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AEC RESEARCH AND DEVELOPMENT REPORT

LOS ALAMOS SCIENTIFIC LABORATORY OF THE UNIVERSITY OF CALIFORNIA • LOS ALAMOS NEW MEXICO

QUARTERLY STATUS REPORT OF LASL ROVER PROGRAM

FOR PERIOD ENDING SEPTEMBER 20, 1960

(Title Unclassified)

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by H. A. C. TIC, date AUG 28 1973
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C-86, NUCLEAR ROCKET AND RAM-JET
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LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA LOS ALAMOS NEW MEXICO

REPORT COMPILED: October 1960

REPORT DISTRIBUTED: October 31, 1960

QUARTERLY STATUS REPORT OF LASL ROVER PROGRAM
FOR PERIOD ENDING SEPTEMBER 20, 1960
(Title Unclassified)

Prepared from material supplied by
CMB, CMF, GMX, J, N, and T Divisions

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NUCLEAR ROCKET AND RAM-JET ENGINES

M-3679 (24th Ed.)

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CHAPTER 1

GENERAL PROGRAM STATUS

The major developments in the LASL Rover Program during the current reporting period are as follows:

1. During the full-power test of Kiwi-A', a module broke at 308 sec after reaching full power; the broken module and all of its fuel elements were ejected from the nozzle. Two more modules failed in a similar manner after the first power step reduction.
2. During disassembly of Kiwi-A', four more modules were found to be broken and extensive cracks were noted in many others. Three of the latter broke during handling operations after removal from the core. Most of the broken and cracked modules were in the vicinity of plenums 2 and 3.
3. Various possibilities for the cause of failure of the modules have been studied, e.g., thermal stresses, excessive vibration due to gas turbulence, and flaws in the graphite stock. No definite cause has yet been identified, but it is felt that an unknown design or environmental factor is responsible.
4. The Kiwi-A' test confirmed the effectiveness of NbC coatings in preventing corrosion of graphite. A number of blisters were observed but none appeared to be large enough to affect the gas flow.
5. The thermal capsules for approximate determination of temperatures, based on the occurrence (or not) of eutectic melting,

proved to be satisfactory in Kiwi-A'. Temperatures as high as 2500°C (4500°F) were indicated in some of the special 27-in. fuel elements. There was no blistering of the NbC liners in these elements.

6. Fission distribution measurements and estimates of power losses show that at the time of a full power run the temperature in a Kiwi-A type reactor can not be known to better than ± 6 percent.

7. Observations on the reactor (analog computer) simulator, using input data based on the actual full power run, show that both power and mass flow can be simulated with accuracy. The temperature results are not quite so good, but this can probably be accounted for by inaccuracies in the input and in the observed temperatures.

8. The Kiwi-A' logarithmic power control system functioned effectively during the full power run. When the first module was ejected, there was a 22 percent drop in power, but this was corrected within about 0.7 sec to a value about 3 percent less than before the module failure.

9. Because the module failures in Kiwi-A' occurred at locations near plenums 2 and 3, it was decided to remachine the Kiwi-A3 elements to eliminate plenum 2. Plenums 3 and 4 do not exist in Kiwi-3 since the last course of fuel elements is 27-in. long. The elimination of plenum 2 was achieved by machining the ends of the appropriate fuel elements and using an unloaded graphite collar to join each pair of elements and to align the flow channels.

10. Recalculation of the expected Kiwi-A3 temperature distribution, in the light of data obtained from the Kiwi-A' test, and the introduction of carbon wool for insulating purposes between the center island and the core indicate that undesirably high temperature gradients would exist in Kiwi-A3. Consequently, the hole size in a number of Course 1 fuel elements has been increased.

11. In addition to the regular Graph-i-Tite G fuel modules in Kiwi-A3, there will be 45 modules of three other graphites in order that their behavior may be compared under actual operating reactor conditions.

12. The Kiwi-A3 reactor at NTS was taken to the Test Cell on September 24, 1960 and the full power test is scheduled for October 15, 1960.

13. The first full-size pressure vessel for Kiwi-B is in the process of fabrication. Structural testing of the unit is scheduled to begin about November 1, 1960.

14. An alternative core support method is being developed for Kiwi-B as a possible alternative to the modular support. This would consist of six full axial length sections drilled to contain the fuel elements. The sectors would be held in place by radial compression from the two-pass pressure drop between the reflector and core.

15. Development work on the fabrication of 7-hole uranium loaded graphite fuel elements for Kiwi-B has progressed satisfactorily. Graphitized elements containing 500 mg/cm³ of uranium and having a minimum carbon density of 1.73 g/cm³ have passed all tests satisfactorily. The extrusion tools for actual fabrication have been ordered.

16. The problem of corrosion protection of the exit end of the Kiwi-B fuel element appears to have been solved successfully, by the use of an unloaded, NbC-coated graphite insert. A piece of tantalum foil is wrapped around the junction with the module and finally the end of the fuel element is given a vapor deposited coating of NbC.

17. Europium, in the form of the sesquioxide, Eu₂O₃, fabricated as a matrix in either aluminum or stainless steel, preferably the former, is being given serious consideration as the poison control material for Kiwi-B.

18. Tests with the Houdaille hydraulic vane actuator indicate that this will prove to be satisfactory for Kiwi-B operation.

19. Calculations have been made of neutron and gamma-ray heating in the Kiwi-B core, reflector, pressure vessel, and control

elements. The rate of heating of various materials located outside but near the reactor has also been estimated.

20. Progress is being made in the design of the Phoebus reactor. Extrusions of the 37-hole fuel element modules have been made successfully and specimens 6 ft long containing 625 mg/cm^3 have been produced for testing purposes. If it is decided to use a 19-hole module, the experience gained with the 37-hole die will be very valuable.

21. Preliminary studies are being made of simplified configurations and control system for a flyable nuclear rocket reactor.

22. Calculations of the absorption of neutrons and gamma rays in the propellant tank in a flyable nuclear rocket show that heating can be minimized by suitable design. The same design will provide maximum protection to personnel located beyond the tank. However, some 5000 lb of shielding would still be required to attenuate the radiations to a tolerable level.

23. Evidence has been obtained that the blistering of NbC-coated graphite fuel elements is due to the liberation of carbon monoxide and nitrogen gases by the interaction of uranium oxide and nitride, respectively, with the graphite upon heating. The uranium oxide is apparently formed by the action of atmospheric moisture on the uranium carbide in the fuel element. Methods are being considered for preventing the access of moisture.

24. Work is proceeding in the development of tungsten-uranium dioxide and uranium carbide-zirconium carbide fuel elements for possible use in fast reactors for nuclear rockets.

CHAPTER 2

KIWI-A' AND KIWI-A3

A. KIWI-A' TEST RESULTS

GENERAL DESCRIPTION

The full power run of Kiwi-A' was successfully completed at NTS on July 8, 1960. A power of about 80 Mw with an exit gas temperature of 3950°R was maintained for 345 sec, followed by a step in power to 50 Mw for 100 sec and an exit gas temperature of 3000°R. After this step there was a reduction of about 50% in the hydrogen flow and then another step reduction in power before shutting down. The power, flow rate and exit gas temperature are shown in Fig. 2A.1. At 308 sec after reaching full power, a module broke at plenum 2 (17 in. from the inlet end). The broken module and all of its fuel elements passed through the nozzle giving the impression of a "Roman candle" to observers at the Control Point. Two more modules failed in a similar way after the first power step reduction; one was between plenums 1 and 2, 14 in. from the inlet end, and the other at plenum 3, 25 in. from the inlet end.

During the subsequent disassembly of the reactor four more modules were found to be broken; two of these were adjacent to modules that broke during the run. Extensive cracks were noted on many of the modules that were adjacent to the center island and three of these broke during handling operations after removal from the core. A number of cracks were observed

Fig. 2A.1 Power, flow rate, and exit gas temperature in full power run of Kiwi-A'

on modules in other locations, particularly at plenums 2 and 3, although several cracks appeared at non-plenum locations.

In addition to the seven broken modules referred to above, 17 others were broken while being handled during disassembly and 35 were found to have transverse cracks. The majority of the latter were located between plenums 3 and 4.

MODULE BREAKAGE

Radiographic and visual observations have so far shed little light on the reason for module breakage. In particular there was a lack of correlation between locations of suspected cracks and the positions at which breaks actually occurred. It was suspected that thermal stresses, resulting from a certain amount of cooling at the plenums where a fuel and carbon void occurs, may have contributed to the module breakage. However, thermal stress experiments on several modules have succeeded in cracking transversely only one module with the very high temperature difference of about 2000°F, combined with restraint against bowing.

Another conceivable cause of breakage is the effect of vibration, due to gas turbulence, in enlarging existing small cracks. In laboratory tests, two modules were broken as a result of longitudinal vibration. However, both broke at the support shoulder for the fuel elements where no breaks or cracks were observed in the Kiwi-A' modules. Work is proceeding in an effort to determine the factors contributing to the module breakage during the full power run.

The possibility was considered that flaws in the Graph-i-Tite G stock from which the modules were made might be responsible for initiating breakage. However, inspection of the broken ends of modules, as well as later inspection of some pieces of stock from the same batch of material, suggests strongly that this is not the cause since very few flaws were found. The fact that modules withstood a tensile test of

250 to 350% of the stress expected in the reactor and appeared to have a safety factor of about 10 over the tensile stress applied in the reactor both argue against this hypothesis. When Graph-i-Tite G stock was being tested prior to manufacture of modules, two kinds of flaw were noted. In one case the stock was observed to be split radially, parallel to the axis of the piece. A few such flaws were observed in modules recovered from Kiwi-A' but they did not seem to be associated with the transverse cracking and breakage that were found. In addition, all breakage of modules was almost perfectly transverse. This immediately suggests that longitudinal flaws were not involved.

The second type of flaw consisted of a split perpendicular to the long axis of the stock. Although in one instance there appeared to be a small inclusion of foreign material at the break, inspection of the broken surfaces of modules recovered from Kiwi-A' did not support the view that such flaws in the stock were responsible for initiating breakage. In general, the evidence suggests that some unidentified design or environmental factor, rather than flaws, is responsible in some, as yet unknown, fashion for the breakage.

Examination of substantially all the fuel elements from Kiwi-A' has shown that, on the basis of tests made in the electrically heated furnace, damage resulting from corrosion is substantially what would be expected at the reactor operating temperature. Also as would be expected, corrosion damage to the fuel elements was very much less than would have been the case in the absence of NbC coatings. There were some fuel elements in which the coatings blistered. The largest number occurred in Course 4 where somewhat less than 8% of elements were blistered while in Course 5 about 3% and in Course 3, 1 to 2% were blistered. It did not appear that gas flow had been stopped anywhere by blistering of coatings.

