LIQUID METAL FUEL REACTOR EXPERIMENT

MONTHLY PROGRESS STATEMENT

DECEMBER 1956

BAW-1002

AEC CONTRACT NO. AT(30-1) - 1940
B&W CONTRACT NO. AEJ-46

SUBMITTED TO THE
UNITED STATES ATOMIC ENERGY COMMISSION
BY
THE BABCOCK & WILCOX COMPANY

LMFRE MONTHLY PROGRESS STATEMENT NO. 1

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I. SUMMARY

During December, thirty-two Babcock & Wilcox Company Atomic Energy Division employees worked full time on the LMFRE. B&W submitted preliminary budget figures for FY 1957 and a proposed research program. Details of the research program were discussed with the Atomic Energy Commission in Washington. Permission was granted to start research work in accordance with Phase II of the contract within the limitations of the existing cost ceiling.

Preliminary design studies of the LMFRE have continued. Several different reactor designs have been drawn up and studied. Heat transfer and physics calculations have been made on some of these designs or parts thereof. Work was started on specifications for high temperature instrumentation and control rods. Studies were made of various liquids and gases to determine their suitability as heat transfer fluids in the intermediate heat exchange system.

Work has continued on abstracting information from research previously performed at Brookhaven National Laboratory. Several research agencies have been approached to determine if they were interested in participating in LMFRE chemical processing research. At B&W's research center in Alliance, Ohio, work has been initiated in the fields of chemical analysis, chemical cleaning, metallurgy, fabrication of graphite-to-metal joints, and behavior of materials in contact with liquid bismuth and additives.

Pending a decision on division of responsibility for BNL Radiation Loop No. 1, B&W continued engineering studies of the out-of-pile section of the loop.

II. ADMINISTRATION

A. The prime contract between Babcock & Wilcox Company and United States Atomic Energy Commission for LMFRE work (AEC Contract No. AT(30-1)-1940; B&W Contract No. 600-0046) was signed November 9, 1956. *

B. During December, the LMFRE project group occupied space in the Hotel Carroll in Lynchburg, Virginia. On December 28th the group moved to B&W's nuclear facility plant in Lynchburg.

C. As of December 25th thirty-two employees of B&W's Atomic Energy Division were engaged full time on LMFRE project work.

D. On December 4th B&W submitted preliminary budget figures for FY 1957 and a proposed research program.

E. Priority rating DO-E-1 was assigned to LMFRE.

F. On December 14th B&W submitted LMFRE procurement policy to the Atomic Energy Commission for approval.

G. On December 18th B&W submitted draft of proposed subcontract between B&W and Union Carbide and Carbon Corporation for AEC approval.

H. On December 20th representatives of B&W and Union Carbide met with the Atomic Energy Commission in Washington to discuss the research and development program.

I. On December 21st approval was granted to start research work in accordance with Phase II of the contract, within the limitations of the existing cost ceiling.

J. On December 28th distributed Quarterly Technical Report No. 1.

K. On December 31st no commitments for purchases were outstanding.

* While this event is outside the reporting period, it is included to put other events in the proper perspective

III. TEST PROGRAM PLANNING (W. R. Foley)

The Test Program Planning Group continued work on the formulation of a Research and Development Program. During the previous month's work it had been established that due to the time schedule for the LMFRE as set forth in the contract, it would be necessary to start some of the research and development during Phase I of the Project work. As a result of this decision, a proposal was submitted to the Atomic Energy Commission on December 4, 1956, for the research and development of materials and processes that would have to be started in the immediate future in order that data could be obtained in time to be useful in the detailed design of the LMFRE. On December 20th, the details of this report were discussed with the AEC in Washington, D. C. Since that time, the implementation of this program has been going forth as rapidly as possible (see Section V).

Work was completed on abstracting metallurgical data from the past work of the Brookhaven National Laboratory. The table of thermal convection loops started in BAW-2 was brought up to date in this abstract, and notes were incorporated from post-operation metallographic examinations. The results of metallographic examinations for the first three runs of high velocity loop #1 have also been included in the abstract.

