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TITLE

N-REACTOR DEPARTMENT RESEARCH AND DEVELOPMENT BUDGET FOR FY 1966 AND REVISION OF BUDGET FOR FY 1965

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AUTHOR

Staff, N-Reactor Department

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HANFORD ATOMIC PRODUCTS OPERATION

N-REACTOR DEPARTMENT RESEARCH AND DEVELOPMENT BUDGET
FOR FY 1966 AND REVISION OF BUDGET FOR FY 1965

by

Staff, N-Reactor Department

March 25, 1964

APPROVED:

M. C. Leverett Manager, Research and Engineering
M. C. Leverett

R. L. Dickeman, General Manager, N-Reactor Department
R. L. Dickeman

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N-REACTOR DEPARTMENT RESEARCH AND DEVELOPMENT BUDGET
FOR FY 1966 AND REVISION OF BUDGET FOR FY 1965

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N-REACTOR DEPARTMENT
RESEARCH AND DEVELOPMENT
BUDGET FOR FY 1966 AND REVISION
OF BUDGET FOR FY 1965

O2-Program - Process Development

N-Reactor Department

FY 1964 FY 1965 FY 1966
DOLLARS IN THOUSANDS

REACTOR

Physics Studies	349	348	360
Thermal-Hydraulic Studies	361	256	213
Zircaloy Process Tubes	263	260	250
Instrument Development	337	200	200
Chemistry	282	350	250
Engineering Research and Development	556	190	150
Gas Atmosphere Studies	138	118	100
Graphite Studies	123	122	120
Nuclear Safety Research		180	207

METALLURGY

Fuels Development	1,682	976	1,150
-------------------	-------	-----	-------

CO-PRODUCT

	515	1,350	700
--	-----	-------	-----

	4,606	4,350	3,700
--	-------	-------	-------

CO-PRODUCT (ALTERNATE)

	515	1,000	1,000
--	-----	-------	-------

	4,606	4,000	4,000
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SUMMARY OF THE N-REACTOR DEPARTMENT RESEARCH AND DEVELOPMENT
PROGRAM FOR FY 1965 AND FY 1966

The N-Reactor Department Research and Development Program for FY 1965, FY 1966, and later years is structured to achieve the following general goals:

- 1) Assurance of a high level of nuclear safety
- 2) Assurance of achieving full plant life
- 3) Reduction in operating costs for a given production rate
- 4) Increase in production rate without proportionate increase in operating costs
- 5) Savings in capital outlays necessary to achieve stated reductions in operating cost or increases in production
- 6) Production of new products of value
- 7) Savings in capital outlays or operating costs to achieve a given level of plant safety.

The program is divided into three general categories: Reactor, Metallurgy, and Co-Product.

The Reactor category is further divided into physics studies, thermal hydraulics studies, zircaloy process tube development, control, instrument and system analyses, chemistry, engineering research and development, gas atmosphere studies, graphite studies, and nuclear safety research.

Research and Development in Reactor Physics will contribute to the achievement of the general program goals through optimization of reactor and fuel nuclear and geometric parameters, increased conversion ratio, optimum utilization of fuel enrichment, enhancement of control strength, provision for isotope production, and methods for calculation of flux and temperature distribution in the fuel.

In the area of Thermal Hydraulics, contributions toward the general goals will be made through experiments to optimize the heat balance between the coolant channels and temperature distribution in the fuel as affected by the coolant mixing, thus achieving optimum fuel design, reduction in fuel failures, and more realistic operating limits through a better knowledge of thermal hydraulic characteristics and nearness to instability limits and boiling burnout.

The principal benefit to be derived from the work in support of Zircaloy process tube technology is in the informed use of the process tubes and thus preventing a serious accident resulting from a tube rupture. Refined knowledge of limiting temperature and pressure may permit increased operating levels without compromising reactor safety.

Work performed in the area of Control, Instrument, and System Analyses will result in increased time operating efficiency, improved reactor safety, greater efficiency in data processing resulting in a need for fewer people to analyze the information necessary to operate the plant, and a reduction in work force as a result of plant simplification.

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In the field of Reactor Chemistry, benefits will be derived from the development of improved water chemistry knowledge that will extend the life of equipment and eliminate fuel failures that might result from excessive corrosion. Chemistry data will also be applied to assure operation with a low level of activity in the coolant system but yet with full capability to decontaminate the system if and where necessary.

Engineering Research and Development will concentrate on the development of new capabilities or new understanding which will achieve improved operating efficiency through identifying areas where faulty equipment should be replaced with more efficient equipment and improved safety, and reduced maintenance costs through development of new and ingenious solutions to equipment problems.

Studies of the Reactor Gas Atmosphere should result in extended Reactor life through reduced oxidation of the graphite and prevention of hydriding of the zircaloy process tubes. Improved knowledge of the limits on these reactions may permit increased reactor power levels without capital outlay.

The knowledge of graphite contraction gained through irradiation testing will permit the reactor to be operated in a manner that will assure its full useful life. Ultimate savings may accrue from the elimination of the need for reboring or reworking the stack.

Research and development in the field of Nuclear Safety is aimed at achieving reduced capital expenditures to provide necessary safety from nuclear hazards and increased safety of the surrounding environs.

The Metallurgy R & D is devoted to the development of increased reliability and decreased cost of the fuel element. These benefits should be derived from new, improved designs and fabricating techniques, an increased knowledge of the fuel performance during irradiation, and the development of alloys resistant to distortion during irradiation. The ultimate objective of the fuel program is to achieve a reduction in the cost of manufacture to three or four dollars per pound of uranium.

In the Co-Product category, contributions toward achievement of the general program objectives will be made through the introduction of the capability to produce two products: plutonium and tritium. The increased enrichment of the uranium necessary to support production of tritium permits an extension of goal exposure without exceeding the Pu 240 content for weapons grade plutonium and a higher conversion ratio which together should produce a reduction in unit total cost of up to \$6 per gram equivalent of production. The research and development in this category will encompass areas of the fuel and target, reactor physics, thermal hydraulics, reactor engineering, and nuclear safety. A concerted effort is needed in each area to solve the technical problems to ensure successful operating of a co-product load.

Though the research and development program in support of N-Reactor is subdivided for purposes of efficient management, the inter-relationships

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between the programs make it very difficult to assign a dollar value to any specific facet of the program. However, the end results of a successfully completed total program can be predicted with reasonable certainty. It is estimated that achieving the improvements in fuel and reactor performance predicted as a result of the increased knowledge gained from this program will result in a decrease in operating cost or increased value of products amounting to 50 per cent of what the operating cost would be without the benefit of the R & D here proposed. There is the additional, less tangible benefit derived from this program; the certainty that N-Reactor will operate without damage to itself or its environs.

As N-Reactor becomes operable and the programs proposed are completed, there will be a reduced need for research and development dollars. The schedule of funds as reported in production studies for the Co-Product operating mode will be:

FY YEAR	R & D DOLLARS IN THOUSANDS
1965	4350
1966	3700
1967	2850
1968	2000
1969	1700
1970	1300
1971 and beyond	1100

This level of research and development funding is considered the minimum level of activity consistent with the efficient production of plutonium and tritium from N-Reactor.

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SCHEDULE 189

U. S. ATOMIC ENERGY COMMISSION

Additional Justification for Operating Costs

RICHLAND
OPERATIONS OFFICE

REACTOR - SAFETY, CONTINUITY
OF OPERATION AND REACTOR LIFE
PROGRAM

1. Contractors: General Electric Company		Contract No. AT-(45-1)-1350	Task No.
2. Project Title: N-Reactor Physics Studies		189 No. R-1	3. Budget Activity No.
4. Date Prepared: February 3, 1964	5. Method of Reporting: Monthly		6. Working Locations: 100 Areas
7. Person in Charge: M. C. Leverett Principal Investigators: P. F. Nichols		8. Project Term From: To:	

9. Man Years:	<u>FY 196 4</u>	<u>FY 196 5</u>	<u>FY 196 6</u>
(a) Scientific and Technical	10.5	7.5	7.5
(b) Other	0.5	1.0	1.0
Total	<u>11.0</u>	<u>8.5</u>	<u>8.5</u>
10. Costs:	<u>FY 196 4</u>	<u>FY 196 5</u>	<u>FY 196 6</u>
(a) Direct Labor (Including Continuity of Service)	228,000	167,000	167,000
(b) Materials, Technical Services, Subcontracts	70,000	130,000	138,000
Total Direct	<u>298,000</u>	<u>297,000</u>	<u>305,000</u>
(c) Indirect Expenses	51,000	51,000	55,000
Total Operating Cost	<u>349,000</u>	<u>348,000</u>	<u>360,000</u>
(d) Equipment		0	0
(e) Irradiation Unit Cost			

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SCHEDULE

RICHLAND

OPERATIONS OFFICE

R-1 - N-Reactor Physics Studies

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated
12. Materials - None
13. Dates and Titles of Publications - To be supplied later
14. Need for Program, Payoff and Benefits

Reactor physics parameters for N-Reactor must be accurately known to avoid undue restrictions in the interest of reactor safety on power levels and rates of change of power level. Total control strengths must be sufficient to shut the reactor down under both normal and abnormal operating conditions. The control system must also be able to act rapidly enough to shut the reactor down before damage to the plant can occur. To ensure that the control criteria are fulfilled, the potential excess reactivity of the lattice must be known under various conditions of temperature, exposure, and flooding. The strength of the control system must be known for each of these conditions, and the speed of the control system must be evaluated in the light of actual or potential reactivity ramps from either normal or abnormal sources. At present, uncertainties in the physics parameters, particularly those related to temperature and exposure transients are relatively large. Reducing the degree of conservatism in estimates of total control strength and speed of control through increased knowledge of the reactor parameters will result in operating specifications permitting increased production and reduced costs.