THERMAL OBSERVATIONS

Inspection of the center island showed only slight fluffing of the thermal paint, indicating poor insulation and high heat flux between the core and center island. This high heat flux may perhaps have caused sufficient thermal stress in the adjacent modules to account for the cracks in these modules, since they occurred predominantly in the highest temperature axial region of the core where the average temperature difference between the modules and center island was approximately 3000°F.

Thermocouple data indicate that a temperature droop existed near the island, with the interior region temperatures running 300-400°F higher than anticipated. There is not enough evidence to indicate positively a temperature droop toward the outside of the core although the data do hint at such a trend.

Thermal capsules, for determining temperatures approximately, by observing whether melting had (or had not) taken place in a eutectic system, were located in regions where the temperatures were expected to be beyond the thermocouple range or where thermocouple leads would be difficult to bring out. Of 600 capsules inserted in Kiwi-A', about half were placed in pairs in selected normal (i.e., shorter) fuel elements and the remainder, in groups of 48 capsules, in six 27-in. long experimental elements of the Kiwi-A3 type (carbide liners formed from metal inserts).

The capsules contained in ~~normal~~ Kiwi-A' fuel elements showed that the temperatures reached were, with a few exceptions, those predicted for operation at full power. Temperature measurement by thermal capsules contained in the 27-in. elements indicated that one had operated at 2200°C, and two at about 2500°C. There was no blistering of the NbC liners even in the hottest 27-in. elements.

NEUTRONIC DATA

Radiochemistry and γ counting have been performed on each course of the disassembled Kiwi-A' reactor. The data were plotted to obtain a radial distribution from which the fissions/gram for each fuel element in a 60° sector of the reactor was obtained. Using loading and hole size data, fissions/gram were converted to fissions/element, and total fissions for each course were obtained by summation. The total number of fissions in the core obtained in this manner was 1.77×10^{21} . From the number of fissions, the operating power of the reactor was calculated to be about 80 Mw, compared with 83 Mw obtained from neutronic instrumentation at the time of the full power run.

The relative number of fissions in each course, that in Course 5 being taken as unity, for the "cold" (low power run) and "hot" (full power run) reactor are tabulated below. The increased fission rate in Courses 1 and 2 for the hot reactor was presumably a result of withdrawing the control

<u>Course</u>	<u>Relative No. Fissions</u>	
	<u>Cold</u>	<u>Hot</u>
1	1.26	1.68
2	1.83	2.36
3	2.31	2.50
4	1.95	1.95
5	1.00	1.00

rods. Except for the reflector side of Course 1, the measured fission distributions determined after the full power test were in good agreement with those predicted on the basis of observations in the cold run and from Zepo studies at LASL.

Reactivity loss at full power was \$7.5, all attributable to temperature change since there was no indication of erosion loss. An additional \$0.2 should be added to this for the positive contribution of hydrogen in the core. The module which broke while the reactor was at full power resulted in a reactivity loss of about \$0.6. The effect of

the modules which were ejected later is masked by the changing reactor temperature. The critical recheck following the hot run showed a reactivity loss of $\$2.4$ from the cold condition. This reactivity change is due to the cumulative effect of core breakage, xenon poisoning, and residual temperature.

POWER AND GAS TEMPERATURE CORRECTIONS

An investigation has been made of the accuracy of, and corrections to, the Kiwi-A' power and exit gas temperature measurements. A study of the combined errors in the Kiwi-A' power calibration has resulted in an estimate of the least possible error in the power measurement for Kiwi-A-type reactors. At the time of the full power run it appears the power can be known to no better than about 6%. After a subsequent radiochemical analysis this error may be lowered to about 4.5%. These estimates include only known sources of error. However, discrepancies in the Kiwi-A' power measurement have indicated the probable presence of unknown sources.

Estimates of power loss to other sinks than the gas have been made, as follows:

Island Jacket Water	690 ± 40 Btu/sec
Island Core	270 ± 30 Btu/sec
Pressure shell	420 ± 20 Btu/sec
Exit Plenum Liner	3000 ± 300 Btu/sec
Nozzle	2700 ± 250 Btu/sec.

In addition, it is estimated that 700 Btu/sec of power is radiated from the end of the core to the exit plenum and nozzle. This power must be subtracted from that (5700 Btu/sec) removed from the exit plenum lines and nozzle before computing the total gas temperature drop between core exit and nozzle exit. The total temperature drop is found to be approximately 200°F .

The power loss to nuclear radiation has been estimated to be $(1.6 \pm 0.2)\%$ of the neutronics power.

The systematic errors in computing the exit gas temperature by electronic analog means at NTS during the Kiwi-A' test run, resulting from the neglect of the following factors, have been investigated: (1) heat loss through nozzle and exit plenum linear walls, (2) velocity of hydrogen at approach to venturi (mass flow meter), (3) deviations from ideal gas in venturi, (4) variation of specific heat in venturi and nozzle, and (5) difference in γ between venturi and nozzle. As a result of the compensating effect of these errors, the net correction on computed exit gas temperature is $-0.1 \pm 2.5\%$.

In order to obtain a better understanding of how well the reactor simulator characteristics agree with the actual reactor system, analog computer data have been obtained with reactor power and hydrogen flow inputs varied to follow quite closely the actual values observed during the full power run of Kiwi-A'.

The power and mass flow outputs from the simulator showed only minor differences from the observed values which are attributed to resolution difficulties in setting up the input to the simulator. The agreement for temperature data is not quite so good. This is partly due to the small difference between the reactor power and the simulation power, and to some extent, to the low temperature readings given by thermocouples because of heat reaction to the nozzle.

CONTROL SYSTEM

The Kiwi-A' logarithmic power control system functioned essentially as expected during the full power run. The system was switched into automatic control at 20 kw, and was kept in this mode of operation until the reactor was shut down after the run was completed. When the first module failed, there was a 22% power drop which was corrected to within 3% of the value before the failure in approximately 0.7 sec.

The only abnormality observed in the power control system was a tendency toward low-amplitude oscillation. The frequency was 2 cps with

an amplitude of 0.5 to 1.0%. A preliminary analysis revealed the following phase shifts through the system:

Log power error to center rod command: 125°

Center rod command to center rod position: 45°

Center rod position to log power measured: 15° .

The above values represent averages of readings taken at several points in time. They could be in error by some 15 to 20° because of the poor quality of the records for such low-amplitude oscillations, but it is significant that the sum of the phase shifts is slightly greater than 180° . All of the values are normal with the exception of the 125° phase shift between the log power error and the center rod command voltage at the TR-10 controller output. This value should have been about 64° . If these data are correct, there must be a non-linear component in the TR-10 controller which has a phase shift that increases considerably as the perturbation amplitude decreases.

The control rod mechanisms functioned properly during the full power run. Several malfunctions occurred in the scram rod valves during the preliminary runs, and these were traced to the sliding spools. When the spools were modified to give 0.002 in. diametral clearance between spool and bore, they worked satisfactorily. The Kiwi-A3 scram valves have been modified accordingly.

Velocity limiting of the Kiwi-A' shim rods was successfully accomplished by use of an 0.018-in. diameter orifice in series with each Miller hydraulic cylinder. The maximum shim rod velocity was 0.6 in./sec, or an average shim-gang reactivity change of about 60¢/sec.

Several irregularities in the operation of the regulating and shim rods were noted and cured at NTS, and all rods operated satisfactorily during the final run. (1) When the power control switch was changed from "off" to "normal" the rods were observed to move rapidly out about 1-1/2 in. and back in again. This phenomenon was ascribed to a voltage offset on the rod command modulators. The correction consisted of

adjusting the rod position to zero while in the "manual" mode. (2) Following a scram, the regulating and shim rod position-error amplifiers went into overload, causing subsequent rod motion when the power control system was being readied for operation. The situation was cured by bleed resistors placed across the 10- μ f integral compensation, plus a 100 sec wait before switching to "manual" operation. (3) As observed with Kiwi-A, there was a substantial drift (1/2 in. to 3/4 in.) in the full-out position of the rods for maximum rod command between the time they were set up early in the morning and the time of their official position calibration for a run some 2 hr later. This effect was due to drift in the command modulators or demodulators. (4) On several occasions a somewhat periodic movement of the center rod was observed in both the manual and automatic modes of operation. The difficulty was caused by a beat phenomenon between the two 400 cps power supplies used in the control rod system. The trouble was corrected temporarily by changing the frequency of one 400 cps power system to 480 cps. The power wiring will be changed before Kiwi-A3 is run to operate the rod system from only one 400 cps power supply.

During the full power run the prompt neutron lifetime was measured to be 2.3×10^{-4} sec, compared with the predicted value of 2×10^{-4} sec. Previous attempts at measuring the neutron lifetime were unsuccessful because of excessive phase shift in the nuclear instrumentation demodulation filter.

B. KIWI-A3

DESIGN AND FABRICATION

Carbide Liners

In the course of preparing carbide liners for the Kiwi-A3 fuel elements, by inserting niobium tubes into the loaded graphite and raising the temperature in stages, it was found that serious bubble formation was caused mainly by the conversion of uranium oxide to the carbide. Since most of the bubbling was observed to occur between 2350 and 2450°C, the heating schedule was changed to permit the complete formation of uranium carbide to occur while the niobium was being carbided. The following treatment eliminated bubbling, although if allowed to stand in air, the uranium carbide was gradually converted back to oxide: 2 to 3 hr at 1900°C, 2 to 3 hr at 2200°C, 5 hr above 2000°C with a peak temperature of 2450°C.

Fuel Elements and Modules

Because of the module failures in Kiwi-A', it was decided to make a radiographic inspection of the Kiwi-A3 modules. Anomalies were detected in some 30%, but based on the arbitrary specification that transverse cracks were cause for rejection if they were more than 3/8 in. long, only 18 out of 193 modules were rejected.

After post-mortem inspection of the Kiwi-A' fuel elements revealed the predominance of cracks and breaks at fuel element plenum locations 2 and 3, a decision was made to remachine the Kiwi-A3 fuel elements to eliminate plenum 2. Plenums 3 and 4 do not exist in Kiwi-A3, since the last course of fuel elements is 27 in. long. Plenum 2 has been eliminated by facing off the plenum cup on the long elements, and machining a shoulder to match the shoulder on the course 2 elements. Flats have been machined on both shoulders and a graphite collar containing no uranium is used to join the two elements and to align the element flow channels.

Re-calculation of Kiwi-A3 temperature distributions in light of the Kiwi-A' fission distributions, and using carbon wool (see below) between the island and core led to some undesirably high temperatures and temperature gradients. To reduce the magnitude of these, the hole sizes in approximately 100 course 1 fuel elements near the center island were increased. A number of the re-machined and re-bored fuel elements were inspected radiographically to determine if these operations had produced any deleterious effects. In the 173 re-machined elements examined, the only change observed was minor chipping of coatings in a few cases. Of the elements of larger bore, 132 were radiographed but none was rejected.