On December 14, 1956, a meeting was held at Lynchburg with representatives of Horizons, Incorporated, of Cleveland. The purpose of this meeting was to discuss slurry technology, liquid metal corrosion testing, and graphite-to-graphite joints. Horizons has completed a project for Brookhaven National Laboratory on constituting a thorium bismuthide in bismuth dispersion. This method is developed to the satisfaction of BNL and is readily adaptable to large scale operation.

On December 19, 1956, a meeting of the Test Program Planning Group was held to discuss the objectives of this group in the preparation of a test program to include all testing performed on or with the LMFRE. Procedures to be followed in the accomplishment of the objectives were established.

Technical data related to materials which had been requested by engineering sections was obtained, documented and distributed.

IV. LMFRE PRELIMINARY DESIGN STUDIES

A. REACTOR ENGINEERING (J. J. Happell)

1. Reactor Design - General

The required prestress in molybdenum core support rods was checked. Required stresses can be reduced by using Croloy "shoes" to limit maximum stress to 25,000 psi. Yield stress for molybdenum is 110,000 psi.

Graphite rods to support the core (Design #2) will of necessity be extruded to obtain strength. Such rods will have a different coefficient of axial expansion than the molded graphite core, and hence under operating conditions the tensile stress in the rods may exceed 1000 psi (the ultimate tensile strength of the rods). Unless molded rods of high strength can be obtained, Design #2 is not practical.

The reactor vessel design pressure was reviewed. No reasons could be advanced for altering the previously selected design pressure of 100 psi, with emergency conditions of 200 psi maximum.

Work continued on thermal calculation procedures. A steady-state temperature distribution is being established for a 4.5' diameter x 4.5' long core.

A literature search was made to determine proper evaluation of forced convection heat transfer film coefficients for bismuth. Channel wall temperatures were recalculated using new coefficients.

No reliable methods for degasser design are known at the present time. The LMFRE will itself have to serve as a means of obtaining design information and hence it appears desirable to incorporate external (separate) degassers in the system to facilitate changing degasser internals, etc. The reactor group has concluded that external or separate degassers should be considered in future designs.

2. Reactor Design #2

Reactor Design #2 incorporates graphite rods for core suspension. It was decided to terminate this design as of Friday, December 7th, and incorporate other general modifications in Design #3. Prior to terminating this design a core experimental port was added. The core experimental port complicates the over-all design and introduces a control rod problem. Two experimental ports were also added in the bottom half of the reactor. A descriptive memo was written, and the layout drawing was modified slightly (degasser trays) and designated B&W DRWG. 50452-E1. Prints and copies of the memo have been distributed within the Project.

3. Reactor Design #3

Core support problems in Design #3, which will utilize molybdenum rods both for core and reflector, were discussed. It has been decided to omit the overhead degasser in this layout in an effort to shorten the over-all reactor height. Reactor vessel wall thickness was rechecked. Vessel closure and core hold-down problems were also discussed. Beryllium control rod thimbles have been specified for this arrangement to seal off the control rod dome against contamination. Instrumentation ports are being included for fission chambers and neutron detectors. Work is approaching the point where secondary containment design conditions and insulation type should be considered. The design has progressed to the point where revised control rod drives will be added. Work has been done in devising promising bellville-spring type core-reflector seals which allow a high sealing pressure and yet offer sufficient freedom of movement so that expansion can be accommodated.

4. Reactor Design #4

Reactor Design #4, incorporating a metal core tank, was initiated and completed during this period. This layout will be carried along and developed as an alternate to the graphite core tank designs in the event that a graphite core tank cannot be developed in time for the LMFRE. An eight-stage degasser has been included which makes the over-all height of the unit rather large.

5. Reactor Design #5

Reactor Design #5 has been started. This design also utilizes a metal core tank and will include beryllium control rod thimbles and instrumentation ports, but will omit the overhead degasser. The control rod drives will be revised. The graphite reflector will also be shown in more detail than in Design #4.

6. Reactor Design #6

Details and development of reactor arrangement #6, which is a modification of #3, are presently being considered, with special attention to sizing construction details to show more realistic proportions.