Economy and efficiency of operation and plant utilization are highly dependent upon accurate and detailed knowledge of the nuclear physical characteristics of the reactor system. The reactor fuel cycle and loading patterns must be optimized to provide a relatively flat power generation to avoid either hot spots or tubes which are producing at too low a level. Control rod patterns must also be optimized to achieve the same result. Heat removal rates must be adjusted to provide the capability of operation at maximum power levels. To achieve maximum production per Mwd, careful attention must be given to ways of increasing the conversion ratio, which depends upon the fuel element dimensions and materials, and the details of the reactor loading

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SCHEDULE

RICHLAND

OPERATIONS OFFICE

R-1 - N-Reactor Physics Studies

patterns. Further consideration is required in the area of nuclear by-products. The production rates of some isotopes need to be evaluated in more detail. Ways to increase the production rates of the by-products such as the use of flux traps or techniques to reduce self shielding effects need further development.

Plant life is affected by the physics aspects of both the reactor and the shield. Graphite and process tube temperatures are dependent upon the degree of fission product gamma attenuation which occurs in the fuel element and process water. This is a function of the materials in the fuel elements and the dimensions of the water annuli. Rates of neutron and gamma attenuation in the thermal and biological shields affect the temperature distribution in these components and are thus important factors both in predicting shield life and in determining whether the shielding is limiting on power level increases.

15. Scope

Work will be done principally on, a) the determination of temperature and exposure transients, control strengths, reactivity and reactivity ramps for abnormal conditions, optimum reactor loadings, heat removal rates, shield properties, and b) the optimization of production rates for plutonium and nuclear by-products.

Analysis of the experiments conducted during the reactor startup period will supply directly some of the information required in this project. This must be supplemented by other experimental measurements on mockup samples of the N-Reactor lattice in such facilities as the Physical Constants Testing Reactor. For cases in which experimental measurements are impossible, insensitive or too expensive, reliance must be placed upon calculations of the parameters. In most cases, this requires the utilization of digital machine codes. Although existing machine codes are sufficient for some problems, others require either the modification of codes presently available or the development of new codes. Some back-up work is required both in theoretical reactor physics and in the refinement of neutron cross section information.

16. Relationship to Other Programs

The results will be obtained specifically for N-Reactor, but will have application to other graphite moderated reactors as well.

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R-1 - N-Reactor Physics Studies

17. Technical Progress in FY-1964

Criticality was achieved in N-Reactor during FY-1964 as scheduled. The physics startup measurements were planned in detail and are being completed on schedule. These will be finished during FY-1964. Preliminary analysis of much of the physics startup data will also be done during the year.

The physics of N-Reactor was reviewed for completeness and adequacy. Particular attention was given to the prediction of temperature transients, neutron leakage and other effects which relate to the lattice reactivity. The effectiveness of spike columns has been evaluated in anticipation of the possible need of additional enrichment in N-Reactor. Neutron absorption rates in the zirconium process tubes have been inferred from measurements in the Physical Constants Testing Reactor (PCTR). Analyses were completed of results from experiments on a mockup N-Reactor lattice in both the PCTR and the exponential pile. Reactor kinetics studies were done which served as a base for hazards analyses. Evaluations were made of the relative advantages and disadvantages of modifications in fuel element dimensions. A small amount of work was also done on fuel cycle calculations for plutonium fuel elements. Calculations of production rates of plutonium from neutron capture in U^{238} and of Np^{237} from neutron interactions in U^{238} , U^{235} , and U^{236} have been extended to higher exposures. The conversion rates of Np^{237} to Pu^{235} and of Bi^{209} to Po^{210} were calculated for postulated N-Reactor irradiation conditions. Preliminary studies were done on the formation rates of the curium isotopes. Development work has continued on computer codes with the capacity to treat neutron spectrum effects and calculate reactivity transients. Improvements have been obtained in the accuracy of neutron cross sections and in the theoretical treatment of neutron interactions with water and graphite moderating materials.

A series of experiments is in progress on the reactor shield which will assist in the evaluation of the shield with respect to deterioration rates and power level limits.

18. Expected Results in FY-1965

Analysis of the startup physics results will be completed in FY-1965. This will include determination of the temperature coefficients, control strength, lattice reactivity and other lattice parameters as well as estimates

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RICHLAND

OPERATIONS OFFICE

R-1 - N-Reactor Physics Studies

of the uncertainties in these quantities. This information will be used to generate operating specifications which will ensure safe and efficient operation. Optimum reactor loading patterns for the production of plutonium will be specified. This may include the utilization of some fuel of a higher enrichment. Changes in fuel element dimensions that will provide improved balance in heat dissipation or improvement in conversion ratio will be evaluated. The predicted production rate of both plutonium and by-products will be verified by experiment insofar as possible in FY-1965. Control rod patterns will be determined which will provide efficient operation. The need for additional control will be evaluated, and methods of increasing the total control strength will be analyzed if such need is indicated. Hazards calculations will be refined in the areas of kinetics and control strength as measured values of such parameters as Ball 3X worths become available to replace calculated values.

Further work will be done on the improvement of computer codes applicable to analysis of N-Reactor. The startup results will be compared with existing theoretical predictions in order to improve the calculational methods. This will make possible more accurate predictions for abnormal reactor conditions for which measurements are not possible. Support of work on the theoretical treatment of neutron spectra in lattices containing water and graphite will continue to improve calculations of temperature and exposure transients. Refinements will be obtained in neutron cross sections in other supported work.

A limited amount of work will be done on the evaluation of thorium as a fertile material in N-Reactor. Work on plutonium recycle will be continued if favorable results are obtained in FY-1964.

The experimental work on the reactor shield will be analyzed to predict shield deterioration rates and to identify any limits on reactor power level that the shield may impose.

19. Expected Results in FY-1966

Although the problem areas in FY-1966 can be less firmly identified, emphasis will be on measurements and calculations of power and exposure effects on reactivity, and the experimental verification of production rates.

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R-1 - N-Reactor Physics Studies

As the operating characteristics and reactivity swings of the reactor become well established, it may be possible to generate still less conservative operating specifications permitting an increase in production with assurance of safety.

The problems will be solved largely with the use of computer codes, and the reliance upon experimental facilities will be somewhat less. Continuing work will be necessary to develop and update the computer codes to permit analysis of complex reactor problems. Some supporting theoretical work will be necessary.

Further attention will be given to developing techniques for studying more efficient reactor loading patterns to achieve increased safety and decreased cost. Methods of obtaining increased production rates for by-products will require additional study. The impact of further increases in power level upon the physical behavior of the system will also need evaluation.

20. Description and Explanation of Major Materials and Offsite Contracts

The upward trend in materials and services reflects an expected shift toward contracting for smaller units of research and development work on a work order basis rather than by yearly allocation.

21. Proposed Future Related Construction Projects

None

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SCHEDULE 189

Additional Justification for Operating Costs

REACTOR - SAFETY, CONTINUITY
OF OPERATION AND REACTOR LIFE
PROGRAM

1. Contractors	General Electric Company	Contract No.	AT-(45-1)-1350	Task No.
2. Project Titles	N-Reactor Thermal Hydraulic Studies	189 No.	R-2	3. Budget Activity No.
4. Date Prepared	January 31, 1964	5. Method of Reportings	Monthly	6. Working Locations
7. Person in Charge	M. C. Leverett	8. Project Term	Continuing	
Principal Investigators	R. H. Shoemaker	From	To	

9. Man Years:	<u>FY 196</u>	<u>FY 196</u>	<u>FY 196</u>
(a) Scientific and Technical	7.0	5.0	4.0
(b) Other	2.0	1.0	0.5
Total	<u>9.0</u>	<u>6.0</u>	<u>4.5</u>
10. Costs:	<u>FY 196</u>	<u>FY 196</u>	<u>FY 196</u>
(a) Direct Labor (Including Continuity of Service)	208,000	130,000	97,000
(b) Materials, Technical Services, Subcontracts	100,000	89,000	83,000
Total Direct	<u>308,000</u>	<u>219,000</u>	<u>180,000</u>
(c) Indirect Expenses	53,000	37,000	33,000
Total Operating Cost	<u>361,000</u>	<u>256,000</u>	<u>213,000</u>
(d) Equipment		0	0
(e) Irradiation Unit Cost		0	0

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SCHEDULE

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R-2 - N-Reactor Engineering Studies

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated
12. Materials - Electrically Heated Test Elements for Laboratory Studies
13. Dates and Titles of Publications

HW-80691, "Heat Transfer from an Annular Heated Tube During Forced Convection Quenching,"
February 15, 1964, J. K. Anderson and W. A. Angle.