In addition to the regular Graph-i-tite G modules in Kiwi-A3, it was decided to include a number of modules made from other forms of graphite. The reason for this decision was the belief that the zone graphitizing process, which is unique to Graph-i-tite G, may induce a larger number of transverse faults in the material than would be the case with other graphites. Consequently, 15 modules each of H4LM (not reimpregnated), AGOT, and 89OT graphites are to be included in Kiwi-A3 to provide a comparison of their behavior with that of Graph-i-tite G in an actual reactor environment.

Insulation

In order to improve the insulation between the core and center island a coat of thermal paint has been applied to the inner module surfaces that face the center island and a carbon wool blanket will be installed in the gap between the core and the island.

Assembly

The kiva assembly of Kiwi-A3 was completed on July 8, 1960 and cold critical operations on July 14, 1960. At this time the fuel elements were removed from the modules and radiographed, as stated above. The assembly of the reactor at NTS, with the new fuel elements and modules, has been completed. The full power run of Kiwi-A3 is scheduled for October 15, 1960.

The differences between Kiwi-A' and Kiwi-A3, in addition to differences in the fuel loading and hole size schedules, are listed below.

	<u>Kiwi-A'</u>	<u>Kiwi-A3</u>
Modules	All Graph-i-tite G	All Graph-i-tite G except for 45 regular modules; 15 regular modules each of H4LM, AGOT, and 890T.
Fuel elements	Five 8-1/2 in. elements with four plenums per module hole. Coldest element uncoated, all others NbC coated by vapor deposition. Fuel element holes misaligned at plenums.	One 27-in. element and two 8-1/2 in. elements per module hole. Plenum between courses one and two only. 27-in. elements coated with NbC liners, one 8-1/2 in. element coated by vapor deposition, coldest element uncoated. Fuel element holes aligned for full length.

NEUTRONICS

The modifications of the Kiwi-A3 core are equivalent to the following: (1) removal of 214 g Ta at the 27 in. location, equivalent to 289 g Ta distributed uniformly; (2) replacement by fuel of void at this location amounting to 0.28% of the total fuel volume, equivalent to replacement of about 0.56% of uniformly-distributed void; (3) unloading of fuel at this location amounting to 0.55% of the total fuel volume, equivalent to about 1.1% uniformly-distributed fuel; (4) removal of 53 g Oy at the inlet surface of the core; and (5) decreasing the graphite density 1% at this surface, equivalent to about 2% density change throughout the inlet reflector. Based on Zepo measurements, estimates of corresponding reactivity changes are:

1) Ta removal	+ 42 cents
2) replacement of void by fuel	~ + 31 cents
3) Oy removal from collars	~ - 16 cents
4) Oy removal at inlet	~ - 5 cents
5) graphite removal at inlet	~ - 7 cents
Total	+ 45 ± 10 cents

With an estimated ± 0.3 in. or ± 30 cents uncertainty in cold critical setting of Kiwi-A3 controls, it appears that the ± 1 in. or ± 1 NTS adjustment in shim zero is adequate.

CONTROLS

Loaded B¹⁰ control rods have been positioned on the Kiwi-A3 control rod mechanism and fixed in place. The full-in positions of the rods relative to the core center line are as follows:

Regulator rod:	2.20 in.	below	center	line
Shim rods	:	5.2 in.	"	"
Scram rods	:	4.5 in.	"	"

These positions are approximately 0.9 in. further out of the core than the corresponding positions for Kiwi-A'. The regulator and shim rods all moved freely through the D₂O baffle. The baffle hole for the No. 4 scram had to be relieved 0.015 in. before smooth operation could be obtained. All rods worked smoothly before the center island was secured in place and pressure tested.

A small pump was used to check scram rod operation. One scram valve failed to operate during the checkout of this system. These valves were modified, cleaned and found to function properly earlier this year when the control mechanism was reconditioned. Experience has shown that the present scram rod actuator system is marginally satisfactory. If additional Kiwi-A tests are conducted it is recommended that the scram system be modified to use hydraulic cylinder actuators driven by hydraulic servo valves. At least 90% of the troubles with the control mechanisms have been due to sticky scram valves.

Study of the use of magnetic amplifiers in control rod position servomechanisms has culminated in design of an amplifier-controller circuit which is to be used with some of the shim rods of Kiwi-A3. This circuit should mean a considerable increase in reliability over the standard operational-amplifier (Kintel) circuits which were used on Kiwi-A and A'.

C. NPS ACTIVITIES

KIWI-A3

The cart for Kiwi-A3 was essentially assembled in July, but because of the modifications to the fuel elements and modules, the core assembly did not start until September 14, 1960. The cart and reactor were taken to the Test Cell September 24, 1960.

Considerable time has been spent collecting and coordinating plans for vibration measurements; the proposals are as follows:

- 1) Three sound measurements with microphone placement as in Kiwi-A', but with modified ranges.
- 2) Six Endevco crystal accelerometers at various locations on the reactor, using a range of 10 cps to 5 kc/sec.
- 3) Three Statham accelerometers on a cart structural member, 0 to 160 cps.
- 4) Five Crescent transducers for displacement of the core and support ring, 0 to 80 cps.
- 5) One Northam pressure transducer close-coupled to the exit plenum liner, 10 to 300 cps.

A 50-ft high camera tower has been constructed 3000 ft south of the Test Cell. Cameras to be installed will provide general color coverage, high-speed color, infra-red, long ultra-violet, and color temperature coverage.

Audible and visible alarm systems were installed in the Control Room, Distribution Building, and test cell area for both hydrogen and neutronics hazards.

A new "electronic rod package" has been designed utilizing balanced d.c. command signals and magnetic amplifiers. It is hoped that the system can be field-tested on the Kiwi-A3 rod package, leaving the old system intact to be used on power runs.

The Sorenson frequency changer which provides 400-cycle excitation for the rod system failed recently. The backup was placed in service. A

detailed investigation of the cause of failure has been started. This is of particular importance, since consideration is being given to placing the rod synchro-system and the Offner amplifiers on the Sorenson rather than the 400-cycle M.G. set.

Modification kits are being supplied to improve the performance of the FR-600 analog recorders. Experience has revealed excessive wow and flutter in these recorders, and it is hoped that the modifications will reduce these defects to a tolerable limit. Capstan motor driven amplifiers and precision 60-cycle reference units have been ordered for all FR-600 recorders to improve their speed stability and provide isolation from power line variations.

The TDI demultiplex set has been modified and is operating on-line. All the equipment for the automatic Analog-to-Digital Conversion System has been delivered. A modification of the time train sync system was made to help overcome noise on E.P. 116 tapes. Present problems consist of improper parity generator action, some timing problems of the time train shift registers, and the handling of missing pulses in the data trains. The high-level multiplex system is on-line.

Two 120-ft poles have been placed near the reactor pad for the suspension of thermocouples to obtain temperature readings surrounding the exhaust flame envelope during the Kiwi-A3 run.

CHAPTER 3

KIWI-B AND PHOEBUS

A. KIWI-B

DESIGN AND FABRICATION

Pressure Vessel

The first full size Kiwi-B vessel is in the process of fabrication. It has been rough machined, welded, and heat treated to T₄ condition. Final machining processes are awaiting delivery of the machining templates. The delay is occasioned by a revision in the nozzle to pressure shell interface design, for which the drawing will be released during the week of September 19, 1960. Structural testing of the unit is scheduled to begin about November 1, 1960.

Reflector

The initial Kiwi-B reflector graphite cylinder and beryllium reflector thermal design study has been completed. This indicates the reflector cylinder can be adequately cooled from a thermal stress standpoint with one row of internal cooling holes. The study also shows that temperature peaking in the beryllium reflector can be kept to a few degrees ($\sim 20^{\circ}\text{F}$). A typical radial temperature profile, at $3\frac{1}{4}$ in. from the reflector coolant inlet, is shown in Fig. 3A.1.

The specifications for machining the Kiwi-B beryllium reflector segments have been released and Brush Beryllium.

Fig. 3A.1 Radial temperature profile in Kiwi-B reflector at 34 in. from coolant inlet.

Co. has indicated that it will be able to double the originally quoted production rate (to 12 per month) on machining of the segments. Specifications have also been released for the beryllium filler rods.

Core Support

An alternative core support method for Kiwi-B is being considered as a backup to the modular support. This would consist of six full axial length graphite sectors drilled to contain the fuel elements and supported in compression on the nozzle rim. The sectors would be held in place by radial compression from the two-pass pressure drop between the reflector and the core. A sector layout has been made and supplied to ACFI, together with the necessary H⁴LM graphite stock, for trial fabrication. The tooling required for machining the experimental sector for the alternative core structure has been started by ACFI; this is expected to take about a month.

Control Rod Cooling

The first of several cooling calculations on the control rod with the initial estimate on cooling hole distribution has been completed. It indicates satisfactory cooling with the poison inserted next to the core. A slightly worse case, with the poison withdrawn from the core, will be examined next. It is not expected this case will be unacceptable, and if this view turns out to be correct, the specifications for the control rods should be ready for release shortly.

Fuel Element Fabrication

The development work on the fabrication of 7-hole uranium loaded graphite fuel elements for Kiwi-B has progressed satisfactorily. Graphitized fuel elements containing 500 mg/cm³ of uranium and possessing a minimum carbon density of 1.73 g/cm³ have passed all tests satisfactorily. The extrusion tooling has been ordered for the actual fabrication of Kiwi-B fuel elements.

A few problems still remain in the fabrication of 27 to 30 in. long fuel elements. The equipment used thus far was that installed for the Kiwi-A plate fabrication and it appears to be very borderline for processing fuel elements of the present length. It may be necessary to replace the existing graphitizing furnaces with longer furnaces; if so, this will be done after experiments now in process have been concluded.

Fuel Element Exit End Design

Several problems are involved in the protection of the exit end of Kiwi-B fuel elements and a number of devices to accomplish this have been tested. The fuel element must be supported against the propellant pressure drop without interfering with the gas flow; this is accomplished by a retaining shoulder at the exit end of the module. In the case of 4-hole Kiwi-A' and Kiwi-A3 elements it was possible to make a sufficiently substantial shoulder without the wall of the gas passages being excessively fragile. This is not the case with the 7-hole Kiwi-B fuel elements and it is therefore necessary to terminate the fuel element at the shoulder and supply some means of preventing the module shoulder and the end of the fuel element from corroding away.

The most successful protection against corrosion was found to be afforded by an unloaded graphite insert resting on the shoulder and extending through and beyond it into the exit plenum. This insert is pierced by a single large hole which collects and carries the gas from all seven holes in the fuel element. The insert is protected from corrosion by a vapor deposited coating of NbC which has proved excellent for this application.

Furnace tests using a mockup of the module show that severe corrosion of the module occurred at the junction of fuel element and insert. This was completely eliminated in mockup tests by wrapping a piece of tantalum foil around the outside of the joint between fuel element and module.

