certain materials, or other mistake.

Conclusion

67. The original Hazards Analysis was in considerable error when it dismissed the risk of fire on the basis that none of the constituent materials of the UCLA Argonaut reactor was combustible. On the contrary, the graphite, uranium metal, magnesium, and even the aluminum can burn. In particular, the graphite, uranium and magnesium all have relatively low ignition points (i.e., temperatures that could quite credibly occur at some point in the reactor's operating lifetime, through accident, equipment malfunction, building fire, etc.)

68. Subsequent analyses relied upon by UCLA are also seriously flawed in their assessment of the potential for fire and other 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 accident are severely underestimated.

69. The reactor is not inherently protected against fire. Substantial fission product release could ensue-- over 90% of the gaseous material (those species volatile at the temperatures attained in the fire) and roughly 40% of the particulate matter, dispersed by the driving force of the fire.

70. Sufficient Wigner energy storage can occur in the UCLA Argonaut to cause melting and/or ignition, if released. Even were a fire not to follow, fuel melting could ensue, releasing greater than 25% of the volatiles.

71. The UCLA reactor is vulnerable to numerous other reactions as well, including metal-water reactions during power excursions or fires and corrosion of fuel cladding.

72. The threshhold temperature for the UCLA reactor in accident is not 640°C, the melting temperature of the fuel, but 170°C, the trigger temperature for Wigner energy release. Thus, numerous accident scenarios which in themselves are not sufficient to put the fuel at risk may be sufficient to trigger the Wigner release, which could push core temperatures over the ignition and melting points.

73. The UCLA Argonaut is not inherently protected against severe core damage from fire, Wigner release, and explosive and other destructive chemical reactions. In fact, numerous inherent design features make the UCLA Argonaut reactor uniquely vulnerable to serious accidents of the sorts described above: low temperature normal operation, low-melting fuel and control blades, fuel made of uranium metal rather than oxide, control blade shrouds made of magnesium, moderator/reflector made of graphite, all with no sealing or inerting.

74. Lastly, we cannot emphasize enough that using water on a graphite-uranium-magnesium fire in the UCLA reactor could be disastrous.

CHEMICAL REACTIONS

Exhibit List

Exhibit Number	Description
C-II-1	"The Windscale Incident", by C. Rogers McCullough
C-II-2	Nuclear Graphite by Nightingale (excerpts)
C-II-3	"Gamma Flux Mapping of the UCLA Training Reactor" by G.B.Bradshaw (excerpts)
C-II-4	L.A.Fire Dept. Emergency Response Plan for fire at NEL
C-II-5	"Aluminum Tank Explosion" (ROE 70-3)
C-II-6	Photos taken within the Nuclear Energy Lab

EXHIBIT C-II-1
12 pages (cover sheet,
+ pgs. 74-84)

TID-7569

proceedings of the 1958 Atomic Energy Commission and contractor safety and fire protection CONFERENCE

held at
Atomic Energy
Commission
Headquarters Building,
Germantown, Maryland
JUNE 24-25, 1958

UNITED STATES ATOMIC ENERGY COMMISSION
Technical Information Service

The Windscale Incident

By C. ROGERS McCULLOUGH

U. S. Atomic Energy Commission, Washington, D. C.

To discuss the Windscale incident, I have broken my talk into two parts. First, I wish to talk about the accident and what actually happened. Then I would like to draw a few conclusions as to what this means and how we can profit by it.

Let me state at the very beginning that this was an accident that was very serious insofar as the reactor was concerned. As far as I am aware, the reactor is still shut down, and the authorities do not know quite what to do with it. Whether it will ever be repaired and put back into service is a really serious question.

However, the damage to people was zero or effectively zero. Exposures of plant personnel were minor. The highest exposure figure was 4.6 r, as I recall it. The damage to people off the plant site was even less.

You are no doubt aware of the publicity given to the destruction of milk; this was a precaution that was taken in order to make sure that good public relations were preserved, that the confidence of the public in the United Kingdom Atomic Energy Authority was preserved, and that there was no possibility of radiation damage.

Actually the milk could have been held for a short time, and radioactive decay would have brought the activity down to tolerance (I calculate something on the order of two weeks), and there would have been no problem.

Before reviewing the actual events of the accident, I want to quote a statement published in a British official paper: "We are particularly conscious that the Windscale accident brought to the surface the latent public anxiety about the hazards of atomic energy work. Now that the nation is committed to a large nuclear power program, we consider of the utmost importance that the hazard of atomic energy should neither be exaggerated nor minimized in the public mind." I think this is the outstanding lesson of Windscale.

Now, to go into the description of the accident: On Monday, October 7, they were carrying out what is called a Wigner release. The Windscale piles are graphite piles (a big cube of graphite, more or less a 50-ft cube). In this cube of graphite, there are channels, holes into which the cartridges or slugs of natural uranium jacketed with aluminum are placed.

These reactors when running at power are cooled entirely by blowing air through the reactor. It is a British custom to push the air through the reactor; whereas in this country we pull the air through. (We have two air-cooled graphite reactors, a small one at Oak Ridge and a somewhat larger one at Brookhaven.) There are some consequences of this, as you will see. I do not mean to say that the British are wrong, because there are things to be said on both sides of the question.

Before proceeding with the time table, let me add that you should realize that, when you have graphite subjected to neutron bombardment (which you must have to get the moderation), the atoms of the graphite are dislocated. The graphite swells and it swells nonuniformly. As a result, you will get a distortion of the holes into which the fuel slugs must be pushed, and after awhile the distortion is so bad that you will not be able to use some of the channels.

Now, Wigner predicted that this effect would take place in the early days of constructing graphite piles in this country at Hanford. The Hanford reactors are water-cooled piles, by the way. But nothing was known about how to take care of this situation.

Quite by accident the British found out one time that annealing took place in one of their reactors. At the same time the graphite is distorted, nonuniformly or nonsymmetrically, energy is stored in the graphite and, if the graphite is heated up to something on the order of 400°F or so, the release of this energy can be triggered, and the temperature will go up still further. During this process you get annealing just like you do when you anneal tempered steel; the energy comes out, and the graphite returns to somewhat its original dimensions.

So it has been customary in the case of the British and American reactors to periodically anneal the graphite to avoid this distortion to channels.

At the time the incident occurred they were carrying out one of their routine annealing operations. Now, as I will point out later, you must remember that this is an operation for which the reactor pile was not designed originally. This is something that was added for good and sufficient reasons after the pile was built.

Anyway, on Monday, October 7, at 7:25 p.m., they started up the reactor in the nuclear sense. The custom was to keep the air flow down to a very minimum; actually, when they start, they turn the air off completely. (I will go through the time table and we will come back and pick up the slides.) They ran this until 2:00 a.m., Tuesday, October 8, and then they shut the nuclear heating off because the temperature had reached the point at which they knew, from experience, that the triggering of the energy release would start.