HW-80692, "Thermal and Hydraulic Characteristics of an NPR Fuel Column,"
March 15, 1964, J. K. Anderson, et al.

14. Need for Program, Payoff and Benefits

A thorough understanding of the thermal and hydraulic behavior of N-Reactor is essential to achievement of most effective utilization of the reactor as a plutonium producer within the bounds of nuclear safety requirements. The primary objective of the investigation described herein is to advance knowledge in this key area to the extent that operating limits for coolant flow, pressures and temperatures may be established to provide maximum useful production within required margins of safety. In order to insure that such operating limits are not unduly restrictive, a continuing research and development effort in thermal hydraulics is required to narrow the range of uncertainty that prevails in existing heat transfer and fluid flow correlations; particularly in those dealing with steady-state and transient two-phase flow. For the most part, the safe upper limits of reactor power level will be affected strongly by the degree of confidence that can be placed in prediction of behavior of the fuel and heat removal capabilities of the cooling system.

Direct benefits from the knowledge gained in this investigation will be in areas of both nuclear safety and production. Laboratory experimentation and analysis will provide an understanding of the thermal hydraulic behavior of the reactor under a wide variety of both controlled and abnormal states of operation, that will

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R-2 - N-Reactor Engineering Studies

allow establishment of accurate and realistic operating limits. At the same time, these results will provide for optimization of fuel design from the standpoint of heat balance and unit weight (pounds per foot of length).

15. Scope

The studies constitute a balance between laboratory experimentation and analysis with the ultimate goal of determination of the thermal-hydraulic characteristics of the N-Reactor fuel and process tube under steady-state and transient conditions. The conditions studied range between planned normal operation and abnormal conditions associated with a wide variety of postulated reactor incidents. In general maximum use is made of electrically heated test sections, operated under prototypic conditions of pressure, temperature, flow and heat generation rates, so that results will be as directly applicable as possible.

16. Relationship to Other Programs

This program is specific to the N-Reactor. Because of the present state of engineering technology, most of the data obtained would be directly applicable to other reactors only for the ranges of conditions and designs studied.

17. Technical Progress in FY-1964

Two-phase pressure drop and plugging experiments with a simulated N-Reactor process tube and fuel column (with stepped cosine heating) were completed in December 1963. The experiments covered a wide range of tube powers, pressures and flows in both single-phase and two-phase regimes of flow. Preliminary results of the studies are:

- a. The potential for flow instability in process tubes is somewhat less than that predicted by analysis, both under normal operating pressures and temperatures and at the most severe extremes of pressure and tube power expected to occur under steady-state full power operation of the reactor.

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R-2 - N-Reactor Engineering Studies

- b. At low operating pressures and tube powers, such as will be encountered during startups, the potential for instability is approximately as great as predicted by the Martinelli-Nelson correlation. However, the laboratory results have been put in a form which is readily applicable to establishment of operating limits which will permit safe operation of the reactor over the entire range of flows, pressures and powers for which it was designed with initial fuel design.
- c. Stable operation of the simulated process tube was achieved under conditions during which bulk boiling was present in the downstream portion of the center flow channel of the fuel, with no apparent deleterious effects. In addition, stable operation was achieved at an equivalent tube power of 6200 kw, which is approximately 24 per cent greater than the power of the design "hot channel" process tube, without burnout of the test section.
- d. Boiling burnout heat flux calculations based on experimental results obtained in FY-1963 were applied directly in the steady-state two-phase pressure drop experiments to determine the extremes of boiling (and exit steam quality) that could be reached in the test section during the tests without occurrence of boiling burnout. Burnout did not occur despite the fact that very small safety factors (or "burnout margins") were applied in calculating the limits (10 per cent and less). This finding conclusively demonstrates both the validity of the burnout correlations employed and their applicability to long, non-uniformly heated sections typifying the N-Reactor fuel column.

Experimental studies of the single-phase pressure drop characteristic of the N-Reactor fuel, process tube and connectors provided data that correlated very satisfactorily with analytical predictions incorporated into the "Flex 2" IBM 7090 computer program utilized for design and analysis of fuel and estimation of reactor performance. These experiments were performed over a sufficiently wide range of temperature conditions to adequately define all Phase I operating conditions. This verification of the validity of computer results with the initial fuel greatly increases the confidence that can be placed in computer results for other fuel designs. Experimental results from in-reactor testing of N-Reactor fuel in the KER loops have confirmed analytical estimates of thermal imbalance among the three coolant channels of the fuel design for the initial load. This

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R-2 - N-Reactor Engineering Studies

imbalance, while not severely limiting in terms of reactor power, will tend to promote boiling in the central channel at outlet temperatures somewhat lower than those at which bulk saturation conditions would occur. This clearly indicates the need for re-design of the tube-in-tube fuel element to achieve the optimum balance in heat transferred to the coolant in the three channels. An experiment was conducted with a short heated model of the inner annulus of the fuel to determine the steam generation rates and heat transfer coefficients associated with a rapid quench from 1500°F with flowing cold water. While the experiment was made specifically to determine critical parameters (principally surface temperatures at transition from film to nucleate boiling) the results represent a significant contribution to knowledge in the fluid flow and heat transfer.

18. Expected Results in FY-1965

It is expected that steady-state and transient experiments with the second generation model of an electrically heated fuel element in a process tube will be completed. These results, together with those of transient experiments, will adequately define the thermal hydraulic behavior of the reactor during abnormal conditions. Thus it will be possible to factor them into operating limits in sufficient time to permit achievement of reactor power ascension on schedule. Results obtained during FY-1964 will be employed to re-design the tube-in-tube fuel element to obtain balanced cooling among the three channels and to achieve the maximum fuel weight per foot consistent with available knowledge of the thermal-hydraulic characteristics.

During the latter part of the fiscal year effort will begin in studies of the behavior of advanced fuels intended for use in dual purpose (Phase II) reactor operation. Such fuel designs will require laboratory investigations because predictions have indicated that such designs may be required to operate under sustained conditions of nucleate boiling and, in general, with smaller margins of instability and boiling burnout than Phase I fuel. Such conditions will derive from two basic factors as follows: a) the secondary cooling system steam pressure demands associated with dual purpose reactor operation will require significant increases in reactor inlet temperature above Phase I conditions (at equivalent reactor powers); b) the fuel designs will tend towards heavy, single tube elements which will operate with higher surface heat fluxes than the tube-in-tube design, due to a decrease in heat transfer area. An additional characteristic of such designs will be a decrease in available mass velocity of coolant caused by reduction of area of coolant channels.

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R-2 - N-Reactor Engineering Studies

Data obtained from experiments with the tube-in-tube fuel will not be applicable because of the radical differences in dimensional and thermal boundary conditions that will be associated with advanced fuel designs. Thus it is expected that near the end of FY-1965 experiments will be in progress to establish limits for boiling burnout heat flux for regimes of higher heat flux and greater degrees of subcooling than those determined for the tube-in-tube design. Plans will be initiated to investigate instability margins and effects associated with sustained operation under nucleate boiling conditions.

19. Expected Results in FY-1966

Boiling burnout experiments for advanced fuels will be completed early in FY-1966. Investigations of instability margins and nucleate boiling for advanced fuel designs will be complete by the end of FY-1966. These results will then be factored into studies made to establish reactor operating limits.

20. Descriptions and Explanation of Major Materials and Offsite Contracts

None

21. Proposed Future Related Construction Projects

None

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Additional Justification for Operating Costs

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OPERATIONS OFFICE

REACTOR - SAFETY, CONTINUITY
OF OPERATION AND REACTOR LIFE
PROGRAM

1. Contractors: General Electric Company		Contract No. AT(45-1)-1350	Task No.
2. Project Title: N-Reactor Zircaloy Process Tube Development		189 No. R-3	3. Budget Activity No.
4. Date Prepared: February 1, 1964	5. Method of Reporting: Monthly		6. Working Locations: 100-300 Areas
7. Person in Charge: M. C. Leverett Principal Investigators: M. Lewis		8. Project Term: Continuing From: To:	

9. Man Years:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Scientific and Technical	5.5	3.5	3.5
(b) Other	2	2	2
Total	<u>7.5</u>	<u>5.5</u>	<u>5.5</u>
10. Costs:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Direct Labor (Including Continuity of Service)	175,000	114,500	114,000
(b) Materials, Technical Services, Subcontracts	50,000	107,500	98,000
Total Direct	<u>225,000</u>	<u>222,000</u>	<u>212,000</u>
(c) Indirect Expenses	38,000	38,000	38,000
Total Operating Cost	<u>263,000</u>	<u>260,000</u>	<u>250,000</u>
(d) Equipment	4,000	46,000	20,000
(e) Irradiation Unit Cost			

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R-3 - N-Reactor Zircaloy Process Tube Development

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated

12. Materials - Zircaloy

13. Dates and Titles of Publications

HW-74955, "Effects of Cold Work and Neutron Irradiation on Tensile Properties of Zr-2," April, 1963
A. L. Bement, Jr.