Finally, even when the module is protected from corrosion by the above mentioned foil wrapping, the hot gas escaping from the end of the fuel element corrodes away the graphite at the end of the fuel element itself, thus exposing the liners and leaving them unsupported. This is effectively prevented by a vapor deposited coating of NbC applied to the end of the NbC-lined fuel element.

Privy Roof Design

Several possible privy roof shield designs have been examined. For a total dose of 5×10^6 rad, shields consisting of 5 in. iron and 10 in. water or 3 in. aluminum, 2 in. lead, and 10 in. water, weighing 125 and 105 g/cm², respectively, appear attractive. For a dose of 10^7 rad, shields of 3 in. iron and 10 in. water, or 3 in. aluminum, 1 in. lead and 10 in. water, weighing 84 and 76 g/cm², respectively, look promising.

B. KIWI-B NEUTRONICS

Temperature Effect on Reactivity

The effect of temperature changes in Kiwi-B has been estimated from the results of a continued neutronic calculational survey of the reactor. One dimensional cylindrical solutions of the neutron transport equation afforded by the DSN code and 24-group cross sections were employed. Because of the approximate nature of the calculations the results given below should be interpreted only as giving the general trend in reactivity. The effective multiplication factor for the cold Kiwi-B was found to be 1.0348 whereas that for operating temperatures was 1.0307. If the beryllium reflector is heated up during the course of operation, the reactivity will increase, but the overall temperature coefficient would remain negative. Temperature changes in the graphite reflector cylinder produce no noticeable effect in reactivity.

Control Material Effectiveness

Sufficient niobium was obtained to allow a replacement of the molybdenum previously used in Honeycomb mockups of Kiwi-B. Details of the new configuration are given in Table 3B.1. The effectiveness of various control rod materials was measured in this mockup, with the material located at the graphite-beryllium interface and centered axially. The relative values of four materials are represented as functions of the areal density in Fig. 3B.1.

Kiwi-B Zepo Mockup

The lash-up reflector for Zepo B, consisting of beryllium plates and wedges, has been assembled around the graphite core liner. Flat Boral strips will be inserted in void spaces between the plates for reactor control. In order to minimize perturbations from the large hydraulic lift platen the core assembly will be carried on a mockup

Fig. 3B.1 Effectiveness of control rod materials in Kiwi-B measured in Honeycomb mockup.

TABLE 3B.1
HONEYCOMB MOCKUP OF KIWI-B
Assembly HB-8

<u>Region</u>	<u>Radial (in.)</u>	<u>Material</u>	<u>Density (g/cm³)</u>
Fuel	0	C	1.41
		Oy	0.151
		Nb	0.0802
Reflector	17.51	C	1.41
	20.12		
Reflector	24.64	Be	1.66

Excess reactivity = $\delta 8.5$

Core length 48 in.

End reflector 4 in. graphite

Peripheral reflector length 52 in.

Honeycomb Aluminum 0.165 g/cm³

Mockup of 12 rotatable control rods in Be reflector.

of the 4-in. thick aluminum fuel support plate. This configuration places Zepo B in a nozzle-up position.

It now appears that Brush Beryllium Co. will do the final machining on the reflector segments, control rods, and filler rods. It is expected that six finished segments will be available 12 weeks after receipt of rough blanks, and then 12 segments per month will be produced until the order for 75 pieces is completed.

Hydrogen Reactivity

Hydrogen reactivity calculations have been made for Kiwi-B based on a power of 1000 Mw and 20% void model rather than the 600 Mw, 15% void model, for which calculations were previously made. The design point value of positive reactivity from the hydrogen is β 2.00 as compared to β 1.40 for the earlier model. The results for various flow rates are summarized in Fig. 3B.2. The dotted line represents operation along a pump constant specific speed line.

Fig. 3B.2 Hydrogen reactivity in Kiwi-B for various flow rates.

C. KIWI-B CONTROL SYSTEM

HEAT EXCHANGER

Start-Up Code

An IBM-704 program (KBS STUP) for studying the extent of two-phase conditions during start-up of liquid hydrogen flow has been written and debugged. Input parameters for the program are mass flow rate and power generation as functions of time. Flow rate is assumed to increase along a constant specific speed line, making inlet pressure a function only of the flow rate. If this assumption is removed, pump rpm must also enter as an input parameter. The program computes fluid properties and average reflector temperature along that portion of the reflector where two-phase flow exists. Heat transfer film coefficients and pressure drops are computed by subroutines.

STUP-1 is a conservative program based on the assumptions that the nozzle warms cryogenic hydrogen to a saturated liquid only and that the heat flux through the entire reflector is the same as that in contact with two-phase flow. The second assumption will be removed in STUP-2, an extension of STUP-1, which will follow two-phase calculations with those for gaseous hydrogen and yield a study of reflector outlet conditions during start-up. STUP-2 is expected to yield more realistic answers than STUP-1 for the start-up studies.

Kiwi-B Code

The IBM-704 program KIB describing the dynamic behavior of the overall Kiwi-B system has been enlarged to include the turbopump feed systems for Kiwi-B1 and B2. Water-hammer effects in the LH₂ supply lines can be included or excluded by using an index. The transfer functions representing the controllers and rod servos can be chosen as any variant of the expression

$$T.F. = \frac{k(\tau S + 1)(\tau S + 1)(\tau S^2 + \tau S + 1)}{S^{\alpha}(\tau S + 1)(\tau S + 1)(\tau S^2 + \tau S + 1)},$$

in which all of the τ 's are considered to be different. Any changes can be made by changing input data. All transfer functions shown on the Kiwi-B signal flow graph can be printed out by changing indexes that are read-in as data. Steady-state values of variables are computed from a given power level and output gas temperature.

Analog Simulation

The equations which describe the static and dynamic behavior of the Kiwi-B1 heat exchanger have been simulated on the analog computer. The core characteristics are represented by a three-lump model. An additional heat exchanger stage is provided for the reflector. At the present time the reflector simulator accuracy is poor for liquid hydrogen flow, but this situation should be improved in the future.

Simulation of Turbopump, Turbopump Feed System and Control

The IBM-704 program which represents the Kiwi-B2 propellant feed system has been debugged. This system uses a hot gas generator to supply the gas to the turbopump turbine. By changing the equations which represent the gas supply to the turbine this program is being modified to represent the Kiwi-B1 propellant feed system.

CONTROL VANE STUDIES

Kiwi-B Accident Studies

A simplified simulation of Kiwi-B has been put on the analog computer to determine optimum values for shim gang velocity limiting during normal operation and for shim scram velocity during reactor scrams. The simulator consists of a six-group neutronic kinetics representation, a simple one-lump heat exchanger, and shim and regulator vane simulators. Additional circuits are incorporated to scram the reactor when the power level reaches 150% of full power. A fixed time delay is included in the scram circuits to simulate the delay imposed by the reactor scram circuits. The regulator vanes were assumed to have a maximum velocity of 360°/sec under all operating

conditions. Shim gang velocity limiting and shim gang scram velocity were treated as variables. Data are obtained by generating accidents at full power and full flow and recording, among other things, reactor power and the core temperature change, ΔT . Most of the data obtained to date are for an accident caused by all of the vanes suddenly starting outward at their maximum velocities. The data obtained so far show that an increase in scram speed beyond $200^\circ/\text{sec}$ does not significantly decrease wall temperature overshoot during an accident. The results also show that shim vane velocity limit during normal operation may be increased from an arbitrary $18^\circ/\text{sec}$ to $45^\circ/\text{sec}$ or $90^\circ/\text{sec}$ without causing additional hazards in reactor operation. Wall temperature overshoot during an accident at full power is actually less with a higher shim vane velocity limit if the scram electronic circuit delay time is less than 35 millisecc.

Reactivity Transients

The IBM-704 neutronics code ROK has been modified, and designated ROL, to calculate the core temperature increases to be expected as a result of control element reactivity transients. It permits Kiwi-B nonlinear control vane reactivities proportional to $\sin^2\theta/2$, to be represented.

Power excursions starting from constant power were computed for both shim and regulating systems for the following start positions: (1) $\theta_0 = 90^\circ$ with both systems in mid-position, (2) both 0.3 sec from full out, and (3) both 0.2 sec from full out.

The resulting relative power curves were examined for scram signals (power level or period), delay times of 0.1 or 0.02 sec were added, and the system then scrammed with full travel scram times of 0.5 sec (occasionally 0.25 sec).

The accompanying power change was interpreted as a power increment above steady state, and the associated temperature rise vs time was computed using a simple IBM-704 code, TVP (Temperature vs Power). The assumptions made for the core were a mass of 545 kg, a specific heat of $0.52 \text{ Btu/lb-}^\circ\text{F}$

and a peak-to-average temperature ratio of 1.28 to 1. The rise in average loaded fuel element temperature, in peak fuel element temperature, and in peak fuel element temperature at the end of the excursion (P/P_0 returned to 1.0) attenuated with a 3 sec time constant, were computed.

The results indicate that for a 20-millisecond delay time, full travel shim time can be as fast as 2 sec and will result in a smaller temperature rise than the slower 18-sec travel time, because the power transient is over sooner. In general, the non-mid-position starting locations of 0.2 and 0.3 sec result in a greater temperature rise than the 90° start. An exception occurs for long delay times and a shim full travel time of 2 sec. In this case, shim and regulating system reactivity rates are comparable and the 90° start yields the steepest power-time profile and hence the greatest temperature rise.

More cases than covered herein could be examined in a shorter time using the analog computer; however, the results outlined above do serve as checkpoints and indicate what can be done to investigate this problem utilizing the IBM-704.

Control Vane Actuator

The Houdaille hydraulic vane actuator was received and is being tested with a complete Kiwi-B1 mockup reflector segment. Preliminary results indicate that the actuator will be acceptable for Kiwi-B1, after some minor modifications have been made as a result of the tests. Reshaping of the slowdown ports is being investigated to produce a smoother slowdown action as the vane nears the stops at high velocity. Purchase orders for 30 actuators will be placed after satisfactory completion of the acceptance testing.

Control Vane Electronics

The dynamic and static vane position transducer assembly is being tested as part of the Kiwi-B1 actuator-control vane mockup. The final design will be firmed up and fabrication begun by ACFI after completion of the Houdaille actuator testing.

Development and evaluation of the Kiwi-B1 control package is continuing. Present plans are to use magnetic amplifier controllers similar in design to the units installed in two of the Kiwi-A3 shim rod positioning systems.

Control Vane Bearings

In order to obtain life test data on Kiwi-B control vane bearings, the Houdaille vane actuator has been used to drive the bearing tester for a total of 600,000 cycles at a frequency of 5 cps and a peak-to-peak amplitude of 30° . The servo system and the seal on the hydraulic vane actuator have not shown any apparent degradation.