However, as they watched the thermocouples, which they had in the reactor, they began to fall; whereas in the normal annealing, the couples would rise slowly and level off, spreading the energy throughout the pile and uniformly annealing the graphite.

Now, remember that the objective here is to get all the energy out of the graphite. I may point out another thing, that, if you keep on storing this energy in graphite without annealing it, you reach the point at which there is enough energy stored in the graphite, so that, if it were triggered, it would go up to a temperature beyond control. In other words, the stored energy would exceed the specific heat of the graphite, and you could have a runaway condition; obviously, you want to anneal in order not to have this occur.

The objective therefore is to anneal the pile completely. You do not want any pockets of unannealed graphite building up this stored energy.

When the Windscale people at least thought they had found thermocouples falling off, a decision was made that they had better give the reactor a second shot of heating. They applied this second shot at 11:00 a.m. on Tuesday, the 8th. Then at 5:00 p.m. they shut it off again.

During this second annealing, the operator slipped a little bit and ran the rate of reaction faster than the rules called for; however, this was not considered a very serious violation of the procedures. The rate of heating was not considered dangerous. It was merely a little bit faster than that normally carried out.

At 2:15 a.m., Wednesday, the 9th (they had been watching these thermocouples all the time), they discovered they were slowly rising. Some of them had gotten to greater than 400°C, so they decided that they had better cool the reactor. This was part of the procedure they had been given.

They opened the dampers. (There is a stack connected with this reactor which, when the dampers are open, lets air suck through them.) They opened them for 10 minutes or 15 minutes first, and the temperatures came down a little and then came up again.

On Thursday, October 10, right after midnight, they opened the dampers again for 10 minutes to try to cool it off. This cooled it very slightly.

Again at 2:15 a.m. they opened the dampers for 13 minutes, at 5:10 a.m. for 30 minutes, again trying to let the draft effect from the stack pull air through to cool the reactor. This did not work, and at 5:40 a.m. they noticed an activity up in the stack — radioactivity. There are filters in the top of the stack; therefore there is a very high background, so the sensitivity of this method of detection is not very good.

Nevertheless, they got a rise. This did not bother them too much because they had found in the past that, when you open the dampers, it pulls some radioactive dust through; this is more or less routine.

Then at noon on the 10th, they found some activity on the roof of the meteorological station; this was unusual, and they knew that something had gone wrong.

In previous experience, when they had slug ruptures in this pile, they had discovered that the activity that gets out and deposits on the ground around the station was the gross mixture of the fission products. They immediately began monitoring and found this activity, but it was not very high, so they had no particular concern.

Then at 12:10 p.m., they opened the dampers again to try to cool the reactor off; now, they got a very marked increase in the stack activity, and they knew they had a slug rupture of some sort.

At 1:40 p.m. they opened the dampers for 5 min, but still no real decrease in the temperature.

At 1:45 p.m. they turned on the so-called "shutdown fans." They had decided that they had to do something to cool this reactor off; it was getting well above the 400° mark, which is dangerous. It is apt to break the cladding of the uranium slugs which will be too hot and will catch fire.

Now, another point here is that in the back of the pile they have a scanner that is supposed to detect slug rupture. In carrying out the Wigner anneal, they cannot run the scanner, but, by turning on the shutdown fans, they can cool it down so that it will operate again. This turned out to be a vain hope. They also wanted to cool down the pile if they could.

At 3:50 p.m. on the 10th, the temperatures—fuel temperatures, the thermocouples on the fuel temperatures—showed that these were hotter than the graphite temperatures. Then they took out some plugs.

At 4:30 p.m. they took out some plugs in the shielding on the front face in order to look in. They found that some channels were glowing red hot, so they knew that they had a fire.

Now, they decided that, first, they were going to push out the channels that were on fire, and they got together all of the push rods etc., then the men put on the protective clothing necessary to work close to the reactor to try to push out the burning channels, but they would not push.

The channels were plugged tight; they were red hot. The push rods came out with molten uranium dripping off them.

Remember, this is exposed uranium. The activity levels got so high in the charge hoist that they abandoned this operation. Then they decided they had to make a fire break. They pushed out all the channels surrounding those, roughly 150 channels, which they suspected being on fire. This was on Friday, October 11.

They realized now that turning the fans on full might either blow the fire out, or it might make it worse, and, if it made it worse, maybe the heat would get up the chimney and burn out the filters. If this should happen, then they would really have a mess. At this point they decided to install equipment to put on water if they decided they finally had to at the last ditch.

About 1:38 a.m. on the 11th they took a pyrometer reading on one of the channels and got a reading of 1300°C. They now had a real hot fire; they got some CO_2 from the Calder Hall reactors, and they blasted it into one of the holes. It did not make a dent in the fire at all.

Now they were faced with the decision either to use water or to let the fire burn up. They decided there was nothing left for them to do but put water in. There was some trepidation about this, as you can imagine, because they well knew that water on glowing uranium makes hydrogen. Water on glowing carbon makes hydrogen and CO; you have then a nice mixture of hydrogen, CO, and air, and you might have an explosion.

But they had no other choice. They followed the technique learned back in the war days of putting out incendiary bombs. They put the water in at the top, using fire hoses. The water getting in would trickle down and gradually cool as it advanced. It finally did cool in this way, and they were able to put the fire out.

Then on Saturday, the 12th, they finally turned the water off. The fire was out.

On the left-hand side of Fig. 1 is the control room and slug storage area. You can also see the place called the charge hoist. This is the spot from which they had to work to charge the pile and to examine it and try to find out what was going on.

In front of the charge hoist there is a double shielding wall. You see the charge space, so-called. There is a wall between it and the charge face. That wall is thick enough to allow