B. NUCLEAR ENGINEERING (J. J. Happell)

Core thermal calculation procedures have been outlined and steady-state temperature distribution analysis has been started.

A calculation was made to determine the xenon and iodine removal rates required to limit the xenon positive temperature coefficient; these calculations indicated 20% removal per pass may be required in the degasser. More detailed calculations will be required before actual removal rates can be specified.

A general information meeting was held at Lynchburg on Thursday, December 13, regarding physics with Messrs. Kouts, Chernick, and J. Fleck from Brookhaven National Laboratory. The B&W reactor group was represented by G. Thomas and T. Engelder. A list of reports regarding kinetics, core thermal calculations, control rod calculations, etc., were presented by BNL. We shall order the entire list for our files.

Kinetics of the LMFRE were discussed during this meeting. Transient core pressures will be limited to about 10 psi above normal operating pressure and hence a large gas volume above the core is not necessarily required. B&W machine calculations will serve as a check on this conclusion.

A comparison of expected transient temperature rise due to a 0.0025 k step change in reactivity was made for the LMFRE and LMFR. Maximum temperature rises were approximately 200 F for the LMFRE and 500 F for a 550 MW LMFR. Pressure increases were not investigated.

A calculation has been started to estimate the flux depression due to a central core experimental thimble (Design #2).

C. PHYSICS AND MATHEMATICS (T. Engelder)

1. Reactor Statics

a. Status of Parametric Survey

The four-group parametric survey of U-Bi-C reactors is awaiting the completion of the Spectral Code, which is being written to obtain automatically the group parameters for various core and reflector compositions. According to the best present estimates, the parametric survey will begin about the second week in February.

The vertical bucklings for a series of cylindrical U-Bi-C reactors of V(Bi)/V(C) = 0.1 to 2.0, and reflector thicknesses of 0.5, 1.5, and 3.0 feet, have been computed for use in the four-group parametric survey.

b. Flux Depression Factors

The thermal neutron flux depression at the surface of the four-inch diameter test holes in the reflector containing 3000 ppm U^{235} in bismuth has been computed on the basis of several arbitrary assumptions:

Reflector Geometry	Unperturbed Flux Shape	Flux Depression
Cylindrical	Flat	0.44
Cylindrical	Parabolic, about test hole	0.01
Slab	Flat	0.45
Slab	Slanted across test hole	0.41 (inside) 0.25 (outside)
Slab	Parabolic, about test hole	0.11

It is apparent from these preliminary figures that fission density in the reflector test holes will be no greater than that in the core itself operating on 1000 ppm fuel.

2. Reactor Dynamics

a. Transient Behavior

Several changes and improvements have been made in the formulation of the generalized set of transient equations since the discussion in Quarterly Technical Report No. 1:

(1) In the core heat balance equation, the approximation that the power removal is a linear function of temperature has been improved. The fuel density and temperature has been arithmetically averaged over the inlet and

outlet values, and the heat flow from the graphite to the fuel has been formulated as a simple linear function:

$$\rho C_F V_F \dot{T}_F = (1 - \alpha)P + A'U'\rho' C_F T' - 4AUC_F(\rho - \rho'/2)(T_F - T'/2) + \theta(T_G - T_F)$$

where the primed quantities denote values at the inlet to the core.

(2) The average density of the fuel in the core has been introduced into the mass equation as the arithmetical mean of the inlet and outlet densities, along with the assumption of constant inlet conditions throughout the duration of the transient.

$$V_F \dot{\rho} = A'U'\rho' - AU(2\rho - \rho')$$

Since the pipe from the core to the pressurizer is short, the average density of the fuel in this pipe is taken equal to its density at the exit of the core.

The programming and coding of this revised set of equations has begun and is continuing.

A typographical error has been discovered in the Quarterly Technical Report No. 1, page 20. The corrected equation should read:

$$\dot{P} = \frac{k_{eff}(1 - \beta)P}{l} - \frac{P}{l} + \frac{E}{l}\frac{k_{eff}}{\nu} V_F \sum_{1}^{6} \lambda_i C_i$$

3. Experimental Program

The first draft of the proposed experimental physics program for the operational phase of the LMFRE has been written and circulated for comments.