HW-80566, "Procurement of Zr-2 Process Tubes for NPR," April, 1964, R. C. Aungst, D. H. Curtiss

HW-80567, "Stress Rupture and Crack Propagation of Zr-2 Reactor Pressure Tubes in Both Normal and Hydrided Conditions," April, 1964, R. C. Aungst, L. J. Defferding

14. Need for Program, Payoff and Benefits

Both the pressure tubes of the N-Reactor primary coolant system and the graphite coolant tubes are fabricated from Zircaloy-2 and represent a significant extension of reactor technology and of the use of zirconium alloys. This use of Zircaloy-2 pressure tubes is preceded only by use in small reactors such as the PRTR at Hanford, the NPD-2 in Canada and the Carolinas-Virginia Reactor.

Though allowance was made in the design of the graphite stack to accommodate a possible pressure tube failure, such an occurrence would lead to a significant interruption in plant operating continuity. Therefore, based upon technical data then available, the tubes were designed in a conservative manner. Subsequent results of research and development programs confirm that the tubes were designed with an adequate safety factor. However, there remains the need to assure the continued safe and informed operation of Zircaloy-2 pressure tubes in N-Reactor by anticipating any gross effects of extended exposure to irradiation and operating environment on the strength and fracture characteristics of Zircaloy-2.

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R-3 - N-Reactor Zircaloy Process Tube Development

The objective of this program is to provide information on the changes in the properties of Zircaloy-2 under simulated and actual service conditions to avoid premature tube replacement which would have a substantial effect on operating economy and to avoid inadvertent tube failure which would have an adverse effect on graphite stack life and production.

15. Scope

To anticipate any gross effects of long-term irradiation on the strength and fracture characteristics of Zircaloy-2, specimens will be irradiated in an environmental test loop in the ETR to an exposure equivalent to at least 25 years of N-Reactor operation. Fundamental creep and fracture studies will be performed to implement extrapolation of results to actual pressure tubes. Pressure tube performance will be determined through pre-irradiation measurement of creep, stress rupture, and fracture characteristics of tube samples, develop instruments and techniques for in-reactor measurement of changes in diameter, unusual corrosion, mechanical damage, and hydrogen pickup and by post-irradiation examination and testing of tubes removed from the reactor at periodic intervals. Special data processing techniques will be utilized for rapid analyses of measurements and test data permitting calculations of the life expectancy of the pressure tubes. The study of the modes and probable consequences of tube failure will be emphasized.

Though no difficulties are anticipated, surveillance of the graphite coolant tubes will be maintained to assure trouble-free operation and to provide additional information on the irradiation behavior of zirconium.

16. Relationship to Other Projects

These studies are directed at the specific technological requirements for N-Reactor. Technical data are utilized from other programs sponsored by the Division of Reactor Development, such as those being conducted in support of FRTR, and the Canadian and British atomic energy programs.

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R-3 - N-Reactor Zircaloy Process Tube Development

17. Technical Progress in FY-1964

Significant progress was made in evaluating the performance parameters of N-Reactor process tubes. The exposure of Zr-2 test specimens irradiated in flowing water at 540 F was extended to 4×10^{21} nvt (fast). Previously observed gradual increases in ultimate strength and decreases in ductility were confirmed. The time to rupture for stress rupture tests conducted at 300 C was extended to 8500 hours. Accelerated tests were performed at temperatures up to 399 C and the data were used in conjunction with the Larson-Miller equation to extrapolate the stress versus time to rupture relationship at 300 C to 20 years. Extension of creep testing of strip samples and stress rupture testing of samples of N-Reactor process tubes show that autoclave heat treatment to 425 C substantially improves the creep resistance of Zr-2.

Project CAH-922, the 6-unit facility for creep and creep rupture testing of irradiated tubing, was completed. Fracture characteristics of unirradiated N-Reactor pressure tubes were determined for the four types of N-Reactor process tubes. Critical stress for rapid crack propagation for various flaw sizes was determined and found to be inversely proportional to the square root of the flaw size. A method of controlled charging of hydrogen into samples of the N-Reactor process tube without annealing the cold work was developed and testing of hydrided samples was initiated. Preliminary results at room temperature confirm the expected decrease in ductility and crack propagation resistance with increased hydrogen content.

Criteria for a process tube monitoring program were developed and design of the probe was initiated. Specification, procurement, and fabrication of various components, including radiation resistant TV camera, ID gage, and readout equipment were initiated. Technical feasibility of detecting hydride at concentrations as low as 250 ppm was demonstrated for both eddy current and ultrasonic techniques.

18. Expected Results in FY-1965

The surveillance program on Zr-2 conducted in the ETR environmental loop will be continued and the effect on tensile properties of irradiation at temperatures of approximately 540 F for exposures up to 8×10^{21} nvt (fast) will be studied. Fundamental studies of the role of deformation and texture, as an aid to understand

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R-3 - N-Reactor Zircaloy Process Tube Development

the fracture characteristics, will be continued. Creep, creep rupture, and crack propagation characteristics of irradiated tubing will be initiated in facilities from Project CAH-922. The effect of various levels of hydrogen on the crack propagation properties will be continued in an effort to quantify an acceptable level of hydrogen, establish critical pressures for rapid crack propagation, and provide a basis for comparing similar results obtained on irradiated tubes removed from the N-Reactor. Development of techniques for monitoring of actual process tube conditions in N-Reactor will be initiated with completion of the monitoring probe and will include inner diameter measurement, depth gage, and visual examinations. The currently demonstrated methods of hydride detection will be adapted to a practical monitoring device.

19. Expected Results in FY-1966

Process tubes removed from the reactor will be tested for radiation induced changes in tensile properties metallurgical condition, hydride concentration, and crack propagation. Comparison of these data with anticipated effects will be used to predict performance and expected life. On the basis of observed and anticipated performance, the monitoring program will be revised in scope and frequency of observation in accordance with sound business and safety practice.

20. Description and Explanation of Major Materials, Equipment and Offsite Contracts

Equipment requirements for the in-reactor monitoring of the process tubes will consist of:

- a. Search head with transducers, television camera, optics and diameter gauge.
- b. Power drive unit to insert, withdraw, and rotate the search head.
- c. Control console with instrument chassis, power supplies, amplifiers, television monitor, recorders and the converters and other auxiliary equipment necessary for computer type data handling systems.

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Additional Justification for Operating Costs

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REACTOR-SAFETY, CONTINUITY OF
OPERATION AND REACTOR LIFE
PROGRAM

1. Contractors: General Electric Company		Contract No. AT-(45-1)-1350	Task No.
2. Project Title: N-Reactor Control, Instrument and System Analysis		189 No. R-5	3. Budget Activity No.
4. Date Prepared: February 3, 1964	5. Method of Reportings: Monthly	6. Working Locations: 100, 300 & 700 Areas	
7. Person in Charge: M. C. Leverett Principal Investigators: D. W. Leiby		8. Project Term: Continuing From: To:	

9. Man Years:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Scientific and Technical	10.0	4.5	4.0
(b) Other	0	0	0
Total	<u>10.0</u>	<u>4.5</u>	<u>4.0</u>
10. Costs:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Direct Labor (Including Continuity of Service)	248,000	104,000	94,000
(b) Materials, Technical Services, Subcontracts	48,000	67,000	76,000
Total Direct	<u>288,000</u>	<u>171,000</u>	<u>170,000</u>
(c) Indirect Expenses	49,000	29,000	30,000
Total Operating Cost	<u>337,000</u>	<u>200,000</u>	<u>200,000</u>
(d) Equipment			
(e) Irradiation Unit Cost			

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R-5 - N-Reactor Control, Instrument and System Analysis

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated
12. Materials - None
13. Title and Dates of Publications - None
14. Need for Program, Payoff and Benefits

Safe, reliable, and economical operation of the N-Reactor and its heat dissipation plant is achieved through the satisfactory performance of an extensive network of control and instrumentation systems. The N-Reactor plant is complex, with inter-related components such that transients in one component may have severe consequences in another unless the situation is adequately sensed and proper corrective action taken by the appropriate control system. The achievement of full production from the N-Reactor at minimum unit cost is dependent upon its ability to operate at or near the technical limits of flow, temperature, pressure, etc., imposed by considerations of nuclear safety and reactor plant life.

The specification of the proper technical limits and the most desirable methods of operating within these limits can be obtained from a thorough knowledge of the performance of the total N-Reactor plant system. Such knowledge can be made available by developing modern methods of system instrumentation, data processing and system simulation and analysis. A program to investigate the adequacy of the present instrument and control systems, to develop new, improved systems, to develop techniques for efficient N-Reactor plant data processing, and to develop techniques for total plant system analysis utilizing system simulation and other analytical techniques should result in improved efficiency, increased production, lower cost, enhanced safety and longer reactor life.

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R-5 - N-Reactor Control, Instrument and System Analysis

The objective of this program is to assure that the safe and economical utilization of the full production capabilities of the N-Reactor are not limited by deficiencies in plant instrumentation, control capabilities, data processing, or methods of system analysis and evaluation.

15. Scope

The scope of the Controls, Instrument and Systems Analysis Program encompasses: 1) investigation of the characteristics of instrument and control systems to determine adequacy of individual components and of the operation of the over-all systems, 2) the development of new instrument and control systems where needed to improve the degree of control of a system component, 3) the development of modern methods of data processing for handling the recorded data from the instrument systems, 4) the development of an accurate analog model of the N-Reactor Plant and its individual components, and 5) the development of techniques for the utilization of this model to obtain knowledge on system performance, and to develop the bases for improved operating methods and optimization techniques.