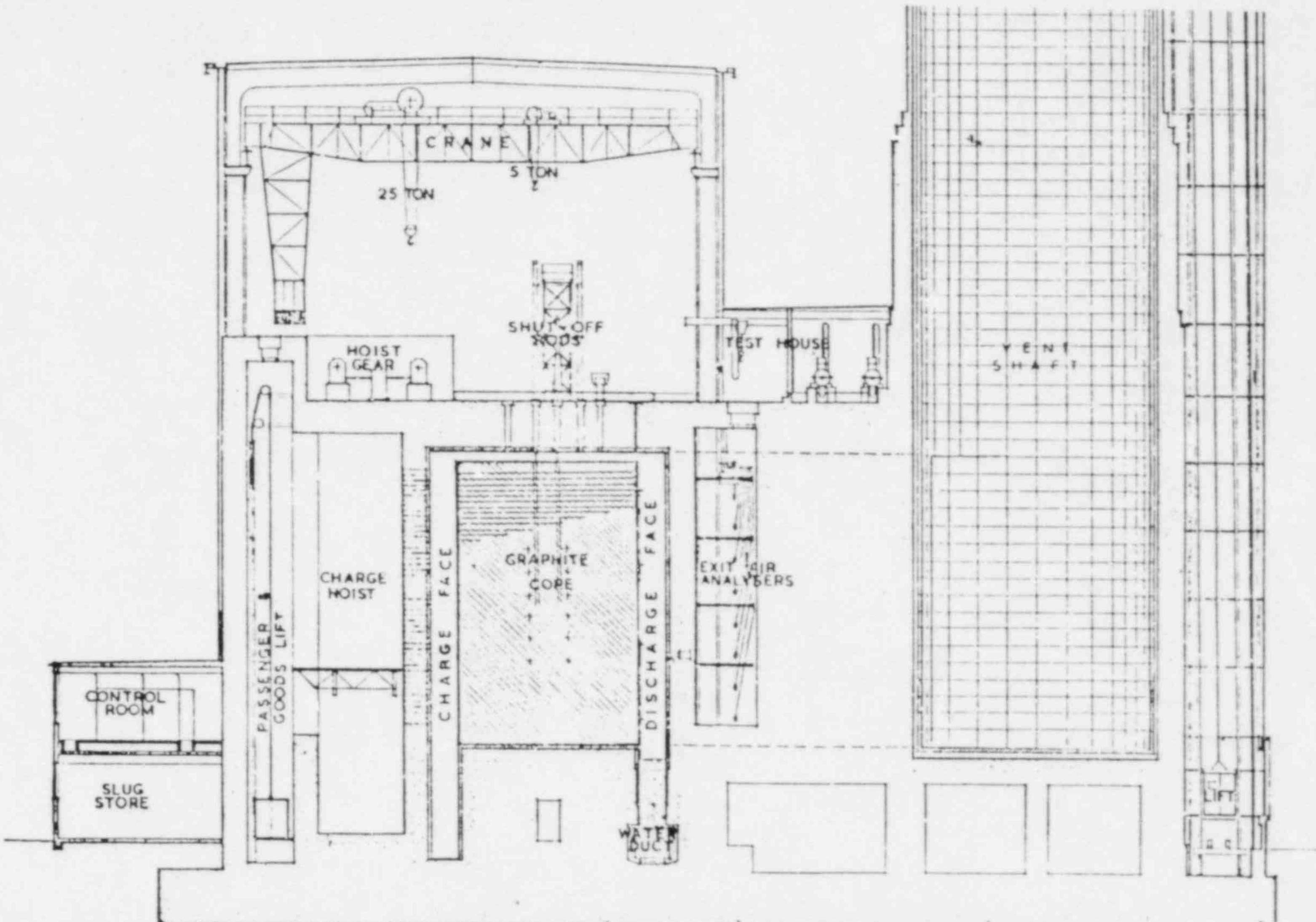

Fig. 1 —Cross section of Windscale pile.

the people to work there when the pile is shut down, but it is not thick enough to shield them with the pile running. There is another wall out beyond the passenger and goods elevator.

In order to work on the charge hoist, the shutdown fan must be run so that there is a pressure built up in the charge hoist that is greater than the air pressure in the graphite in order to keep contamination from falling out into the charge hoist.

Now, the air goes through the pile, goes in the plenum chamber of the discharge face, goes to this chamber in the back where there are some exit air analyzers, which were not used, by the way, during this operation; then it goes through two chambers and up the so-called "vent shaft," which is a chimney 40 ft in diameter and 400 ft high.

At the top of the vent shaft are the filters. These are just ordinary glass fiber filters, something similar to those you put in your air-conditioning units at home.

The next figure, Fig. 2, shows the slug storage, the goods hoist, and the charging platform where the men work.

The little black dots that can be seen on the wall are plugs that can be removed to charge the reactor. Each plug services four graphite channels. Guide tubes to slide the fuel in at an angle are placed in these channels. Then it goes through the graphite block and into the plenum chamber in the back of the reactor.

There are monitors at the top of the stack, under the glass fiber filters, which show activity; but, because of the accumulation of activity on the filters, these are not very sensitive devices.

Notice the control-rod system. (I might mention here that part of the trouble was that the Wigner release is a nonroutine operation, and procedures had not really been worked out, and some of the problems had not been foreseen.) The procedure was to put in the control rods at the top and actually run the reactor from the bottom half, but the monitoring chambers are at the top corners of this reactor.

When you have this situation, the monitors, with the control rods all in on the top half, are not a reliable indication of power. In the second nuclear heating, they probably went up to a higher level and more rapidly than they really realized.

The reason they adopted this procedure was that, if you generate the heat at the bottom due to convection current, a more uniform heating of the block of graphite is obtained. This, I think, contributed to their trouble, because they did not know exactly what they were doing in the nuclear heating.

Figure 3 shows the fan pushing the air in the various chambers. The shutoff rods are at the top.

Figure 4 shows a plan view; in one of the discharge ducts shown is the scanner, which enables them to take samples of the air coming out of every one of the fuel channels when the pile is in normal operation. This works very well in normal operation, but, when carrying out a Wigner release, you have to raise the temperature of this air in the back much higher than in normal operation; this jams the scanners.

That is the reason the scanners do not work during the Wigner operation; they were not designed for this purpose. They had no particular worries about this because previous experience had shown no reason why a slug should rupture during the Wigner release.

The danger of slug ruptures is present when you are running the reactor normally, or so they thought. There are sampling devices in the chamber which, again, they did not use because they did not feel that there was any danger of a slug's rupturing, and they were not aware that they were in trouble until the situation had progressed quite a ways. Then they did try to run these samplers, but the indications were not very satisfactory; they did not quite know where they were.

I think it took a great deal of courage on the part of these people to put water on this reactor. They did it with fear and trepidation, and in talking with them they will not guarantee that they could do it a second time without an explosion.

Let us now discuss the consequences. Remember, I made the point that all their previous experience had shown that, when you get activity out, you have the fission products in the proportions in which they exist in the slugs. Therefore, for some time they did not appreciate the fact that they had a probable escape of radioactivity because the general level was fairly low on the ground around the plant site.