4. Miscellaneous

Equations governing the diffusion of xenon from the fuel droplets in the degasser have been checked and reformulated for solution on the Electrodata computer.

D. INSTRUMENTATION AND CONTROL (J. P. Sluss)

Literature was reviewed to obtain data and information necessary to establish the parameters for high temperature neutron detectors. A preliminary specification was established for each of the liquid metal and radiation instruments, and preliminary specifications for research and development in relation to instrumentation and control were established. Outside vendors were contacted to establish interest in high temperature detectors and high temperature liquid instrumentation. A preliminary schedule for the instrumentation and control aspects of the LMFRE is being formulated.

Control rods were discussed during this period. A central regulating rod is very desirable, and various ideas were advanced regarding how such a regulating rod can be included while still retaining a core experimental thimble. Physics and Math Group has also agreed to investigate the particular control rod problems of the LMFRE and advise if some simplification can be obtained.

A preliminary layout drawing of a hollow tantalum and boron carbide control rod has been completed. An arrangement drawing of a control rod drive has been initiated.

Control rod dome operating temperature was discussed. Oil-type hydraulic motors are presently being considered for the drives; this limits the maximum allowable operating temperature to about 150 - 200 F. It appears that the rod drive shafts will have to be lengthened and containment seals provided to allow a moderate gradient along the shaft and to keep containment heating gas away from the motors. The longer drive shafts can probably be cooled using cell ventilating air.

Work continued on component arrangement for maintenance and on revision of control rod drive design to allow easier disassembly of the control rod tower in the event core removal is required after low power operation.

E. SYSTEMS ENGINEERING (S. S. Waldron)

Work carried out on cycle determination during this period covered several aspects of the LMFRE system. A number of fluids were considered for use in the intermediate loop:

<u>Liquids</u>	<u>Gases</u>
Sodium-potassium	Helium
Sodium	Carbon dioxide
Mercury	Steam
Fused salts	Air
Bismuth	Nitrogen
Lead	Argon
Lead-bismuth	Helium-carbon dioxide mixture
Polyphenyls	Hydrogen
	Tetra fluorides

These fluids were investigated on the basis of pumping power required, heat transfer characteristics, hazards, stability, and corrosion. No decision has been made as to what fluid we will ultimately use for the LMFRE. Studies of the various fluids were made on the basis of a 125 MW heat plant to get comparisons in terms of a large scale LMFR which might use one or more 125 MW heat exchange systems.

A separate study was made on the steam system of the LMFRE to determine the best heat extraction cycle which would reasonably approximate normal stationary power plant operation. More work has to be done on this aspect. Directly associated with this problem is the choice of steam generator to be used. This will affect not only the nature of the extraction system but also the over-all system. A preliminary study was started to determine best type of steam generator for use with the intermediate fluids under consideration; this study is continuing.

A conceptual design was made of LMFRE system using helium as the intermediate fluid to indicate some of the problems involved when considering gas as the intermediate fluid.

V. RESEARCH AND DEVELOPMENT

Research and development work for the LMFRE will be performed by Babcock & Wilcox Company at its Research Center in Alliance, Ohio, and by various subcontractors. The anticipated work is summarized in a "Proposal to U. S. Atomic Energy Commission for Research and Development of Materials and Processes for Liquid Metal Fuel Reactor Experiment" submitted to the AEC's Brookhaven Area Office with a covering letter dated December 4, 1956.

A. CHEMICAL PROCESSING (R. D. Pierce, R. W. Rebholz)

Several research agencies were approached during December to determine if they were interested in participating in the LMFRE Chemical Processing research and development program:

Battelle Memorial Institute
Southwest Research Institute
Nuclear Science and Engineering
Horizons, Inc.
Ionics, Inc.

All expressed interest and gave indications of their capabilities at the present time.