16. Relationship to Other Programs

The work proposed is specifically in support of N-Reactor. Use will be made of technology of reactor control developed through the nuclear industry and techniques developed for N-Reactor should have widespread application throughout the AEC complex.

17. Technical Progress in FY-1964

A technique was developed to measure the characteristics of the rupture monitor system utilizing a prototype

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R-5 - N-Reactor Control, Instrument and System Analysis

of the monitoring system which reproduced the N-Reactor conditions as faithfully as possible. The threshold sensitivity was measured by reproducing the corrosion product environment which would occur in a N-Reactor process tube after the perforation of a fuel target. Under the prototypical conditions used the rupture monitor had more than adequate sensitivity and operated satisfactorily.

The basic N-Reactor engineering data system was developed and the effort required to put the system into operation was scoped. A detailed study of the data production capabilities of the N-Reactor Plant was completed. From an evaluation of the source data, the specification and description of the input data to the reactor information file were developed.

Analogs were developed for the following systems: Reactor Kinetics, Primary System Injection and Pressurizer, Primary Loop Pump and Flow Control, the entire Primary Coolant System, and the entire Secondary Coolant System. The development of an analog program for the simulation of the combined reactor and heat dissipation system was initiated.

18. Expected Results in FY-1965

The characteristics of the rupture monitor system in N-Reactor will be investigated to determine the system sensitivity and its effectiveness under actual operating conditions and methods for improving the accuracy. The possible improvements in sensitivity of measuring the impurities in the reactor Gas System will be investigated. The affect of sampling location on the gas composition as measured by existing instrumentation will be determined. The development of the analog simulation of the combined reactor and heat dissipation plants should be completed, techniques will be developed to enable the study of the total system performance under varying operating conditions, and plant simplification studies will be initiated. The Reactor Engineering data system will be programmed.

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R-5 - N-Reactor Control, Instrument and System Analysis

19. Expected Results in FY-1966

Through analysis of startup and operational tests of various plant systems new, improved instrumentation will be developed. Inputs from the data handling system will be used to modify the N-Reactor plant model to improve its accuracy. Utilizing the improved analog simulation of the reactor heat and dissipation plants, analyses will be performed to develop methods for reducing product costs. The effects of transients in various parts of the reactor system will be simulated to develop optimum operating techniques to provide maximum plant safety and increased efficiency of operation.

20. Description and Explanation of Major Materials, Equipment and Offsite Contracts

The rising trend in materials and services costs reflects increased use of analog and digital computers on a work order basis.

21. Proposed Future Related Construction Projects

None

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Additional Justification for Operating Costs

REACTOR - SAFETY, CONTINUITY OF
OPERATION AND REACTOR LIFE

PROGRAM

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OPERATIONS OFFICE

1. Contractors: General Electric Company		Contract No. AT(45-1)-1350	Task No.
2. Project Title: N-Reactor Chemistry		189 No. R-6	3. Budget Activity No.
4. Date Prepared: January 30, 1964	5. Method of Reporting: Monthly		6. Working Locations: 100 and 300 Areas
7. Person in Charge: M. C. Leverett Principal Investigators: M. Lewis		8. Project Term: Continuing From: To:	

9. Man Years:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Scientific and Technical	6	4	5.5
(b) Other	2	1.5	1.5
Total	<u>8</u>	<u>5.5</u>	<u>7.0</u>
10. Costs:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Direct Labor (Including Continuity of Service)	174,000	120,000	154,000
(b) Materials, Technical Services, Subcontracts	67,000	179,000	58,000
Total Direct	<u>241,000</u>	<u>299,000</u>	<u>212,000</u>
(c) Indirect Expenses	41,000	51,000	38,000
Total Operating Cost	<u>282,000</u>	<u>350,000</u>	<u>250,000</u>
(d) Equipment	0	0	0
(e) Irradiation Unit Cost	0	0	0

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R-6 - N-Reactor Chemistry

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated
12. Materials - Laboratory Chemicals
13. Dates and Titles of Publications

HW-79050, "N-Reactor Materials Manual," April 1964, B. S. Kosut and J. M. Bird

HW-79295, "Ammonium Hydroxide for pH Control in Pressurized Water Systems out of Reactor Tests - Part I," November 1963, T. F. Demmitt, V. F. Fitzpatrick, A. P. Larrick

14. Need for Program, Payoff and Benefits

In a complex system like the N-Reactor, consisting of low and high temperature water coolant systems, mixed metal loops, large heat exchangers, miles of high pressure piping and the complication of irradiation induced chemical reactions, it is reasonable to expect technical difficulties to arise during startup and operation. Problems common to all high temperature recirculating water cooled reactors, such as corrosion and system radioactivity caused by deposition of activated corrosion products, will arise in N-Reactor. A research and development program encompassing water chemistry and "crud" formation, decontamination and corrosion will result in longer equipment life, decreased downtime and other system economies through anticipating and solving problems before they arise in actual reactor operation.

The objective of this program is the development of the basic technology necessary to an understanding of the physico-chemical processes in the reactor piping systems, and necessary to the establishment of specifications of coolant composition and treatment which will minimize corrosion, improve equipment and fuel life, and insure low radioactivity in the reactor primary, secondary and tertiary cooling systems. Information on which to base specifications for decontamination procedures is also sought. Another objective is the development of more economical waste disposal methods and reduced radioactive contamination in the river.

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R-6 - N-Reactor Chemistry

15. Scope

The scope of the N-Reactor chemistry studies encompasses the technology of the many water treatment systems, water cooling loops and heat exchangers, the interaction of the water with the fuel elements and various metallic containers and piping systems, the decontamination of the primary system and the disposal of any radioactive waste products produced during these operations. This study will include an economic analysis of dumping the bleed water to the river versus cleanup for recycle.

16. Relations to Other Programs

These studies are directed at specific technological requirements for N-Reactor. Technical data are utilized from other programs in support of existing reactors, especially tube-type, sponsored by the Division of Reactor Development. Examples are those being conducted in support of PRTR, Carolina-Virginia, and Canadian atomic energy programs, as well as information from commercial reactor projects. Pertinent information is also made available to those programs as it develops.

17. Technical Progress in FY-1964

Water Quality Control - An experimental comparison of LiOH and NH₄OH for coolant pH control under conditions of Zr-2 crevice boiling using electrically heated specimens revealed no Zr-2 attack with NH₄OH and definite Zr-2 corrosion with LiOH. Operation with ammoniated coolant subsequent to decontamination of a carbon steel in-reactor loop showed no greater crud deposition on irradiated fuel with NH₄OH treated coolant than with LiOH treated coolant. Work was started to determine the composition and quantity of crud deposited on fuel elements irradiated in ammoniated coolant in a carbon steel loop and defining the conditions affecting deposition.

In-reactor studies of NH₄OH for primary system coolant pH control gave information about decomposition and makeup rates, decomposition products, ease of control, and loop activity as a function of coolant temperature, pH, concentration, and residence time.

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A crud monitor element was developed and installed in N-Reactor to give warning of excessive crud deposition on fuel elements during initial operation.

Decontamination Studies - A decontamination procedure was developed through laboratory tests for decontaminating corroded steam generator tubes without aggravating their condition. Decontamination procedures and requirements were established and documented for full or partial decontamination of the N-Reactor primary system.

Corrosion - A materials manual for the alloys in contact with the "N" primary and secondary coolant has been prepared. Poor corrosion resistance or service failure of a metal in these systems will enable easy location of all other applications of the metal for early replacement. As a supplement to the above manual, a special document that catalogues metals in the above systems that are especially sensitive to their environment has also been completed. Laboratory test loop results have been documented on some of these materials while long term tests are still in progress.

Continuous evaluation of the corrosion behavior of the structural metals in contact with the "N" coolant is desirable. To this end, a literature search was made, extensive R&E experience and laboratory tests have been used to obtain a suitable material for use as a sealant in an electrical resistance measurement device called a "corrosometer." Tests of these instruments employing prospective sealants have begun in high temperature (535 F) test loops.

The change-over from a lithiated to an ammoniated coolant in the primary loop has necessitated a materials search for copper and silver alloys that might be sensitive to ammoniated water or a moist ammonia atmosphere.

Nondestructive and destructive tests were conducted on N-Reactor rupture monitor chambers to determine expected life and integrity.

18. Expected Results in FY-1965

Water Quality Control - Techniques of water analysis and water quality control for N-Reactor will be evaluated during initial operation and procedures modified to optimize control at minimum cost. Studies of the effect

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of coolant temperature, pH, concentration, and residence time on NH_4OH decomposition, gaseous decomposition products, oxygen control, hydrogen requirements, and loop activity will continue in N-Reactor and other irradiation facilities. Results of these studies will be applied to improve water quality control to reduce corrosion and system radioactivity, leading to improved system component life and reduced maintenance expense. The application of NH_4OH for pH control in the graphite coolant loop will be evaluated.

Evaluation of quantity and composition of crud deposited on fuel elements as a function of coolant operating parameters will continue in N-Reactor to establish the relationships between crud deposition on fuel elements and crud-induced activity on primary system components.