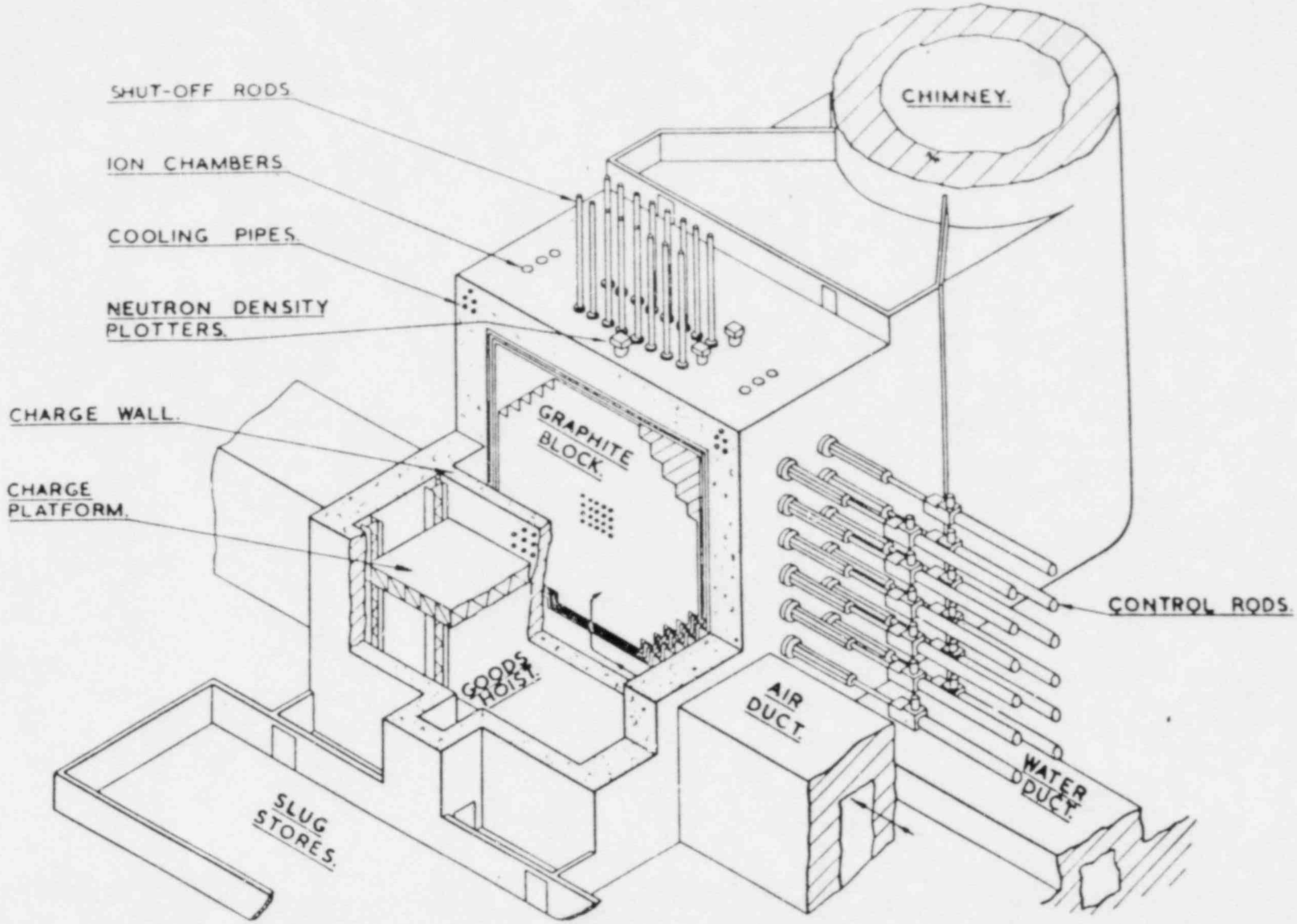

Fig. 2—Isometric diagram of a Windscale pile.

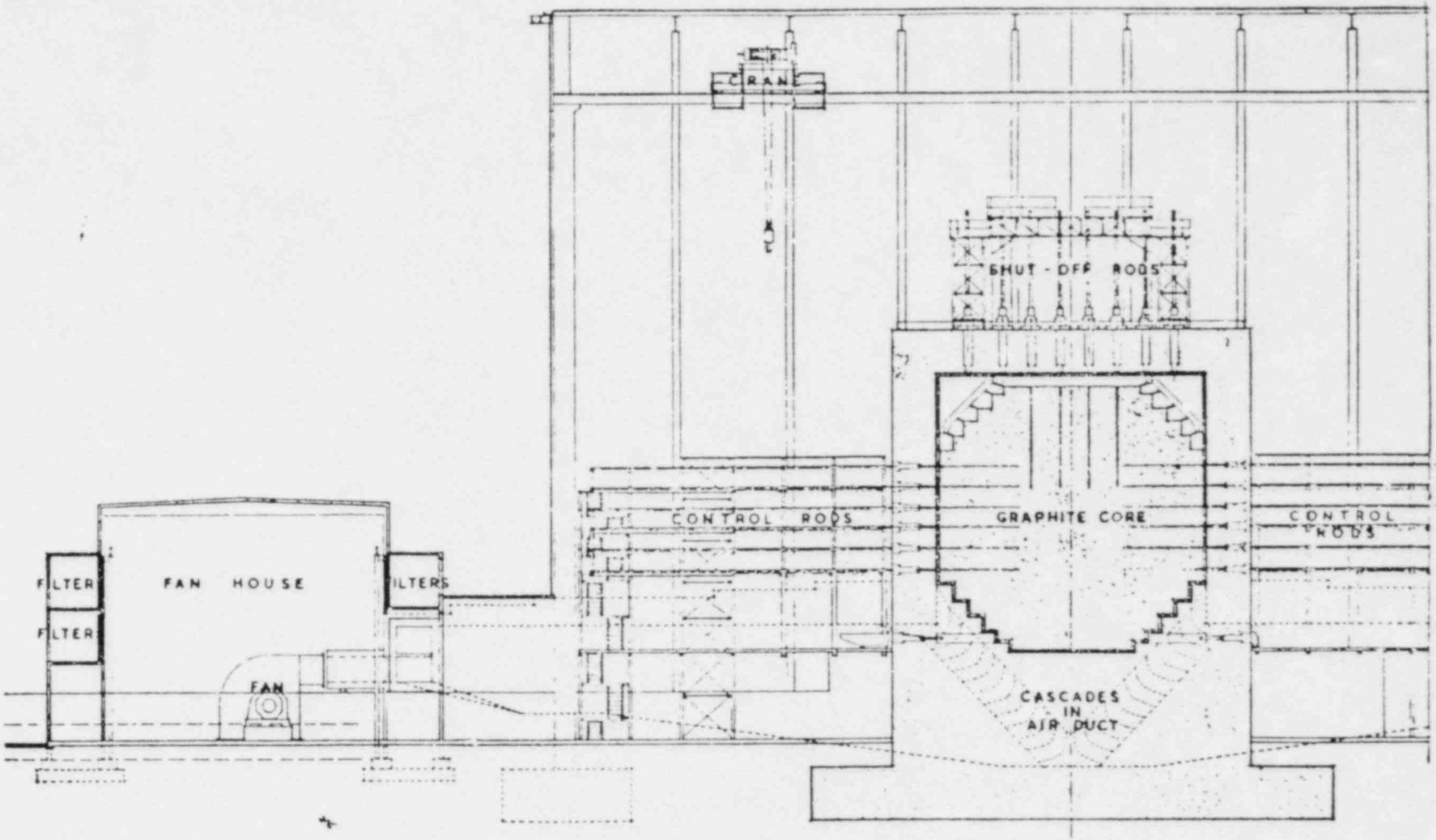

Fig. 3—Longitudinal section of Windscale pile.