Pneumatic Vane Actuator

Preliminary layouts of a pneumatic vane actuator have been started. The present design concept is to construct the vane so that the sealing surface of graphite or asbestos is held against the interior housing with springs. It is hoped that this design will offer a satisfactory arrangement to take care of wear during prolonged use.

D. RADIATION HEATING IN KIWI-B

Heating in Reactor

Neutron and gamma-ray heating calculations have been made for a reactor having the material properties summarized in Table 3D.1 (see Fig. 3D.1). The results, which are averages for the various regions, are shown in Fig. 3D.1 expressed as Mw/ft³. The core-averaged power is

TABLE 3D.1
MATERIAL PROPERTIES OF KIWI-B REACTOR

<u>Region</u>	<u>Material</u>	<u>Density (g/cm³)</u>
A	Aluminum	2.70
B	Aluminum	0.81
C	Carbon -1.42, Oralloys -0.144, and Niobium -0.045	1.609
D	Carbon	1.70
E	Beryllium	1.65
F	Nickel	8.90

The fuel properties above are suitable for a core which has 44% structure at $\rho_C = 1.80$ g/cm³; 20% void; and 36% inserts with $\rho_C = 1.75$ g/cm³, $\rho_{Oy} = 0.400$ g/cm³, and $\rho_{Nb} = 0.125$ g/cm³.

2.65 Mw/ft³ and the power averaged over the entire pressure shell is about 210 kw /ft³ or 1.2 kw/lb. The results are believed to be correct within $\pm 15\%$ in the fuel region, whereas in the reflector and pressure shell the durations could be as large as $\pm 20\%$.

The data in Fig. 3D.1 are based on the supposition of a homogeneous core. Since the core is not truly homogeneous, the heating values for inserts and modules were each evaluated. This detailed calculation showed that for any region of the core, the heating within an actual insert

piece is 1.52 times the average total heating value as given in Fig. 3D.1, and the heating within the modules in that region is 1.03 times the average.

Heat Generation in Control Elements

The heat generated by (n,α) reactions, neutron scattering, and gamma absorption reactions in the Kiwi-B control elements has been recalculated using the DSN transport code for the latest Kiwi-B configuration (400 mg/cm³ loading, and niobium mocked up as molybdenum). An individual control vane, estimated to be worth $\sim 70\beta$ reactivity change from full-out to full-in rotation, appears as 60 mils of 10 w/o B¹⁰ Boral covering one third of the surface of a 4-in. o.d. x 52 in. long cylinder. Heating contributions are estimated to be about 200 kw from (n,α) , 10 kw from neutron scattering, and 10 kw from gamma absorption, or a total of approximately 220 kw.

In europium-stainless steel vanes of $\sim 70\beta$ reactivity worth (30 mils Eu₂O₃ + 70 mils Fe), about 12 or 13% of the neutron capture gammas are locally absorbed. This generates about 75 kw due to (n,γ) absorption, plus 100 kw due to "ambient" gamma flux absorption, for a total heating of about 180 kw.

In europium-aluminum vanes of $\sim 70\beta$ reactivity worth (30 mils Eu₂O₃ + 70 mils Al), roughly 7% of the capture gammas are locally absorbed to generate 40 kw. About 15 kw come from ambient gamma to give a total heating of approximately 60 kw.

Material Heating at Test Reactors

The approximate rate of temperature rise to be expected when small samples of material are exposed to radiation near to the side pressure shell of various NTS test reactors is given in Table 3D.2.

These values apply to specimens of the order of 0.5-in. thick in the direction of the escaping flux. They are not necessarily applicable to either very much thinner or much thicker pieces, but they do serve to illustrate conditions likely to be encountered in tests.

TABLE 3D.2

CALCULATED RATE OF TEMPERATURE RISE

<u>Material</u>	<u>Specific Heat (cal/g-°C)</u>	<u>Temperature Rise (°C/sec) Beside Pressure Shell</u>		
		<u>100 Mw (Kiwi-A3)</u>	<u>1000 Mw (Kiwi-B)</u>	<u>4000 Mw (Phoebus)</u>
Aluminum	0.20-0.21	0.083	5.0	20.
Iron*	0.11	0.166	10.	40.
Lead	0.031	1.10	66.	264.
Paraffin	0.69	0.040	3.6**	14.4**

*Metals of neighboring atomic number such as Cr, Mn, Co, Ni, and Cu, will have about the same power deposition per gram as Fe.

**Water would exhibit about 60% of this rate of temperature rise.

E. PHOEBUS

DESIGN

Testing of various module support configurations is in progress. Approximately a dozen modules have been tested using the gas flow tensile test machine and the results are encouraging. Arrangements have been made to continue these tests on a linear tensile machine. A considerable gain in the speed and ease of testing the supports is expected.

A radial power density profile with the edge spike reduced by a 33 mg/cm^2 cadmium curtain is now being used. The center/min/edge values for this profile are 1.17/.84/1.60 normalized to an average power of 1.00. Core heat transfer analysis is being adjusted for this profile, for a larger core diameter (37.625 in.), and for a thicker (2.5 mil) NbC liner. A core pressure drop of 162 psi is obtained for this model. Graphite hole diameters range from 97 to 114 mils.

DSN calculations indicate that a poison sheet is necessary to reduce the power level at the cold end of the core. A 0.25 g/cm^2 -cadmium sheet is estimated to be adequate if a 70% void aluminum support plate is used.

Pressure shell design and heat transfer calculations for the Phoebus reactor have been started. The value of gamma and neutron radiation heating used in this study is four times the value for Kiwi-B. Possible assembly procedures for Phoebus are also being investigated.

FUEL MODULES

The 37-hole extrusion die for the Phoebus type fuel element has performed extremely well considering that such an extrusion had never before been attempted at LASL. Extrusions produced with this die and processed through the graphitizing stage have shown densities on the order of 1.81 g/cm^3 . Specimens 6 ft long, containing 625 mg/cm^3 of uranium have been made for testing purposes; they have been crack-free and of high quality. The main problem encountered with the extrusion die has been

balancing the flow of material through the 37 pins so that the pins are not moved from their true position. Considerable experience and information have been obtained with respect to this problem by modifying certain portions of the die.

There is a distinct possibility that a 19-hole fuel element module may be utilized in place of a 37-hole design for the Phoebus reactor concept. In this case the experience obtained in studying the flow of material through a 37-hole die will be invaluable and the design of the 19-hole extrusion die will be simplified and its performance more predictable.

F. NTS ACTIVITIES

TEST CELL A

Air Products, Inc. has continued design work for the expansion of Test Cell A, and final mechanical flow sheets for all systems have been approved. It is expected that plans and specifications will be submitted by about October 17, 1960. This expansion will provide additional gas storage and a liquid hydrogen flow capability for the Test Cell. A contract for the fabrication of the two 28,000-gallon liquid hydrogen dewars will be issued as soon as funds are made available. The existing Distribution Building is to be used as a forward control room for this test cell.

TEST CELL C

Work started on the first major construction contract for Test Cell C on July 6, 1960, and it is estimated that the contract will be completed by February 1, 1961. Plans and specifications for the piping and electrical installation at Test Cell C were mailed to bidders and bid opening is scheduled for October 11, 1960. Erection of the two 50,000-gallon liquid hydrogen dewars is scheduled to start in October.

Construction of the 12.5 kv power line to Test Cell C was completed and work was started on the 69 kv power line to Test Cell C during the period. The development of Well J-12 and the connecting water line is scheduled for completion on November 1, 1960.

TEST CELL D

Negotiations conducted during the period by the AEC resulted in the selection of Aetron (a division of Aerojet) as the Architect-Engineer for the Test Cell D facility. Authorization for A-E design is expected to be forthcoming in October.

Design criteria for the propellant storage transfer and run systems are being formulated. Preliminary calculations are being made to suggest the design approach and to indicate alternatives in choices of design

parameters to be considered by the A-E. Flow diagrams of the major systems are now being prepared for evaluation. The following criteria are being observed:

Run tank volume: 70,000 gallons

Liquid hydrogen storage: 250,000 gallons

High-pressure gas storage: 2,250,000 scf

Liquid hydrogen flow rate for Phoebus (4000 Mw)

MISCELLANEOUS

Construction was started on the new high-bay viewing window addition to the MAD Building disassembly section.

Plans and specifications for the Equipment Testing Laboratory (to be built in the vicinity of Test Cell A) were issued to bidders on September 23, 1960. This laboratory is designed for the testing of a variety of components, such as shut-off, control, relief, and check valves, venturis, orifices, nozzles, turbine meters, filters, and regulators. In general all components which will be used in the test loops can be evaluated.

Criteria for a new assembly bay for the MAD Building have been submitted to the A-E (Holmes and Narver) for preliminary design.

CHAPTER 4

GENERAL DESIGN STUDIES

A. FLYABLE NUCLEAR REACTORS

GENERAL CHARACTERISTICS OF SIMPLIFIED SYSTEM

A study of a 100,000-lb thrust nuclear rocket engine system has been started. The purpose of the investigation is to help establish a control philosophy for a flight test system as well as for the Kiwi-B test reactors. Curves have been obtained using a Kiwi-B core configuration for variations of the following: thrust coefficient vs temperature, specific impulse vs temperature and nozzle expansion ratio, heat transfer coefficient vs temperature, and ratio of static pressure to stagnation pressure vs temperature. The thrust coefficient varied between 1.408 at 500°R and 1.434 at 5000°R for the nozzle designs considered. This result is of interest since it shows that thrust is essentially a function only of nozzle design and of stagnation pressure at the nozzle entrance. It was decided to use a nozzle expansion ratio of 20 and a throat area of 61.43 in.². Efficiency factors were applied to the nozzle to account for losses and divergence. Considering these factors the system has a specific impulse of about 765 sec.

The system includes a two-lump heat exchanger, six delayed neutron group kinetics, core pressure drop, temperature and propellant reactivities, vane actuators, poison vanes, nozzle, and controllers.

CONTROL PROCEDURE

Several engine thrust control systems have been examined with emphasis being placed on one which uses no moving poison rods. A static rod is included whose position is determined by the steady state operating level desired. The startup and dynamic control are attributed to the propellant feed system via the propellant's reactivity. Analog computer simulation of such a system shows that satisfactory performance is obtained by merely closing the thrust loop (or reactor exit pressure) through a simple proportional plus integral control. The loop was found to have an effective time constant of 0.02 sec. By lowering the proportional gain, which effectively removes lead compensation, the system could be made to go unstable. The feed system included a simple but realistic turbo-pump with an inertial time constant of 0.5 sec. This system approaches the ultimate in simplicity, which is especially desirable for a flyable reactor.