Decontamination - Improved decontamination procedures will be developed through laboratory studies and in-reactor and out-of-reactor loop tests to provide adequate and safe decontamination effectiveness while minimizing required chemical storage, downtime for decontamination, and volume of radioactive decontaminating solutions for disposition. Radioactive waste disposal procedures will be evaluated for the operating plant.

Corrosion - The FY-1965 corrosion program will involve the following:

- a. Provide expert consultation when needed to N-Reactor projects and related groups on problems involving corrosion in the coolant loops and components.
- b. Conduct laboratory tests under simulated N-Reactor operating conditions to determine corrosion effects or physical properties changes on prototypical N structural materials. Emphasis will be made to conduct long term and short term tests on samples selected from the critical materials list.
- c. Develop techniques for measuring the corrosion of the primary and secondary piping systems including insertion of samples in the loop and a continuous reading corrosometer.

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19. Expected Results in FY-1966

The corrosion evaluation program in the reactor coolant loops should provide pertinent information regarding coolant effects on the structural materials. Corrective action by either coolant chemistry changes or material replacement will be instituted as required.

Optimized decontamination methods will be developed that are applicable to the system at the time decontamination is required. Major emphasis will be on effective removal of long-aged films on stainless steel. Improved control of radioactivity in the primary system will be attained.

20. Description and Explanation of Major Materials, Equipment and Offsite Contracts

Increased materials and services costs during FY-1965 reflects assignment of support of in-reactor loop experiments on water quality and crud deposition. Loop costs previously had been borne by fuel development programs.

21. Proposed Related Construction Projects

None

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OPERATIONS OFFICE

REACTOR SAFETY, CONTINUITY
OF OPERATION AND REACTOR LIFE
PROGRAM

1. Contractors General Electric Company		Contract No. AT-(45-1)-1350	Task No.
2. Project Titles N-Reactor, Engineering Research and Development		189 No. R-7	3. Budget Activity No.
4. Date Prepareds February 14, 1964	5. Method of Reportings		6. Working Locations
7. Person in Charges J. S. McMahon Principal Investigators D. L. Condotta - L. P. Reinig		8. Project Term From To	

9. Man Years:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Scientific and Technical	10	4.5	3.5
(b) Other	1	0	0
Total	<u>11</u>	<u>4.5</u>	<u>3.5</u>
10. Costs:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Direct Labor (Including Continuity of Service)	225,000	81,000	63,000
(b) Materials, Technical Services, Subcontracts	250,000	81,000	64,000
Total Direct	<u>475,000</u>	<u>162,000</u>	<u>127,000</u>
(c) Indirect Expenses	91,000	28,000	23,000
Total Operating Cost	<u>566,000</u>	<u>190,000</u>	<u>150,000</u>
(d) Equipment	0	15,000	10,000
(e) Irradiation Unit Cost			

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RICHLAND

OPERATIONS OFFICE

R-7 - N-Reactor, Engineering Research and Development

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated

12. Materials - None

13. Dates and Titles of Publications

HW-79392, "User's Manual for N Heat, N-Reactor Lattice Heat Transfer Program for the IBM-7090 Computer,"
October 30, 1963, F. J. Mollerus, Jr.

HW-79791, "NPR Fuel Melting Time Following Loss of Coolant," December 4, 1963, J. Muraoka and
D. D. Stepnewski.

14. Need for Program, Payoff, and Benefits

The N-Reactor incorporates a complex of interrelated systems that must function satisfactorily over a wide variety of modes to permit safe and efficient operation of the reactor under all conditions. The design utilized advanced and unusual concepts of reactor technology, engineering analysis and instrumentation and equipment applications. The effective operation of these systems will in some cases require the development of new technology, or development of new and original analytical techniques for the study of the interactions of equipment, instrumentation and process fluids. In some cases these analyses are crucial to determination of the behavior of the plant under abnormal conditions, and thus relate to plant safety. In other cases this project will provide new technical capabilities which will in turn lead to enhanced economy of operation and lengthened plant life.

15. Scope

The work to be performed in this program will embody the development of technology in the areas of reactor cooling systems, mechanical vibrations, stress analysis, nuclear safety and confinement concepts, and technical principles of key equipment. The key objective of this work is to make the necessary contributions to the technology to permit achievement of minimum unit cost within the bounds imposed by nuclear

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R-7 - N-Reactor, Engineering Research and Development

safety requirements. The interrelationships that exist among the various reactor cooling and safety systems require that the scope of this program must include support of other N-Reactor research and development programs, particularly in the areas of hazards analysis, thermal hydraulic and instrument development.

16. Relationships to Other Programs

This program brings together the necessary technology for specific application to the N-Reactor complex. However, the technological advances and concepts that result from this program will have the potential for broad application in other atomic energy programs.

17. Technical Progress in FY-1964

Continued operation of prototype test facilities in the 189-D Equipment Laboratory has been carried out. These facilities have been utilized for performance tests of reactor components under simulated reactor environmental conditions. Such tests have identified potential problem areas and have enabled performance of the development work required to attain the necessary levels of operability and reliability for reactor applications. Examples of the results of such work are as follows:

- a. Primary cooling system relief valve development. Technology was provided for changes and improvements to unique relief valves for the primary cooling system.
- b. Corrosion problems with inlet valve actuator were identified and solved. Packing problems in the actuator of both inlet and diversion valves were identified, indicating the need for a development program slanted toward improved seals for these environments.

Results of work of this nature prevented serious and expensive delays in the startup schedule and have eliminated many potential safety hazards.

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Development and testing activity in support of fuel loading resulted in improved magazines, nozzle couplers and magazine loader. These improvements significantly reduced the potential for fuel element damage during charging identified during charging machine tests.

Development assistance to procurement was provided in several areas. Evaluation of materials for nozzle cap usage allowed timely delivery of the caps to meet construction schedules. Tests were completed on filters for the 117-N Building which demonstrated the functional acceptance of these items. Additional testing performed on repaired filters resulted in their acceptance and establishment of a filter repair technique. Testing of the Clare Mercury Wetted Relay was completed indicating satisfactory performance but a desirability for improved filler material within the switch. Evaluation of the fuel element dummy under flow testing resulted in a modification necessary to stabilize column pressure drop characteristics. Testing of the N-Reactor Safety Flow Control Leg piping established proper calibration to be used during construction installation. Evaluation testing was completed on the fog spray nozzles indicating satisfactory performance and some areas of improvement needed. Results of the evaluation of confinement seal plugs under irradiation testing indicated acceptable sealing characteristics and established a norm for determining replacement needs.

Analytical assistance was provided in areas of hazards analysis, systems control and reliability, pre-startup testing and related subjects. Some examples of these analyses are as follows:

- a. Fuel column expansion analysis and dummy fuel element crush tests.
- b. Steam generator leak analysis as pertaining to possible nuclear safety, hazards, operating level potential and total reactor power potential.
- c. Analysis of emergency cooling system reliability and effectiveness, together with study of the nuclear hazards aspects of emergency cooling system actuation.
- d. Confinement system studies for postulated reactor cooling accidents.

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- e. Analysis of a non-nuclear depressurization transient test from the standpoint of potential for thermal shock to primary piping and equipment and ability to accurately simulate an actual depressurization incident.

Development of computer programs and analytical techniques was continued. These have included a piping stress analysis program, a reactor lattice heat transfer program, a coolant systems operational analysis program, and a fuel element transient heat transfer analysis program. These programs permit rapid and accurate evaluations of the operating conditions throughout the complex N-Reactor plant.

18. Expected Results in FY-1965

Equipment testing, design analysis and design modification studies will be continued to provide new, improved equipment concepts, to identify factors that might result in reduced life (or other marginal performance of nuclear reactor hardware), to document progress in reports, and further define needed areas of equipment development support.

On a high priority basis, the N-Reactor Prototype Concept Evaluation Loop in the 189-D Laboratory will continue operation in evaluating primary loop components under operating conditions to flag early problem areas in performance. Included in this evaluation are the tube-to-nozzle rolled joints, nozzle caps, inlet valves, diversion valves, venturis, pipe couplings, RTD's and flow monitoring instrumentation. It is expected that through coordinated programs of development off-site and testing within the loop, solutions to the problem of inlet and diversion valve actuator packing leakage will be obtained. Improved concepts for nozzle caps will be evaluated by loop testing in attempts to establish a more easily operable cap design.

Through the means of off-site development contracts, conclusive results are expected in special areas such as dry-film lubricants for N-Reactor environmental use and the solution of the valve actuator packing/seal problem.

A decisive need exists for improved primary pump seals; it is expected that improvements will be realized through development efforts planned immediately for off-site and at Hanford. A key element here is analysis and experimentation aimed at basically understanding the behavior of water-cooled and water-lubricated rotating seals.

Another area in which there must be developed basic understanding is that of reliability of the electrical

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R-7 - N-Reactor, Engineering Research and Development

systems and components of N-Reactor. Careful analysis of experienced failures and performance of exploratory experiments will be required to establish failure mechanisms and to relate failure frequency to operating conditions or design parameters.