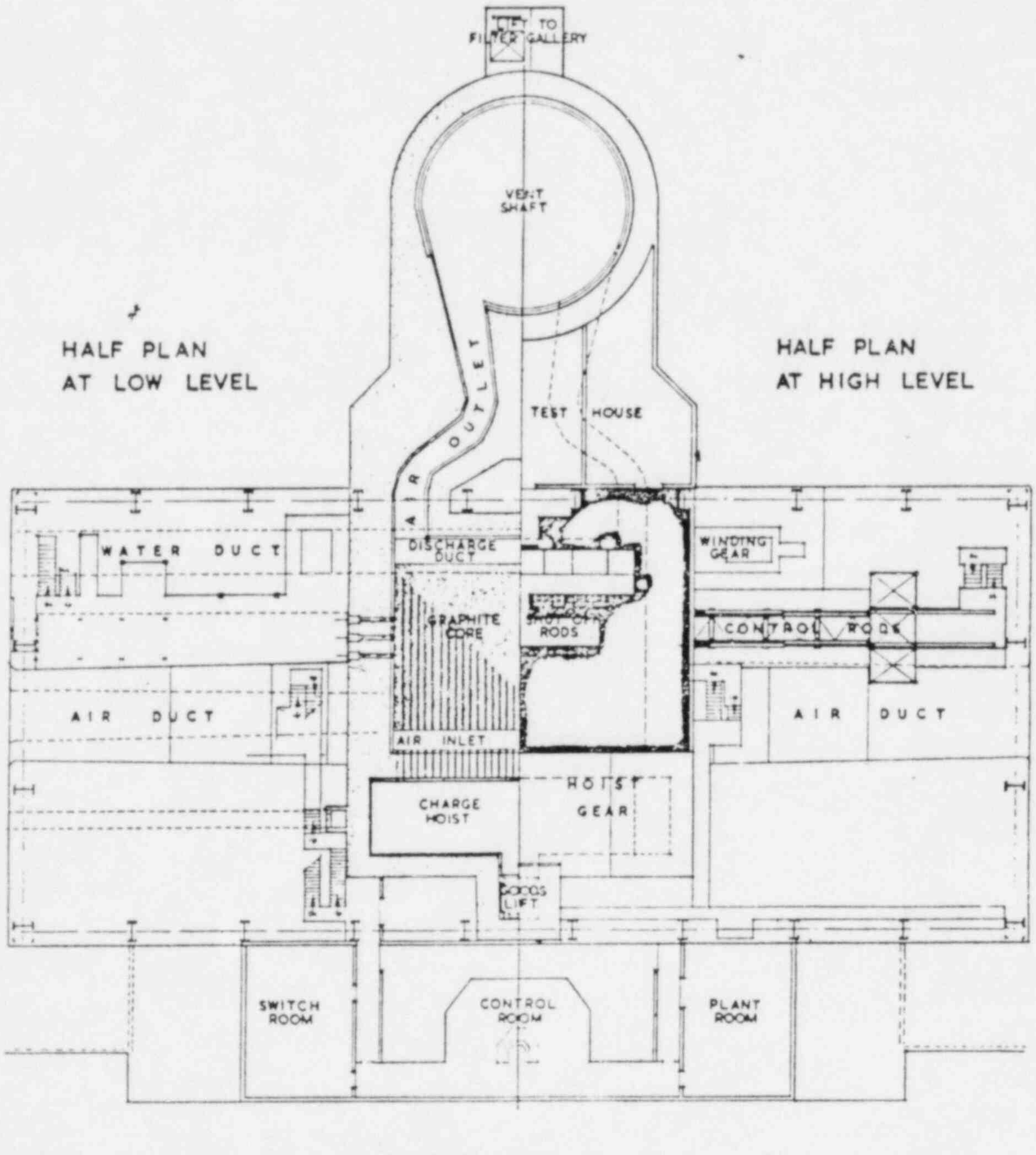

Fig. 4—Plan of Windscale pile.

On Saturday afternoon, a day or two after they knew they had an accident on their hands, they began to realize that they had an excess of iodine released. At this point they began to sample milk. They took, of course, the first milk samples near the plant site. The analyses of the milk took a little time.

They began to find radioactive iodine and they kept extending the area of milk sampling. Volunteers came in to help them carry out the sampling program. The Army went out to help them by gathering the samples; meanwhile, there were up to 200 workers in the laboratory analyzing milk samples.

They finally ended up with 200 sq miles under a milk ban. They analyzed samples from all the different dairy farms in the area.

No tolerances had been set up for iodine in milk because this had not been foreseen as a problem, and they had to make a quick decision, which they made on Monday, I believe. They decided to set the limit of radioactive iodine in the milk at $^1/_{10}$ μc/liter, which is an exceedingly low value.

It turns out that a medical board has endorsed this figure, and I think the International Committee on Radiation Protection will come along with a figure very similar to this, if not the same one.

Now, in reference to the activity on the people, those who worked there worked at a tolerance of 3 rads (or roentgens) to the worker in a 13-week period.

Over the 13-week period up to October 24, they read the film badges. They did not have any really good way of telling how much radiation the people received at the time of the accident except the levels shown on those film badges covering the 13-week period. This was not an exactly accurate reading for the accident. Fourteen of the workers exceeded the permissible limit of 3 r. The highest figure was 4.66 r. Two workers were estimated to have received 4.5 r and four others, 2 r.

Thyroid surveys for iodine in the workers' thyroids were made, and nothing alarming was found on that score. At the last report they were still surveying thyroids and were finding nothing very significant. The highest activity found in the thyroid was about $^1/_2$ μc.

They offered to let the people of the vicinity come in on a voluntary basis and be examined for thyroid activity. Quite a number of people did this, and in no case have they found anything — the last I knew — very alarming.

During the milk survey, they developed an instrument right on the spot that would enable them to take a milk can and check whether or not its activity was low enough to let the can pass without further examination. In this way, many samples were eliminated. Otherwise, it would be difficult to see how they would have gotten through. Again I want to point out that they did not need to dump this milk; in the first place, within a couple of weeks it would have been found to have decayed to tolerance. The highest sample was only 20 times the tolerance of $^1/_{10}$ μc/liter.

Moreover, if they had made the milk into cheese or some other dairy product, there would have been no real radioactivity problem. But, since children were consumers of milk, they wanted to be very sure, so they just dumped it.

Now let us talk about the lessons learned. I made the point that these reactors were designed in the early days and were not designed to carry out the Wigner release. This was an operation which had been added.

Therefore, the first point is that the Wigner release was an operation for which the pile was not originally designed. Point two: the Windscale piles had operated so well that confidence in continued operation without trouble had built up to a dangerous degree. The subtleties of nuclear reactors had been lost sight of to some extent (especially the possible difficulties of the Wigner release had not been recognized).