Atomic Energy Commission approval was granted to allocate approximately $280,000 of existing funds for research and development during FY 1957. Subsequent to the approval a general discussion of funds resulted in the tentative allocation of $43,000 for chemical processing studies. Program specifications within this limit are being prepared. In anticipation of the allocation of additional funds, other specifications will also be considered.

At the Alliance Research Center work has been started in the fields of chemistry, metallurgy, fabrication, and engineering as itemized below:

B. CHEMISTRY (W. A. Keilbaugh)

1. E-1281 Analysis

A start has been made on the chemical analytical problems associated with the operation of test facilities applying to the development of the LMFRE. Literature surveys are under way and Chemical Laboratory personnel visited

Brookhaven National Laboratory during December to confer with those people who have been most intimately associated with the LMFR chemical analytical work during the investigations accomplished there to date.

2. E-1282 Cleaning

Also underway are preliminary considerations relating to the equipment cleaning procedures. These are necessary to avoid the oxidation of uranium and attendant reduced concentration and the transport of undesirable system impurities in the uranium-bismuth solution. This problem was discussed with qualified people at Brookhaven in order to benefit from their experience.

C. METALLURGY (Dr. F. Eberle)

1. E-1291 Metallurgical Examinations

A corroded weld from Brookhaven National Laboratory was examined. This piece came from "loop G" exposed to bismuth, and was useful in building up background information for this work.

2. E-1292 Zirconium Nitride Film Theory

A study was initiated to investigate the theory, background, and variables involved in the possible protective film of zirconium nitride on materials exposed to bismuth. Mill records for Croloy 2¼ and Croloy 1¼ in our Tubular Products Division were examined with respect to nitrogen and aluminum content. Arrangements were made to obtain sample materials from a number of heats to check for significant chemistry variations as a guide to how they might affect formation and maintenance of the zirconium nitride film.

D. FABRICATION (M. Christensen)

1. E-1283 Graphite-Metal Joints

Graphite was bonded to zirconium, titanium, molybdenum, tungsten, and 310 stainless steel by an inert-gas, tungsten-arc welding procedure, the metal being fused filler rod. Zirconium and titanium seem, in preliminary stages, to have the best bonding properties. Tube to tube-sheet joints were simulated with 3/4-inch diameter, 1/8-inch thick graphite tubes welded to approximately 11/16-inch graphite tube sheets with zirconium and titanium weld metal.

2. E-1280 Remote Maintenance

The problems involved in maintenance and repair of radioactive reactor system components are being evaluated, particularly with respect to welding operations which might be required.

E. ENGINEERING (W. Markert, Jr.)

1. E-1288 Liquid Mismuth Pump

The special gas-sealed Croloy 2¼ Deming centrifugal pump is being constructed for the pump loop. The necessary Croloy 2¼ material is also on order. Delivery of these items is expected at the end of January 1957. The loop and auxiliary equipment, including heat exchanger, heaters, coolers, sampling devices, and charging apparatus have been designed.

2., 3. E-1263, E-1318 Equipment

Preliminary work was completed on the design of the tilting capsule corrosion apparatus. It is planned to build a single unit with a capacity of 20 capsules. A test program is being initiated on some Croloy 2¼ in bismuth to provide specimens for analysis work in the Metallurgical and Chemical Sections. Further work on these subjects will be done under E-1318.

VI. BNL RADIATION LOOP NO. 1

A. No decision has been reached on what part, if any, B&W will play in the design, fabrication, erection, and operation of Radiation Loop No. 1 at Brookhaven National Laboratory. Pending this decision, B&W continued its work on the out-of-pile section of the loop.

B. The Test Program Planning Group reviewed and approved drawings for the out-of-pile section.

C. Material specifications, welding, and cleaning procedures applicable to the loop were issued.

D. The Functional Engineering group in Barberton checked and confirmed all calculations and specifications received from Lynchburg AED.

E. The Stress Analysis group in Barberton performed a complete check of heat exchanger design. A U-tube design was decided upon and approved by Stress Analysis and Lynchburg AED.

F. Preliminary drawings for the melt tank, pump tank, cooler, disposal tank, heat exchanger, and general arrangement were completed.