Research and development will continue in problem areas identified by hazards analyses, reliability studies and developments in systems control associated with advanced concepts of operation and advanced fuel designs. Improved system analysis programs will be employed to assist in establishment of operating limits for the primary cooling system to permit achievement of maximum power levels consistent with nuclear safety requirements. These studies will include exploration into reactor operation with limited boiling in the process tubes. A revision and refinement of a computer program for confinement system studies, as well as work in pipe vibration and stress analysis will serve to more adequately define operating limits and provide an improved basis for analysis of reactor safety hazards.

19. Expected Results in FY-1966

Technological proving of components and equipment for N-Reactor in dual-purpose operation will be made in FY-1966. It is expected that much will be learned about the serviceability and reliability of equipment and components for nuclear reactor applications. In this area specific progress is expected in development of mechanical seals for the primary coolant pumps. Analytical support will continue in the areas of hazards analysis, systems control and predictions of reactor performance under conditions associated with advanced operation and fuel concepts.

20. Description of Materials, Equipment and Off-Site Contracts

Off-site contracts will be required in some areas to properly identify development needs, to make material compatibility investigations and to solve special mechanical equipment problems. Such work will be associated primarily with safety and reliability considerations.

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Additional Justification for Operating Costs

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RICHLAND
OPERATIONS OFFICE

REACTOR - SAFETY, CONTINUITY
OF OPERATION AND REACTOR LIFE
PROGRAM

1. Contractors: General Electric Company		Contract No. AT-(45-1)-1350	Task No.
2. Project Title: N-Reactor Gas Atmosphere Studies		189 No. R-8	3. Budget Activity No.
4. Date Prepared: February 1, 1964	5. Method of Reportings: Monthly	6. Working Locations: 300 Area	
7. Person in Charge: M. C. Leverett Principal Investigators: M. Lewis		8. Project Term Continuing From: To:	

9. Man Years:	<u>FY 196 4</u>	<u>FY 196 5</u>	<u>FY 196 6</u>
(a) Scientific and Technical	2.5	2.5	2.0
(b) Other	2.0	1.0	1.0
Total	<u>4.5</u>	<u>3.5</u>	<u>3.0</u>
10. Costs:	<u>FY 196 4</u>	<u>FY 196 5</u>	<u>FY 196 6</u>
(a) Direct Labor (Including Continuity of Service)	88,000	86,000	65,000
(b) Materials, Technical Services, Subcontracts	30,000	14,000	20,000
Total Direct	<u>118,000</u>	<u>100,000</u>	<u>85,000</u>
(c) Indirect Expenses	20,000	18,000	15,000
Total Operating Cost	<u>138,000</u>	<u>118,000</u>	<u>100,000</u>
(d) Equipment	0	0	0
(e) Irradiation Unit Cost	0	0	0

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SCHEDULE

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R-8 - N-Reactor Gas Atmosphere Studies

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated

12. Materials - Graphite, Zircaloy

13. Dates and Titles of Publications

HW-80527, "Graphite-Zirconium Compatibility in N-Reactor Interim Report," February 14, 1964
R. C. Giberson, D. W. Shannon, R. E. Woodley

HW-80416, "Report of Foreign Travel, Visits to United Kingdom and French Laboratories,"
January 14, 1964, R. E. Woodley

HW-76562 Rev., "Role of Oxidation Rate on Hydriding of Zirconium Alloys in Gas Atmosphere Containing
Hydrogen," February 1963, D. W. Shannon

HW-74755, "Radiation Effects on Corrosion and Hydriding of Zircaloy in Contaminated Helium
Atmosphere," February 1963, R. S. Hope, D. W. Shannon

14. Need for Program, Payoff and Benefits

Minor impurities present in the helium atmosphere and the inevitable in-leakage of air may result in detrimental reactions with the N-Reactor graphite stack and the Zircaloy pressure tubes. The need for a program to periodically assess the degree of graphite burnout has been demonstrated by experience with the old reactors. The possibility of accelerated hydriding with accompanying embrittlement of the Zircaloy-2 pressure tubes has been demonstrated experimentally under conditions where the reactor atmosphere is non-oxidizing with respect to the Zircaloy process tubes. To assure safe, long-lived operation of N-Reactor, a continuing program is needed to define and optimize the gas atmosphere composition.

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R-8 - N-Reactor Gas Atmosphere Studies

15. Scope

To define the levels of impurities in the N-Reactor gas atmosphere that are compatible with the Zr-2 process tubes and the graphite stack, an experimental program will be conducted to determine, 1) the oxidation characteristics of N-Reactor graphite using controlled simulated gas compositions circulated through the ex-reactor gas loop facility, 2) the effect of variable gas composition on the hydride characteristics of Zr-2 having a thick, heavily oxidized surface, and 3) the effect of radiation on pertinent gas phase and gas-solid reactions.

16. Relationship to Other Programs

These studies are directed at specific technological requirements unique to N-Reactor. Technical data from programs conducted in support of the gas cooled reactor program (both here at HAP0 and offsite), and the British and French reactor programs will be utilized.

17. Technical Progress - FY-1964

The diffusion rate of water vapor through full size graphite blocks was found to be significantly greater than previous measurements on small samples. Calculations based upon this higher diffusion rate indicate that considerably less water vapor will be required in the reactor atmosphere to protect the Zr-2 process tubes from gas phase hydriding than was calculated a year ago. Experiments have demonstrated that the thickness of the oxide film on the surface of Zr-2 is a direct function of the rate and extent of the oxidation reaction and that the normally protective film loses its protective quality against gas phase hydriding if the film becomes thick as a result of excessive oxidation. Oxidation studies using water vapor and N-Reactor graphite have shown the rate of oxidation of large samples is less than the small laboratory samples. Instrumentation was developed having high sensitivity in analyzing gas compositions containing H_2 , O_2 , N_2 , and CO. A computer program has defined the gas composition to be used during initial N-Reactor operation.

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R-8 - N-Reactor Gas Atmosphere Studies

18. Expected Results in FY-1965

Significant results expected in 1965 will be the determination of the oxidation characteristics of full size bars in flowing gas of simulated reactor composition in the gas loop facility, confirmation of the gas atmosphere composition from results of computer programs using updated experimental results, and determination of critical parameters in the hydriding of Zr-2 with thick oxide films. These studies have the objective of quantifying the rate of hydrogen pickup by the process tube and establishment of procedures to control this rate to an acceptable level without deleterious effects to the graphite.

19. Expected Results in FY-1966

Significant goals that may be achieved in FY-1966 are the redefinition of the gas atmosphere based on computer programs using observed graphite temperatures, gas compositions, in-reactor oxidation monitoring results, and observed effects on process tubes. Feasibility of using methods other than water vapor to inhibit gas phase hydriding of the process tube will be defined.

20. Description and Explanation of Major Materials, Equipment and Offsite Contracts

None

21. Proposed Future Related Construction Projects

None

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Additional Justification for Operating Costs

REACTOR - SAFETY, CONTINUITY OF
OPERATION AND REACTOR LIFE

RICHLAND
OPERATIONS OFFICE

PROGRAM

1. Contractors: General Electric Company		Contract No. AT(45-1)-1350	Task No.
2. Project Title: N-Reactor Graphite Studies		189 No. R-9	3. Budget Activity No.
4. Date Prepared: February 1, 1964	5. Method of Reporting: Monthly	6. Working Location: 300 Area	
7. Person in Charge: M. C. Leverett Principal Investigators: M. Lewis		8. Project Term: Continuing From: To:	

9. Man Years:	FY 1964	FY 1965	FY 1966
(a) Scientific and Technical	1.5	1.5	1.5
(b) Other	1	1	1
Total	2.5	2.5	2.5
10. Costs:	FY 1964	FY 1965	FY 1966
(a) Direct Labor (Including Continuity of Service)	45,000	45,000	45,000
(b) Materials, Technical Services, Subcontracts	60,000	59,000	57,000
Total Direct	105,000	104,000	102,000
(c) Indirect Expenses	18,000	18,000	18,000
Total Operating Cost	123,000	122,000	120,000
(d) Equipment	0	0	0
(e) Irradiation Unit Cost	11,500	19,000	19,000

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R-9 - N-Reactor Graphite Studies

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated
12. Materials - Graphite
13. Dates and Titles of Publications

HW-SA-2996, "Radiation Induced Dimensional Changes in Large Graphite Bars," December 18, 1963,
R. E. Nightingale and E. M. Woodruff

HW-SA-2925, "Effect of Low Compressive Stresses on Radiation Induced Dimensional Changes in Graphite,"
June 3, 1963, R. C. Giberson, W. C. Morgan

HW-SA-2926, "Effect of Massive Neutron Exposure on the Distortion of Reactor Graphite,"
December 12, 1963, J. W. Helm and J. M. Davidson

"Radiation Damage in Carbons and Graphites," H. Yoshikawa, E. M. Woodruff, J. M. Davidson, J. W. Helm,
R. E. Nightingale, Radiation Damage in Reactor Materials, International Atomic Energy Agency
Vienna - 1963, pages 581-592.