Three: there had been no systematic study of the accidents that could happen during the operation of the Windscale pile, including the Wigner release operation and the provision of adequate facilities to cope with burst slugs during the Wigner release.

Four: the means of detecting burst slugs during the Wigner release were not adequate.

Five: means of measuring slug and graphite temperatures throughout the pile were not adequate. They had very few, relatively, thermocouples.

Six: means of detecting the graphite fire were not provided.

Seven: there were no written procedures for carrying out the Wigner release with criteria determining the steps to be taken in case of an abnormal operation.

Eight: there was insufficient technical manpower available to the operating crew to study the problems, if they became abnormal, and to advise of the actions to be taken.

Nine: organization and procedures for dealing with the consequence of the accident when it occurred were inadequate.

From the viewpoint of these lessons, we have examined our own reactor procedures (I told you earlier that we have two graphite reactors that are air cooled in this country). It did not take many minutes really from the time we heard about the Windscale incident until the operating groups of those two reactors were right on the ball studying their own problems to be sure that they would not fall in the trap that had beset our British friends.

Now, I want to make another point here. I think it is pretty obvious that the British had not foreseen what would happen. I do not believe that we can foresee everything that can happen, but I do think we can work very hard at it. As a result of having worked hard at it over quite a few years, I think the results of this care and foresight show up in our operating safety record.

At the same time I want to warn you that we have been lucky, very lucky; I am sorry, but I just do not believe that we are humanly perfect enough to avoid radioactive releases or accidents in an industry as big as this. Thus we must be prepared to face some oversights that will occur. This does not mean, however, that we should not keep trying to keep our accident record as good as we possibly can. Thank you.

DISCUSSION

HAYES: Dr. McCullough, I am sure there may be some questions asked. I would like to ask you one, myself. I notice that as a last resort they turned to water; I did not realize that the British had to do that at Windscale. Do you have any recommendations or suggestions as to when we determine whether we can put water on the fire? We would like to know whether research is needed or whether, as a result of this accident, any studies are being carried on which will give us some clues to what should be done in the case of a fire.

McCULLOUGH: Yes. We are making studies at Brookhaven on how you would go about putting out a fire if one occurred, but, first, I should say that we have assured ourselves that, barring some very extraordinary change of conditions, we will not experience a graphite fire. However, if a graphite fire should occur, we have taken steps to be able to smother it. So far, we feel this is a safer procedure than putting water on it, because, if you once get a fire in hot uranium and hot graphite, I do not quite know how you would get around the danger of a hydrogen or CO air explosion. Research work is going on; we are not satisfied that we know the ignition point of graphite. By the way, this is an amusing point. The belief had grown up on the part of many people in this country that graphite will not burn. This is nonsense. Graphite is carbon, and anyone knows that carbon will burn if you get it hot enough. But this glib remark, that graphite will not catch on fire, had become prevalent. At any rate, research is going on to learn more about the ignition temperature. It is a tough problem to solve, and we are exploring possibilities.

HAYES: It seems too bad to have to depend on a bucket full of sand as they did at the NRU reactor to put out a fire. Does anyone in the audience know of any research that is being done which will be helpful in the practical matter of putting out a uranium fire? We have heard a lot about the theories that have been developed. Dr. Quigley, have you any words of wisdom on this? Are there any other questions that you would like to ask Dr. McCullough?

KNAPP: This was definitely a metal fire rather than graphite fire?

McCULLOUGH: Both. Metal was burning and graphite was definitely burning.

KNAPP: Graphite did not produce any extinguishment problem, but the metal fire did?

McCULLOUGH: Even a hot graphite fire and water will give you hydrogen and CO.

KNAPP: Would your hydrogen necessarily have been dangerous? They apparently showed by putting the water on that they could have gotten rid of the hydrogen before it caused trouble. In metal it is so complicated you might get into trouble anyway.

McCULLOUGH: That is right. They could not avoid a certain amount of air being present all the time. Incidentally, when they put water on, clouds of steam came out of the stack. Again the iodine, most of the iodine, was caught by the filters, only a few thousand curies got out past the filters. The base of the stack, by the way, was very hot. The stuff fell out, settled, in the base of the stack.

KNAPP: Are there any figures on what the incident cost the British government?

McCULLOUGH: Yes, there is a figure, but I cannot remember exactly. I can say this: it was less than $200,000. I remember two numbers. One of them is $80,000 and the other is greater than $140,000. I know it was under $200,000; that is neglecting the cost of the reactor, by the way.

EXHIBIT C-II-2
4 pages (cover sheet
+ pgs. 328,330,345)

NUCLEAR GRAPHITE

Edited by
R. E. NIGHTINGALE
Hanford Laboratories
General Electric Company

Prepared under the auspices of the
Division of Technical Information
United States Atomic Energy Commission

ACADEMIC PRESS – 1962

New York and London

Two other methods for measuring total stored energy have been tried but have met with little success. One involved an attempt to measure the free energy of graphite from electrode potentials established by graphite in various solutions.[8] The second consisted in measuring the heat of reaction with potassium.[7] Although this latter method was attractive because of the relatively low heat of reaction of graphite with potassium compared with the heat of combustion (81 ± 2 cal/g at 66 to 95°C vs. 7800 cal/g at 25°C), the excess heat of reaction of irradiated graphite did not agree with the excess heat of combustion; nor was there a constant relation between them for different samples. Furthermore, the excess heat of reaction did not decrease when an irradiated sample was annealed. It was concluded that the final state of the products of the potassium–graphite reaction was different for irradiated and unirradiated graphite both with respect to the composition of the graphite–potassium compounds formed and with respect to the structure of the residual graphite lattice.

In summary, we may conclude that it is possible to measure S quite accurately by differences in heats of combustion if a great deal of care is taken. Often only one irradiated sample is available for a determination. In this case the precision in S is limited in present techniques to ±3 to 4 cal/g. This is sufficiently precise for most requirements, particularly for heavily damaged samples (>100 cal/g). Some improvement in precision is desirable for samples with small amounts of stored energy.

12-2.2 Build-up of Total Stored Energy with Exposure

The accumulation of stored energy as a function of reactor irradiation is shown in Fig. 12.2. The exposures for the measurements from the Windscale Laboratories were reported in units of Mwd/At$_e$ (Sec. 7-5.5). The recommended[9] conversion 1 Mwd/At = 0.6 Mwd/At$_e$ was used. Kinchin's data[11] at 30°C, which are reported in thermal neutrons/cm^2, fall on the 30°C curve of Fig. 12.2 if

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

This is slightly higher than the value of 5.5×10^{17} derived from other property changes (Sec. 7-5). The general character of the 30°C curve is similar to that of most other radiation-induced property changes. The initial rate of accumulation is about 500 cal/g per 1000 Mwd/At. This decreases to 25 cal/g per 1000 Mwd/At in the 4000 to 5000 Mwd/At exposure range.