B. REACTOR CALCULATIONS

The wide variation in neutron flux spectrum over the Kiwi-A and -B reactors makes it necessary to look in some detail at spectrum dependent fission and absorption processes. Previous studies have investigated the integral effects of neutron absorption and escape as a function of elemental materials and geometry for heavy water, beryllium, beryllium oxide, and carbon at room temperature. Further work has been done on the available experimental data at higher temperature (to 1500°R) to verify the gas model assumption, in order to satisfy the need for reactor constants at high temperature and power. The most recent studies have been directed to absorption and fission resonance analyses, since these effects are important for the intermediate spectrum reactors, including the Rover series.

The nuclear temperature coefficients for beryllium oxide-moderated assemblies, given in the preceding Quarterly Rover Report (LAMS-2448, p. 54), have been re-evaluated. The experimental coefficient is $\$0.39/100^{\circ}\text{F}$ with which the calculated (gas model) value of $\$0.40/100^{\circ}\text{F}$ is in excellent agreement.

C. RADIATION HEATING AND DOSAGE

PROPELLANT HEATING

Approximate and exact methods have been used to determine the amount of energy deposited in the liquid hydrogen propellant, in a tank adjacent to a nuclear reactor in a rocket, as a result of absorption of radiations. The latter included gamma rays and neutrons from the reactor and gamma radiation accompanying capture of neutrons by hydrogen. To a good approximation the total energy absorption from a 1000-Mw reactor with a propellant flow rate of 65 lb/sec may be expressed by

$$E \approx 62 (1 - \cos \alpha) \text{ cal/g,}$$

where α is defined as follows. Consider a tank with its front tapered into a conical surface, having a flat end, whose apex is at the reactor fuel center, then α is the half-angle of the taper. Of the energy deposited, 45% comes from the reactor gamma rays, 38% from capture gammas, and 17% from neutrons. It is seen that the heating of the propellant can be minimized by decreasing the taper angle of the tank.

The result given above would apply equally well to other reactors provided the total power and the propellant flow rate are increased by the same factor. If the reactor power remains constant but the flow rate is increased, the heating by radiation is decreased proportionately.

PAYLOAD DOSE

As far as the radiation dose to the payload is concerned, neutrons can be disregarded since they are mostly absorbed by the liquid hydrogen between the payload and the reactor. Calculations show that the gamma doses at the payloads are likely to range from a few thousand rads to (perhaps) 100,000 rads. These would not constitute a problem for most kinds of equipment, but any human beings carried in the payload would, of course, have to be shielded. However, since the existing radiations in space will require a 4π personnel shield for many manned missions, it is possible that the use of nuclear propulsion will not result in any major weight penalties on that account.

To illustrate the approximate order of the personnel shielding problem, it would appear that a shadow shield of lead, about 8 in. thick, might provide proper protection against the propulsion sources, the exact amount depending somewhat on the tank-reactor configuration and on the dose which can be accepted. The thickness is as much as this because most of the dose comes from gamma rays of energy above 2 Mev, where lead is least effective in attenuating. Such a shield, 54 in. in diameter, would weigh some 7500 lb. It may be mentioned that tank tapering has beneficial results for payload dose just as it does for propellant heating.

D. CAVITY REACTOR

The Cavity Reactor assembly was brought to delayed critical for the first time on August 12, 1960. The condition for critical consisted of 7.354 kg of 0.003 in. thick oralloy foil on the cavity drum and the cadmium control rod withdrawn 40.00 in.

The control rod has been calibrated in terms of cents of reactivity by means of positive period measurements. Various delayed critical positions were obtained by adjusting the mass of oralloy on the cavity drum. The assembly was placed on a positive period by withdrawing the control rod, the period determined, and converted to cents of reactivity by means of inhour data. Based on these results, the aluminum rod connecting the control rod to the screw drive has been shortened 11 in. so that initial withdrawal of the rod will give reactivity response near the peak of the calibration curve. The dry well for the control rod will be shortened appropriately.

Incremental-type measurements are being made in order to estimate the negative reactivity contribution of aluminum that separates the heavy water moderator from the oralloy foil.

E. FLUIDIZED BED REACTOR

Experiments to determine the particle-to-gas heat transfer coefficient in fluidized beds are being continued. The container is made of quartz tubing 2 to 3 cm in diameter and approximately 10 cm long, positioned with its axis on a vertical line and the bottom end of the tube is closed. The distributing gas inlet, e.g., a porous quartz disc, is sealed inside the tube about 2 cm above the closed end or bottom. The fluidizing gas is admitted through a port in the wall of the tube at a point between the closed end and the distributing gas inlet. The bed of solid material to be fluidized is supported in the tube by the porous gas inlet. The work coil of an induction heater is generally wound around the cylindrical bed container so that the axes of the cylinder and the coil coincide. In some cases two work coils connected in parallel are used, one on each side of the cylindrical bed, with the axes of the coils normal to the axis of the bed.

Helium fluidized beds of zirconium carbide are heated to approximately 900°C for these experiments. Accurate heat transfer coefficients have not yet been determined owing to errors in the gas temperature measurement, largely due to conditions existing at the upper surface of the fluidized bed.

Another approach to the heat transfer problem has been to use an experimental procedure which requires less accuracy in the gas temperature measurement for computing acceptable heat transfer coefficients. Initial experiments utilized fluid beds of depths comparable to the bed diameter, but in this case small errors in the gas temperature led to large discrepancies in the heat transfer coefficient. But this difficulty can be overcome by the use of shallow beds. Shallow beds of zirconium carbide are difficult to heat by induction because the coupling from the work coil to the bed is poor; however, some progress has been made toward heating beds 2 to 3 cm in diameter and 1 or 2 mm in depth.

A "two-dimensional" bed has been constructed so as to study the dynamics of a bubbling bed, in order to provide a better understanding

of bubbling and its effects in fluid beds. Bubbling beds quite obviously have a desirable property of being well mixed, but at the same time the bubbling creates large variations in the character and amount of void volumes throughout the bed. For these experiments, the two-dimensional bed container was constructed of Lucite to give a bed width of 6 in., a thickness of $1/4$ in., and a bed depth which could be as much as 24 in. Bubbling was studied in a 6 in.-deep bed of copper particles by viewing from the side through the Lucite container walls. With a bed depth of 6 in., bubbles were seen to fill the entire thickness of the bed as they formed near the bottom and propagated upward. Motion pictures showed that bubbles propagate upward in the bed both by fall-through of solids and by migration of solids around the void. Bubbles enlarge as they rise through the bed by the consolidation of smaller bubbles and voids.

Experience with induction heated fluid beds has shown that frequently a temperature gradient exists in the solid particles from the inlet toward the outlet of the bed. Heat transfer from the particles to the gas is greater if all of the solid particles are maintained at the same temperature. Well mixed beds have this uniform temperature of the solid particles. Beds operating in the bubbling state have the desired mixing, but the bubbles tend to lower the heat transfer rate because of poor gas-particle contact.

A way to achieve desirable mixing and at the same time maintain a homogeneous bed is by use of "directed inlet" beds. Such beds have been constructed and operated at ambient temperatures. The desired mixing was made possible by the construction of the distributing gas inlet for the bed. This inlet was made of a metal plate through which holes were drilled at an angle so that the incoming gas has a tangential component of momentum. The pattern of the inlet holes was arranged to give a motion of the bed particles which results in the desired mixing. These directed inlet systems will be studied further in connection with heat transfer measurements.

CHAPTER 5

GENERAL SUPPORT AND RESEARCH ACTIVITIES

A. GRAPHITE FUEL ELEMENT DEVELOPMENT

PRODUCTION

The production of various fuel elements and modules for particular reactors is described under the headings of the respective reactors in Chapters 2 and 3.

STRESS-RUPTURE TESTS

In order to detect the same kind of failure as occurred in some of the Graph-i-tite G parts in Kiwi-A' a series of stress-rupture tests have been made at a constant stress of 500 psi on 1/4-in. diameter test bars of this material. A total of 40 specimens was tested, 14 at 1000°C, 18 at 1500°C, and 8 at 2000°C. No specimens failed during the test times, which ranged from 3.3 to 22.8 hr.

As a result of visual and radiographic examination, transverse cracks, as well as fractures were detected, even though the calculated stresses were much less than the strength of Graph-i-tite G. It was suggested that perhaps some unidentified kind of defect present in the material, together with a small applied stress at an elevated temperature, might have caused crack formation, growth, and the fractures encountered in the Kiwi-A' test. Because of the relatively small number of samples

examined, it is possible that the negative results of the stress-rupture tests do not permit any definite conclusions to be drawn.

EXTRUDED GRAPHITES

Furfuryl Binder

A number of graphite flour-Thermax formulations were prepared having different filler ratios. For satisfactory extrusion conditions the furfuryl resin content had to be adjusted for the various ratios.

Properties of graphitized samples are as follows:

<u>Graphite/Thermax</u> <u>Furfuryl Resin/Filler</u>	<u>75/25</u> <u>25/100</u>	<u>80/20</u> <u>26/100</u>	<u>85/15</u> <u>27/100</u>
Density, g/cm ³	1.86	1.84	1.78
Flexural strength (psi)	--	5700	4800
Resistivity (milliohm-cm)	--	1.34	1.42
Accessible porosity (%) (above 0.1 μ pore diam)	4.1	7.0	10.3
Plain permeability (cm ² /sec)	4x10 ⁻⁴	1x10 ⁻³	4x10 ⁻³
"Skinned" permeability (cm ² /sec)	7x10 ⁻⁴	4x10 ⁻³	1x10 ⁻²

Although tubular samples, 5/8 in x 3/8 in, baked satisfactorily in the 75/25 formulation, strip samples used for strength and resistivity determinations spalled severely, apparently because the low permeability of the stock inhibited the escape of decomposition products during the baking cycle. In evaluating these formulations, the typical properties were measured at several baking temperatures ranging from 1000 to 2600°C. An optimum in most properties was observed for temperatures in the range of 1200 to 1400°C; permeability and resistivity were low with strength at a maximum. This peaking appeared to be related to dimensional changes in the binder.

Samples prepared from the three formulations were subjected to several curing-baking schedules. Graphitized properties of these specimens

were found to be strongly dependent on the prior heat treatment. Although the spalling tendency was reduced by using an extended low-temperature curing and baking treatment, specimens heated on such a schedule were generally inferior.

Schedules: A - No cure, standard baking cycle.

B - 75°C/16 hr cure, followed by standard baking cycle.

C - 75°C/16 hr cure, 75 to 220°C. Post-cure over 140 hr, followed by standard baking cycle.

Graphitized Properties

<u>Filler Ratio Graphite/Thermax</u>	<u>Density g/cm³</u>	<u>Permeability cm²/sec(skinned)</u>	<u>Porosity % bulk vol. (> 0.1μ)</u>
<u>85/15</u>			
A	1.78	1.5×10^{-3}	9.3
B	1.78	1.1×10^{-3}	9.6
C	1.57	2.0×10^{-1}	21.3
<u>80/20</u>			
A	1.82	1.1×10^{-4}	5.8
B	--	--	--
C	1.65	5.8×10^{-2}	14.7
<u>75/25</u>			
A	1.83	4.8×10^{-4}	5.5
B	1.82	2.8×10^{-4}	4.4
C	1.67	4.8×10^{-3}	8.0

Strength and resistivity values also suffered when green stock was heated on the extended cycle (C); in comparison with schedule A or B, flexural strength was approximately one-half and resistivity was about 50% higher.