A relatively large amount of energy, 630 cal/g, is stored when graphite is exposed to 5000 Mwd/At at 30°C. This is equal to 7.5 kcal/gram atom, several times the estimated interlayer binding energy in unirradiated graphite (Sec. 5-3). This amount of energy also corresponds to the integrated heat capacity of unirradiated graphite between 100 and 1550°C.

longer times are required to reach saturation at the higher temperatures. The ratio k_{30}/k_T shown in the last column is equal to the dose required to attain a given per cent of S_∞ at T divided by the dose required to attain the same per cent of S_∞ at 30°C. Thus at 200°C three times the 30°C dose is necessary to get to any given fraction of S_∞. The 300°C curve seems to be an exception; however, at this temperature the amount of stored energy is small, and the values of S_∞ and k are sensitive to changes in S of 5 to 10 cal/g.

Table 12.1 — PARAMETERS FOR THE EQUATION $S = S_\infty\,(1 - e^{-kE})$

Irradiation temperature, °C	S_∞, cal/g	k, per 1000 Mwd/At	k_{30}/k_T
30	685	0.526	1
150	600	0.242	2.2
200	375	0.169	3.1
250	200	0.151	3.5
300	50	0.393	1.3

In the original derivation of Eq. 12.1 by Newgard, k is the rate constant for annealing displaced atoms. The numerical value of k should increase with irradiation temperature. However, except for the 300°C curve, the k derived from Fig. 12.2 decreases with temperature. There are several possible explanations for this apparent anomaly, all of which relate to the likelihood that the simple model assumed in the derivation of the equation is not adequate, particularly when the graphite becomes highly damaged. Therefore k depends not only on T but also on E. The k in Table 12.1 should be regarded only as an empirical parameter and should not be interpreted as having the physical significance that Newgard originally attached to it.

The 150 and 200°C points on Fig. 12.2 from the curves of Davidson[7] were obtained from samples irradiated in the Hanford controlled-temperature facility (Sec. 8-3.2). These points fall below the curves at the corresponding temperatures. The curves were obtained from irradiations carried out inside hollow fuel elements in high-flux reactors (DIDO, PLUTO, and DMTR) for which the intensity of the damaging flux was considerably greater than normal for a graphite-moderated reactor. It is possible that under such conditions the radiation effects produced at a given total dose are significantly greater (Sec. 7-5.6). In fact, an "equivalent Calder temperature" (indicated in parentheses in Fig. 12.2) has been assigned[9,33] to the irradiations to convert to the irradiation temperature in a Calder reactor at which the observed stored energy would be predicted. Although this brings the points and curves of Fig. 12.2 into better agreement, further studies will be necessary to establish with certainty the effects of flux intensity on stored energy and other radiation-induced changes in properties.

mates of the energy stored by interstitial–vacancy pairs give values of this magnitude. The following values in kilocalories per gram atom have been assumed or calculated for H_1 by various investigators: 250 (Ref. 19), 230 (Ref. 11), and 207 (Ref. 39).

Clustering will, of course, decrease the average energy stored per displaced atom. If it is assumed that interstitial C_2 groups have a binding energy equal to that of C_2 vapor (140 kcal/mole),[40] then the net increase in energy content for the formation of C_2 interstitials and vacancies is $240 - (140/2) = 170$ kcal/gram atom.

12-5.2 Displacement Rate from Stored-energy Measurements

For the calculation of displacement rates, the rate of stored-energy build-up with exposure (dS/dE) must be measured near zero exposure at temperatures low enough to ensure that no clustering or annealing to surfaces has occurred. The alternative is to estimate the energy stored for each atom originally displaced at the temperature for which dS/dE is measured.

The lowest temperature for which dS/dE has been measured is about 30°C. On the basis of property changes produced by irradiation at liquid-helium and liquid-nitrogen temperatures (Sec. 12-4.2), it is estimated that 30 per cent or more of the displaced atoms reintegrate during irradiations at 30°C. The displacement rate is therefore

$$R \simeq \frac{4}{3}\,\frac{dS/dE}{H_1} \tag{12.7}$$

At 30°C dS/dE from Fig. 12.2 is 0.5 cal/Mwd/At. More-accurate values derived from measurements at very low exposures range from 0.6 to 1.0 cal/Mwd/At.† Assuming a value of 1 cal/Mwd/At,

$$R \simeq \frac{4}{3}\,\frac{6 \times 10^{23}}{240 \times 1000} = 3.3 \times 10^{18}\,\frac{\text{displacements}}{\text{g} - \text{Mwd/At}}$$

which, for nuclear graphite with a density of 1.7 g/cm³, is

$$R = 5.7 \times 10^{18}\,\frac{\text{displacements}}{\text{cm}^3 - \text{Mwd/At}}$$

Values of R calculated from displacement theory and from other property changes agree within an order of magnitude with this number (Sec. 7.4).

12-6 Relation of Stored Energy to Other Radiation-induced Property Changes

Careful and time-consuming measurements are required for the determination of stored energy. In addition, the radiation effects are at least partially removed when stored-energy release curves are determined, and

† See Ref. 41 for a discussion of dS/dE measurements.

EXHIBIT C-II-3
2 pages (cover sheet +
p. 53)

UNIVERSITY OF CALIFORNIA

Los Angeles

Gamma Flux Mapping of the

U.C.L.A. Training Reactor

A thesis submitted in partial satisfaction of the
requirements for the degree Master of Science
in Engineering

by

George Brown Bradshaw

Committee in charge:

Professor Thomas E. Hicks, Chairman

Professor Rolf Schroeder

Professor Paul S. Farrington

1965

Table 4

	Total dose measured, r.	Total neutron flux, neu/cm^2 sec.	Dose due to neutrons	% dose due to neutrons	Gamma dose
C.V.T. at 1 kw for 1 hr.					
6"	19,000 ± 600	1.12×10^{10}	8,000 ± 25%	42%	11,000 ± 20%
12"	44,000 ± 1200	2.4×10^{10}	17,300 "	39	27,000 ± 20%
18"	63,700 ± 2500	2.9 "	20,900 "	32	43,000 ± 20%
24"	77,300 ± 3330	3.35 "	24,000 "	31	53,000 ± 20%
*24"	64,000 ± 3000	1.85 "	13,300 "	21	51,000 ± 20%
30"	64,000 ± 1600	3.1 "	22,400 "	35	42,000 ± 20%
36"	40,000 ± 1400	1.98 "	14,300 "	36	26,000 ± 20%
42"	18,000 ± 500	1.16 "	8,300 "	46	9,700 ± 20%
48"	7,300 ± 100	5.0×10^{9}	3,600 "	49	3,700 ± 20%
54"	2,630 ± 30	2.08 "	1,500 "	57	1,100 ± 20%
60"	1,020 ± 20	8.8×10^{8}	635 "	62	390 ± 20%
West half of core, at 1 kw for 1 hr.					
6"	73,000 ± 4000	3.0×10^{10}	22,000 ± 25%	30%	51,000 ± 20%
**8"	57,200 ± 900	2.6 "	18,700 "	33	38,000 ± 20%
14"	34,700 ± 600	1.9 "	13,700 "	40	21,000 ± 20%
22"	13,800 ± 1740	8.0×10^{9}	5,700 "	41	8,000 ± 20%
30"	5,380 ± 150	2.6 "	1,870 "	35	3,500 ± 20%
East half of core, at 1 kw for 1 hr.					
6"	70,500 ± 1300	2.9×10^{10}	20,900 ± 25%	30%	49,000 ± 20%
8"	53,800 ± 2600	2.5 "	18,000 "	33	36,000 ± 20%

*Measurement made in Li thermal neutron shield, corrected for epithermal neutrons only.
**W.V.T. access port location.

CITY OF LOS ANGELES
CALIFORNIA

TOM BRADLEY
MAYOR

DEPARTMENT OF FIRE
200 NORTH MAIN ST
LOS ANGELES CALIF 90012

JOHN C. GERARD
CHIEF ENGINEER
AND
GENERAL MANAGER

September 16, 1981

Donald W. Reichenbach
U.C.L.A. Fire Marshal
Community Safety Department
Office of Research and
Occupational Safety
112 Physical Plant Office
405 Hilgard Avenue
Los Angeles, California 90024

Dear Mr. Reichenbach:

Emergency Response Plan, Nuclear Energy Laboratory at U.C.L.A.

Attached is a copy of the plan which you requested.

If you have questions or comments, please contact Captain Leslie E. Hawkes in the Planning Section, (213) 485-6034.

Very truly yours,

JOHN C. GERARD
Chief Engineer and General Manager

Ross L. Williams

ROSS L. WILLIAMS
Battalion Chief
Planning Section

RLW:LEH:lmg

Attachment

cc: Battalion Commanders
Battalion 9

EMERGENCY RESPONSE PLAN, NUCLEAR
ENERGY LABORATORY AT U.C.L.A.

The Los Angeles City Fire Department provides fire protection to the University of California, Los Angeles.

With regard to the Nuclear Energy Laboratory specifically, the following operational plans are in effect.

1. A first alarm assignment will be dispatched to the Laboratory.

2. Upon arrival, the first Fire Officer on scene will contact campus or building security to determine the exact location and nature of the call.

   a. Fire Only - No Nuclear or Radiation Problem

      The Fire Department will handle as a routine structure fire.

   b. Radiation Problem

      The Fire Department Incident Commander will confer with the Laboratory personnel to determine the extent of the problem.

      Notify the Fire Department's Operations Control Division who will notify the Los Angeles County Department of Health Services who, in turn, will dispatch a team to handle the control and decontamination problems. The Fire Department will also dispatch the on-call Radiological Defense Officer to the incident to assist.

      The Los Angeles County Department of Health Services is under contract with the State of California to handle radiological incidents.

      The Fire Department will monitor the incident and will make rescues if necessary. The Fire Department will prevent entry into the area until the Los Angeles County Department of Health Services' team arrives on scene. The Los Angeles Fire Department will maintain command of the incident.

Exhibit O-II-5

page 1 of 3

Nuclear Safety Information Center

ABNORMAL REACTOR OPERATING EXPERIENCES 1969-1971

U.S. Atomic Energy Commission
Division of Reactor Licensing

MAY 1972

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

Aluminum Tank Explosion

Summary

A leak developed in an underwater aluminum ballast tank which initially contained air at atmospheric pressure. The tank was drained and left overnight to dry prior to weld repair of the leak. The next day, WHEN THE WELDER STRUCK AN ARC, THE TANK EXPLODED. Investigation showed that an EXPLOSIVE HYDROGEN-AIR MIXUTRE HAD EVOLVED FROM CORROSION OF THE ALUMINUM.

Circumstances

At a test reactor, an underwater fuel transfer cart for transporting irradiated fuel elements was equipped with an aluminum airfilled ballast tank to provide some buoyancy for ease of movement of the cart. The rectangular tank was approximately 2 ft. × 4 ft. × 1 ft. Each end had a 3/4-inch bung.

When a leak developed in the tank, the tank was removed from the cart; the two bung holes were opened to permit the leakage water to drain out, and the tank was left in air to dry overnight. The tank was open to the atmosphere for a total of about 24 hours prior to starting weld repair of the leak. When the welder struck an arc, the tank exploded. The welder was knocked over backwards. Although he appeared to be uninjured, he was sent to the hospital for a checkup. No significant injuries were found and the man was able to return to work during the same shift in which the incident occurred. The explosion caused a severe bulging of the sides of the tank and a complete rupture along one of the seams.

Investigation

An investigation into the cause of the explosion was made by the radiochemistry section of the operating organization. The interior surface of the exploded tank was found to be coated with a non-uniform layer of yellowish-white crystalline material. A sample of the crystalline-interior coating was taken by scraping the surface with a spatula. About 1 gram of material was removed from several areas totaling approximately 50 square inches. The sample material was non-radioactive, non-combustible, non-explosive and insoluble in water. Analysis by emission spectrography and gravimetric methods showed that the major constituent was $Al_2O_3.H_2O$.

Samples of gases from ballast tanks used under similar conditions were taken. Analysis of the gas from a comparable ballast tank showed approximately 2% by volume of hydrogen, with the balance being nitrogen-enriched air. From the appearance of the interior surface of the exploded tank, the investigator assumed that all interior surfaces were equally exposed to corrosion by water vapor. The corrosion of aluminum produces hydrogen according to the reaction

$$5\ H_2O + 2\ Al \rightarrow Al_2O_3.2H_2O + 3\ H_2$$

[redacted]

ROE 70 3

The total interior surface was 3700 square inches. It was calculated that at least 35 liters, or 15% by volume, of hydrogen was produced. An additional quantity of hydrogen was probably produced by radiolytic decomposition of water, but since the amount of water and its exposure to gamma ray energy was not accurately known, no meaningful calculation could be made. This quantity was conservatively disregarded in the computation.

A calculation of diffusion through the two vents showed that the atmosphere in the tank after 24 hours contained approximately 6.5% by volume of hydrogen (the lower flammability limit of hydrogen in air is 4.1%). The conclusion of the investigators was that the most probable cause of the explosion of the fuel cart ballast tank was the ignition of a hydrogen-air mixture in the tank by the welding arc.

Corrective Action

Since this occurrence all aluminum ballast tanks used at this facility are being replaced with stainless steel tanks which will be filled with helium. Aluminum tanks still in use are now filled with helium and periodic samples are taken to assure maintenance of an inert atmosphere. In addition, welding procedures which require sampling for explosive gases prior to welding will be strictly enforced for all closed systems and containers.