Apparently extended heating periods at temperatures in the binder decomposition region (200 to 240°C) allow the structure to bloat and fissure

excessively before binder solidification or "coking" is completed. The use of such cycles, however, is still indicated for preparing impregnated stock. The baked carbon matrix in this case is capable, using long post-cures, of withstanding the disruptive forces present during a furfuryl decomposition.

The three furfuryl binder graphites described above, having relatively low gas permeabilities, were examined for ash content. The data presented below were obtained by ashing the graphitized samples in an air atmosphere at 800°C for 96 hr.

<u>Filler Ratio</u>	<u>Permeability(cm²/sec)</u>	<u>Ash content(ppm[*])</u>
85/15	1 x 10 ⁻²	320
80/20	4 x 10 ⁻³	410
75/25	7 x 10 ⁻⁴	975

*Baked stock, heated only to 800°C, has an ash content of about 4000 ppm.

While purity should show some relationship to permeability, the degree would not be expected to be as great as demonstrated since the samples were exposed to a temperature of 2600°C in processing. At this graphitizing temperature most impurities volatilize readily and ash values of 100 to 200 ppm may be expected in small, thin specimens of typical graphites. These results suggest that appreciable fission product retention may be possible in graphite matrix elements if the base is a low permeability stock ($K = 10^{-4}$ cm²/sec or less). This effect would be emphasized if the element operated at moderate temperatures of 800 to 1200°C.

Multiple Impregnations

Several typical graphites were given multiple impregnations with uncatalyzed furfuryl alcohol polymer, the samples being graphitized before and after each impregnation. Data on this series are given on the following page; the first values in parentheses are for samples with 0.01 in. skin removed and the second parentheses give the accessible porosity above 0.1 μ pore diameter.

<u>Formulation</u>		<u>Permeability (cm²/sec)</u>		
Pet. coke/Thermax/Pitch 60/40 filler ratio, one pitch impregnation	Base	5x10 ⁻³	(6x10 ⁻³)	(12.1%)
	1X	6x10 ⁻⁴	(2x10 ⁻³)	(7.7%)
	2X	2x10 ⁻⁴	(8x10 ⁻⁴)	(6.4%)
	3X	8x10 ⁻⁷	(6x10 ⁻⁴)	(5.5%)
Graphite/Thermax/Furfuryl 80/20 filler ratio	Base	1x10 ⁻³	(4x10 ⁻³)	(7.0%)
	1X	9x10 ⁻⁵	(6x10 ⁻⁴)	(6.0%)
	2X	3x10 ⁻⁶	(1x10 ⁻⁴)	(4.8%)
	3X	1x10 ⁻⁶	(4x10 ⁻⁶)	(4.8%)

Particle Size of UO₂ Loading

The relationship of various properties and the particle size of loading was determined for a nominal span of 10 to 100 μ diameter using a furfuryl binder graphite as a matrix. Properties of these and a comparable unloaded graphite were measured as follows:

<u>85275 Formulation</u>	<u>Graphitized Properties</u>		
	<u>—</u>	<u>10μ(-325 mesh)</u>	<u>100μ(7μ to 104μ)</u>
Loading (mg/cm ³)	0	200	200
Flexural strength (psi)	5000	5000	4000
Resistivity (milliohm-cm)	1.25	0.60	1.00
Density (g/cm ³)	1.81	2.06	2.05
Permeability (skinned)(cm ² /sec)	1.2x10 ⁻²	1.2x10 ⁻²	about 1
Porosity(% bulk vol. > 0.1 μ)	8.0	7.1	10.6

The helium permeability was the only property which presented an appreciable contrast between the two loaded graphites. This was apparently due to the different packing relationships in the filler and the relative size of the cavities formed in the conversion of the oxide to the carbide. The carbon consumption (or cavity formation) was demonstrated in permeability measurements made on both stocks after baking to various temperatures. The coefficient for a 1000°C bake, where conversion had not occurred, was approximately one-tenth that of the 2500°C value where the reaction had been completed.

BLISTERING OF FUEL ELEMENTS

Gas Evolution

Mass spectrometer measurements have shown that both carbon monoxide and nitrogen are evolved when uranium loaded fuel elements are heated. These gases result from the reaction of uranium oxide and nitride, respectively, with the graphite. In the case of the oxide, the reaction is probably

the UO_2 arising, to varying degrees, from the nature of the fuel element processing and from the reaction of the uranium carbides with moisture in air (see below). When the carbon monoxide and nitrogen gases are formed at a greater rate than they can escape, in one way or another, the remainder will collect underneath the niobium carbide coating and produce blisters. It has been observed that carbon monoxide comes off at about 1850°C in the induction heater where the external pressure is 1 atm while blistering of coatings (and evolution of gas) in the test furnace occurs at 2400° to 2450°C under 200 to 800 psig. This seems to be adequately accounted for by assuming that carbon monoxide pressure must equal the ambient pressure in order for the gas to stream out of the pores in the graphite. At lower temperatures, and hence lower carbon monoxide pressure, the reaction of uranium oxide with carbon proceeds only as fast as permitted by the relatively slow removal of gas from the interior of the fuel element.

Hydrolysis of Carbides

There is little doubt that, upon standing, the uranium carbides in the fuel elements react with moisture to form the oxide (or oxides). Experiments on the hydrolysis of the carbides have shown that UC_2 reacts much more rapidly than does UC. The gaseous products contain some hydrogen but in the case of UC_2 they are mostly unsaturated hydrocarbons. With UC, the main product (77%) is methane. The solid residues were found to contain UO_2 .

A possible method for preventing UC hydrolysis would be to stabilize it in solid solution with an isomorphous carbide, such as ZrC. Samples containing 30 m/o UC and 70 m/o ZrC were obtained and exposed to water at room temperature. There was no evidence of the evolution of either hydrogen or hydrocarbons, and x-ray diffraction examination of the solids revealed no change. It appears, therefore, that ZrC will stabilize UC in solid solution against hydrolysis in the particular system studied. Work is proceeding with solid solutions containing larger proportions of UC.

A number of attempts have been made to coat the fuel elements, e.g., with a polymer, to protect the uranium carbides from attack by moisture. The results so far have not been promising. Other possibilities are also being investigated in order to overcome the blistering problem.

B. METAL FUEL ELEMENT DEVELOPMENT

TUNGSTEN-UO₂ SYSTEMS

The program to provide a W-50 v/o UO₂ fuel element to function at temperatures above 2000°C has shown some interesting results. Mixtures of the above composition have been powder-rolled and sintered as well as cold-pressed and sintered. A coarse tungsten powder was found to be more satisfactory for the powder rolling technique whereas a fine powder gave superior results when cold-pressed and sintered. The ultimate thickness of the fuel element may determine which process will be used.

An important development has been the ability of the tungsten coating to retain UO₂ during the high-temperature test. The tungsten coat can be applied by spraying a slurry of the metal on the surface of the W-UO₂ piece or by depositing tungsten from the carbonyl. Each coat is very thin (< 1 mil) and is sintered at high temperature prior to applying the subsequent coating. At 2350°C in flowing hydrogen for 10 min, UO₂ losses have been less than 2.0% when two or more coats have been applied with some tests indicating as low as 0.3% UO₂ loss. At 2600°C, the UO₂ losses have been less than 3.4%. Cycling tests at high temperature will be undertaken to determine the effect of more than one heating on the UO₂ retention in the fuel element.

TUNGSTEN-TUNGSTEN BONDING

High-temperature diffusion bonding experiments to join tungsten to tungsten look very encouraging. The use of Ni, Ni-Re, or Mo flash on the surface of the tungsten serves to promote the diffusion bonding and produces a strong joint. Temperatures above 2000°C have been found to be most successful for this process. Shear strengths in the range of 170 to 240 psi have been obtained on such bonds when tested at 2450°C. These values are higher than the proposed reactor strength specifications.

POWDER ROLLING

Reproducibility of discharge data continued to be the main problem in the powder rolling program. The hopper mounting technique which previously gave reproducible results was slightly modified to insure a constant and reproducible opening. This led to a non-reproducible mode of hopper vibration. A new feed hopper is currently being built based upon the experience gained with the present hopper. It will be extremely simple and rigid and will be adjustable only for apex or orifice opening. It is believed that the new hopper will lead to reproducible discharge results.

A brief experimental program has been initiated to obtain basic information on the flow behavior of metal powders. A small size (not a true scale model) hopper has been built from Lucite. Various modes of vibration can be imposed on this model by means of a variable frequency oscillator. Although the quantitative results obtained for the model system will not be directly applicable to the full scale hopper system, the following qualitative information applicable to the full scale system is expected:

- 1) Dependence of powder fluidity on vibrational frequency (in the range 1 cps to 1200 cps).
- 2) Dependence of powder fluidity on vibrational amplitude.
- 3) Dependence of powder fluidity on vibrational resonance in the powder mass or vibrational resonance in the hopper system.

Preliminary experiments with the model system indicated a definite increase in powder fluidity in the frequency range 120 to 160 cps with a decrease in fluidity to no flow above 300 cps, but it is not clear whether the increased fluidity was due to frequency dependence or to an increase in effective amplitude due to resonance in the hopper structure.

C. CARBIDE FUEL ELEMENT DEVELOPMENT

FABRICATION

An effort has been made to produce a plate or a small rod consisting of complete solid solution UC-ZrC of high density. It has been observed that UC + ZrC mixtures, cold pressed and sintered at 1160°C , do not form solid solutions. The product of this treatment, however, when hot pressed in vacuum at 1700°C does yield a complete solid solution and the pressed pieces have the theoretical density.

Mixtures of UC and ZrC have been reacted in a crucible at 1700°C in vacuum and have also produced complete solid solutions. This material, when ground to powder and hot pressed in vacuum at 1700°C , yields high-density pieces.

The process of cold pressing and sintering of UC-ZrC solid solution powder has not yielded satisfactory results. The densities obtained are far below those found in hot pressed pieces. In view of the fact that this process is highly desirable from the standpoint of producing large numbers of pieces, work will continue in an effort to obtain higher density pieces.

The best results to date for the preparation of UC have been obtained by the direct reaction of uranium and carbon at temperatures between 1000°C and 1160°C . A fast, exothermic reaction, indicating UC formation, is noted at approximately 1000°C . The results of the uranium-methane reaction have not been too successful, since the presence of UC_2 or carbon is indicated in x-ray diffraction patterns. The temperature for this reaction appears to be extremely critical if only UC is desired.

HEATING IN HYDROGEN

Two slabs of 30 m/o UC-70 m/o ZrC were coated with NbC and heated in flowing hydrogen at a mass flow rate of 31.6 lb/hr to temperatures ranging from 1800 to 2300°C . No loss of weight or crack formation was observed following a 5-min heating period. Losses may well occur, however, if the heating is prolonged.

D. CERAMICS AND CERMETS

URANIUM CARBIDE

Preliminary measurements indicate that uranium carbide vaporizes congruently at a composition of $UC_{1.1 \pm 0.1}$. Arc melted compositions of uranium carbide between $UC_{1.76}$ and $UC_{1.05}$ were heated in high vacuum, $< 10^{-6}$ mm of Hg, for extended periods of time at temperatures above $2100^{\circ}C$. Upwards of 10% of the total sample weights were lost by vaporization. All samples lost carbon preferentially, with the exception of the composition $UC_{1.05}$.

Vapor pressure measurements of $U(g)$ over UC_{2-x} , at unit carbon activity, were conducted by the effusion technique. Assuming the reaction

the vapor pressures were calculated using the fundamental Knudsen equation. The values ranged from about 2×10^{-9} atm at $2150^{\circ}K$ to 15×10^{-9} atm at $2280^{\circ}K$.

The melting point of UC of compositions from $UC_{1.02}$ to $UC_{1.04}$ has been observed to be $2495 \pm 30^{\circ}C$. The melting point of 90 m/o UC-10 m/o ZrC is about $100^{\circ}C$ higher.

TANTALUM CARBIDES

Samples of nominal composition $TaC_{0.5}$ and $TaC_{0.6}$ have been heated at temperatures from 1800 to $2400^{\circ}C$ to study the formation and lattice parameters of the Ta_2C phase. A Ta_2C sample heated alone for 70 hr at 2000° still was not at equilibrium. No systematic variation of lattice parameter with heating temperature has been found, and no single-phase Ta_2C patterns, even from a sample of analyzed composition $TaC_{0.493}$.

X-ray and analytical data have been obtained for a sample prepared by heating a mixture of TaC_x and Ta_2O_5 . The analysis shows: Ta 93.29%,

C 4.59%, O > 0.92%. At the temperature at which this sample was prepared (1800°), TaC in equilibrium with Ta₂C has a lattice parameter of $a = 4.416\text{\AA}$, whereas for Ta₂C in equilibrium with TaC the parameters are approximately $a = 3.106$ and $c = 4.942\text{\AA}$. The ternary sample exhibits lattice parameters as follows: for the Ta₂C phase, $a = 3.102 \pm 0.003$, $c = 4.934 \pm 0.004\text{\AA}$, and for the TaC phase, $a = 4.363 \pm 0.002\text{\AA}$. The low lattice parameter of the TaC phase indicates a considerable solubility of oxygen in this phase.

A tantalum carbide sample was formed by heating the elemental powders in a graphite crucible for 10 min at 2400°. The resulting plug, of initial composition TaC_{0.6}, was heated for 227 hr at about 1800°C. During this period the TaC phase increased in quantity while the Ta₂C phase decreased. The sample was then ground to a powder, and heated in a graphite crucible for 36 hr at 1900°. It was again ground to a powder and heated for another hour at 1900°, in the crucible. X-ray patterns taken after these last two heatings agreed quite well with the pattern of the "zeta-phase" described in the literature.

NIOBIUM CARBIDES

A sample of niobium carbide of composition NbC_{0.993} was subjected to x-ray diffraction analysis; the lattice constant was found to be 4.47095Å. The theoretical density (for 4 NbC_{0.993} per unit cell) is 7.79 g/cm³ and the Nb-C bond distance for coordination number six is 2.2355Å.

For carbides ranging in composition from C/Nb equal to 0.996 down to 0.700, the lattice constant is given by

$$a_0 = 4.09847 + 0.71820 (C/Nb) - 0.34570 (C/Nb)^2.$$

There is a density minimum of 7.716 g/cm³ at about NbC_{0.79} and a maximum of 7.796 g/cm³ at NbC_{1.00}. The density of Nb₂C (hexagonal lattice) is about 7.95 g/cm³ and that of Nb (body centered cubic) is 8.53 g/cm³. The slight decrease in cell volume and the nearly linear decrease in density at high C/Nb ratios suggests a defect structure. At lower C/Nb ratios, however, the loss of carbon results in a much more rapid collapse of the cell.

Niobium foil, which had been doped with 5% ThO₂, was carbided in the induction furnace and the resultant mixture examined metallographically for grain growth inhibition. The difference between the doped NbC and the pure NbC was small, probably due to the coarseness of the ThO₂ suspension. It appears that since the ThC and NbC are immiscible, inhibition of the grain growth and subsequent keying of the NbC structure is feasible.

MOLYBDENUM CARBIDE

X-ray diffraction studies have been made of molybdenum dicarbide of composition Mo₂.08C. The lattice parameters are $a_0 = 3.00292\text{\AA}$, $c_0 = 4.72895\text{\AA}$, and $c_0/a_0 = 1.575$. The volume of the hexagonal unit cell is therefore $36.929\text{\AA}^3$ and the theoretical density (for one Mo₂C per unit cell) is 9.167 g/cm^3 at 25°C .

RUTHENIUM AND OSMIUM CARBIDE

The preparation and crystal structures of RuC and OsC have been described in an earlier report; physical measurements obtained since then are tabulated below. Both carbides have the hexagonal WC-type structure.

	$a_0(\text{\AA})$	$c_0(\text{\AA})$	c_0/a_0	$d_{\text{calc}}(\text{g/cm}^3)$	Microhardness (kg/mm^2)
RuC	2.90785	2.82186	0.9704	9.088	3480
OsC	2.90769	2.82182	0.9705	16.25	2000

EUROPIUM OXIDE

Lack of required amounts of suitable B¹⁰ for Kiwi-B application has spurred interest in the lanthanons as control materials. After careful consideration it was concluded that the element which appears to be most promising from the nuclear standpoint was europium. The maximum concentration of this element necessary for Kiwi-B control will be 250 mg/cm^2 . The most desirable compound to use for control rod application appears to be the

sesquioxide (Eu_2O_3), so that 290 mg/cm^2 of the oxide would be required. If the Eu_2O_3 is to be fabricated as a suspension in aluminum, a 30 v/o loading would give a total thickness of 0.050 in., assuming theoretical densities. The temperature rise in this sheet would be about 25°C , based on the (n, γ) reaction and the gamma heating.

It is estimated that Kiwi-B would require about 5.2 kg of the oxide. Present production of Eu_2O_3 in the U.S. is about 75 kg per year (99+% pure), so this offers no apparent problem. It is further estimated that the ultimate production of Eu_2O_3 from monazite ore will be about 250 kg per year in this country. The present cost is about \$2 per gram of the oxide.

The details necessary for the production of Eu_2O_3 suspensions in stainless steel have been worked out. KAPL reports that once the Eu_2O_3 powder is properly prepared, there is no difficulty in making the suspension in an aluminum matrix. Since the thermal conductivity of aluminum is so much better than that of stainless steel, this is the more desirable matrix for Kiwi reactors.

E. HIGH-TEMPERATURE METALS

VANADIUM-ZINC

By heating pressed pellets of vanadium and zinc powders in a vacuum at 1000°C , evidence was obtained for the formation of a hitherto unidentified compound.

NIOBIUM-TANTALUM

Samples of Nb and Ta, and of systems having Nb/Ta ratios of 3/1, 1/1, and 1/3 have been examined for superconductivity. Preliminary results indicate that the transition temperatures vary monotonically from that for pure Nb, down to the value for Ta. It appears that, for certain metal systems, the determination of superconductive properties can be a powerful tool for the detection of compound formation.

F. TRANSPORT PROPERTIES OF HYDROGEN

THERMAL CONDUCTIVITY

Three empirical equations have been developed describing the thermal conductivity of hydrogen, both liquid and gas, over the temperature range 0°K to 2080°K . An equation for thermal conductivity of normal gaseous hydrogen at one atmosphere pressure, which was reported earlier (IAMS-2422, p. 79), has been revised. A second polynomial has been developed which gives a standard deviation of fit of $1.18 \text{ cal/cm-sec-}^{\circ}\text{K}$ for the conductivity as a function of density and temperature. A third equation giving the thermal conductivity ratio of para to normal gaseous hydrogen was referred to in IAMS-2422, p. 80.

VISCOSITY

A polynomial equation in powers of the absolute temperature has been developed to make an empirical correlation of the 1-atm viscosity data from 13.97°K to 1280°K . The standard deviation of the fit is 1.1 g/cm-sec .

Data above 1280°K were correlated with a two-dimensional equation in temperature and pressure. The data used were the computed values which take into account dissociation effects. The equation was in agreement with theoretical values in the temperature range from 1500°K to 5000°K and with pressures from 0.1 to 100 atm within 3.9%. The standard deviation of the equation over the 1500 to 5000°K range is 77 g/cm-sec .

G. CRYOGENICS

MISCELLANEOUS

ACF Industries have erected their facility at IASL for testing cryogenic gaskets and closures. Numerous runs with liquid hydrogen (LH₂) and liquid nitrogen have been made. When the apparatus was first set up difficulties were encountered with valves freezing and sticking at the low temperatures involved. Modifications made locally corrected these deficiencies. Tests have been made on both a static "cold" seal using differential contraction to further compress a rubber seal and a "warm" bayonet type of seal built to withstand small axial motions. These joints will be used on the Kiwi-B reactor test railroad car.

Two loads of LH₂ were received at IASL, one from Florida and one from California. Both were transferred directly into the three portable 6000L Beech dewars for local storage. This hydrogen is being used for the following Rover projects: ACF Industries Cryogenic Joint Testing, the Reactor Sector Flow Experiments, and the Temperature Transducer Experiment.

Numerous LH₂ runs have been made with the temperature transducer experiment. Several temperature probes have been checked at various temperatures and different pressures. Currently three Nacimco probes and one Rosemount are in the apparatus. Small shifts have been observed in reading these probes at constant temperature when the pressure is increased. A vapor pressure thermometer is used for temperature calibration. One of these probes will be used in the Reactor Sector Flow experiment following calibration.

The testing in Florida by Air Products, Inc. of flanged pipe couplings for cryogenic use is continuing. A test flange using highly compressed natural rubber O-rings and which was fabricated at IASL has been very successful. A leakage rate as low as 5×10^{-7} standard cm³/sec has been obtained from a 6-1/2 in. O-ring under a pressure of LH₂ at

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1200 psi. It was also found that Teflon coated self-energizing stainless steel O-rings do not hold as well under these conditions.

Test Cell D calculations have been made concerning boil-off and cool-down rates for various tank and insulation configurations. Preliminary calculations of piping sizes are proceeding.

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