14. Need for Program, Payoff and Benefits

The N-Reactor represents an extension of Hanford reactor technology having specific design features and operating conditions significantly different from existing Hanford reactor facilities. The N-Reactor is the first graphite moderated reactor designed since it was recognized that at high temperatures graphite contracts under neutron irradiation. Though a calculated level of contraction was established as a basis for N-Reactor design, precise definition of long range graphite moderator behavior is difficult because the total irradiation to be received by the N-Reactor stack over a 25-year life is some four times greater than the maximum exposure experience in existing reactors or available from controlled test results. From the best estimate of long range graphite contraction behavior it is concluded that the plant operating life

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R-9 - N-Reactor Graphite Studies

will not be impaired. However, because of the uncertainties involved in making this estimate, an active program is needed to anticipate the amount of irradiation induced graphite contraction and its effect on the unique N-Reactor stacking arrangement and relating test and mockup results to moderator stack behavior.

15. Scope

To investigate the contraction of N-Reactor graphite, samples will be irradiated under controlled conditions in test capsules installed in the GETR. Exposure of the test samples is accumulated at the rate of 4 to 5 years of equivalent N-Reactor exposure per year of test irradiation. To achieve exposure equivalent to 25 years of N-Reactor operation will require the test irradiation program be continued through FY-1967. The contraction of test samples will be related to the expected behavior of the moderator stack through experiments with full sized graphite bars, observation of existing reactors and mockup testing.

16. Relationship to Other Programs

These studies are directed toward the specific technological requirements of N-Reactor. Data obtained from other programs conducted in support of existing reactors, gas cooled reactors, British and French programs will be utilized.

17. Technical Progress in FY-1964

Capsule irradiations of N-Reactor graphite were completed to an exposure equivalent to 10 years of N-Reactor operation. Analysis of the data obtained shows that the contraction of nuclear grade graphite in the transverse direction will saturate at a level dependent upon irradiation temperature, type of graphite and exposure. Contraction in the parallel direction continues at an increasing rate with exposure. The effect of irradiation temperature on the contraction of N-Reactor graphite was determined over the range 475 C to 800 C in the GETR and up to 1200 C in the ETR. Analysis of data on CSF graphite shows that full size bars contract ~2.5 times as much in cross-section as laboratory samples cut from similar bars. Neutron energy spectrum was determined in N-Reactor.

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R-9 - N-Reactor Graphite Studies

18. Expected Results in FY-1965

The accumulated test reactor exposure of N-Reactor graphite will be extended to 14-15 years of equivalent N-Reactor operation in the temperature range 475 C to 800 C in the GETR. Exposures up to ~10 years at a temperature of 1200 C will be obtained in ETR. The critical parameters involved in moderator integrity as influenced by the differential contraction (parallel versus transverse) will be defined. The criteria for a physical mockup of a portion of the moderator stack will be prepared.

19. Expected Results in FY-1966

The long range goal of these studies is to predict with accuracy the distortion pattern of the N-Reactor moderator to provide a basis for preventive action should conditions become severe enough to threaten plant life. A significant milestone will be the definition of problem areas in reactor operation with regard to control rod, ball channels, and tube replacement.

20. Description and Explanation of Major Materials, Equipment, and Off-Site Contracts

Continuation of the contract to irradiate test samples in the GETR will be required at the existing level through FY-1966.

A mockup of a portion of the moderator stack will be required to anticipate and evaluate reactor operational problems associated with stack distortion.

21. Proposed Related Construction Projects

None

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Additional Justification for Operating Costs

REACTOR - SAFETY, CONTINUITY
OF OPERATION AND REACTOR LIFE

RICHLAND
OPERATIONS OFFICE

PROGRAM

1. Contractors General Electric Company		Contract No. AT-(46-1)-1350	Task No.
2. Project Titles Nuclear Safety Research		189 No. R-10	3. Budget Activity No.
4. Date Prepareds March 25, 1964	5. Method of Reportings Quarterly	6. Working Locations 100,300, 700 Areas	
7. Person in Charges M.C. Leverett Principal Investigators R.E. Trumble		8. Project Term Continuing From: To:	

9. Man Years:	FY 1964	FY 1965	FY 1966
(a) Scientific and Technical	-	4	4
(b) Other	-	0	0
Total	0	4	4
10. Costs:	FY 1964	FY 1965	FY 1966
(a) Direct Labor (Including Continuity of Service)	-	95	95
(b) Materials, Technical Services, Subcontracts	-	59	81
Total Direct	-	154	176
(c) Indirect Expenses	-	26	31
Total Operating Cost	-	180	207
(d) Equipment		0	0
(e) Irradiation Unit Cost			

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R-10 - Nuclear Safety Research

-
11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated
 12. Materials - Miscellaneous - Not identified in advance
 13. Title and Date of Publications - None
 14. Need for Program, Payoffs and Benefits

Of prime consideration in the operation of nuclear reactors is the assurance of adequate safety from an uncontrolled release of fission products to the environs of the plant. Hazards analyses continually evaluate the potential for the release of radioactive fission products during normal operation and during creditable emergency situations. Nuclear control parameters, heat dissipation systems and means for control of released fission products are studied and evaluated in light of potential situations. Finally, the consequences of a potential release of fission products are determined as a measure of the degree of effort to be expended to avoid such a release.

Historically in nuclear industry the desire for safety predominates necessitating conservative assessments of potential hazards in cases where any uncertainty may exist. From time to time this conservatism may require unwarranted expensive capital investment or restrictive operational procedures were adequate knowledge available. Therefore, it is reasonable to devote research and development funds to investigate those situations requiring extensive capital investment or restrictive operating procedures, to provide adequate knowledge upon which to base realistic judgment of the real hazards involved. For example, should a situation arise requiring the dumping of the primary coolant at a time when fission gases were dissolved in water, there is a possibility of undesirable release of these gases from the open dump quench tank. One solution might be the construction of an expensive cover for the quench tank; however, experiments may be possible that could result in simple control measures that would obviate this expenditure of capital funds.

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R-10 - Nuclear Safety Research

15. Scope

Theoretical and experimental studies will be performed in support of hazards analyses in the areas of nuclear control, thermal hydraulics, heat dissipation systems and control and disposition of radioactive liquid wastes.

16. Relationships to Other Projects

These studies are specifically in support of the safe and efficient operation of N-Reactor; however, information generated will be useful in hazards analyses of all types of reactors.

17. Technical Progress in FY 1964

Although not identified as a separate program, theoretical and experimental work was performed in support of the hazards analysis for Phase I and II operation in the areas of nuclear control, thermal hydraulics and fuel technology.

Control strengths under various operating situations were evaluated and found adequate. Heating rates of fuel elements were calculated to determine the maximum temperature the tube-and-tube and co-product fuel elements would reach in the event of loss of primary coolant. Experiments were performed to measure the effect of heating the fuel to 1800 F and quenching to simulate a loss of primary coolant and a delay before initiating last cooling.

18. Expected Results in FY 1965

Theoretical and experimental studies based upon analysis of startup data should result in a better understanding of the limitation of existing nuclear control systems. Extension of these studies is expected to result in improvements in the reliability and simplicity of these controls and the manner in which they are operated. Studies will be made to support the design of systems to provide improved control of routine or emergency release of radioactive materials.

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R-10 - Nuclear Safety Research

18. (continued)

These studies will include the investigation of additives or surface films to control radioactive materials in open tanks of water and the determination of percolation rates through the soil between open pits (cribs) and the river at 100-N Area.

19. Expected Results in FY 1966

Experimental and theoretical studies performed during FY 1966 will be determined by analyses of results of startup, power ascension and operation at full power. The close coupling of these studies in support of problems identified during continuing hazards analyses makes prognostication of FY 1966 results especially difficult.

20. Description and Explanation of Major Materials and Offsite Contracts

None

21. Proposed Future Related Constructions Projects

None

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Additional Justification for Operating Costs

METALLURGY - SAFETY, CONTINUITY
OF OPERATION AND REACTOR LIFE

PROGRAM

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1. Contractors General Electric Company		Contract No. AT-(45-1)-1350	Task No.
2. Project Title: N-Reactor Fuel Development		189 No. M-1	3. Budget Activity No.
4. Date Prepared: March 25, 1964	5. Method of Reporting: Monthly	6. Working Locations: 100 - 300 Areas	
7. Person in Charge: M.C. Leverett Principal Investigators: M. Lewis		8. Project Term: Continuing From: To:	

9. Man Years:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Scientific and Technical	12	14	14
(b) Other	8	6	6
Total	<u>20</u>	<u>20</u>	<u>20</u>
10. Costs:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Direct Labor (Including Continuity of Service)	420,000	445,000	445,000
(b) Materials, Technical Services, Subcontracts	1,018,000	389,000	530,000
Total Direct	<u>1,438,000</u>	<u>834,000</u>	<u>975,000</u>
(c) Indirect Expenses	244,000	142,000	175,000
Total Operating Cost	<u>1,682,000</u>	<u>976,000</u>	<u>1,150,000</u>
(d) Equipment	250,000	900,000	150,000
(e) Irradiation Unit Cost	0	0	0

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M-1 - N-Reactor Fuel Development

11. Reactor Concept - Pressurized Water Cooled, Graphite Moderated
12. Materials - Uranium, Zircaloy
13. Date and Title of Publications

None

14. Need for Program, Payoff and Benefits

The imminent use of pressurized water-cooled, metallic uranium fuel elements on a large scale in the N-Reactor not only represents an extrapolation from previous Hanford fuel technology, it represents the only production-scale application of this concept in this country or abroad. Provision of a supporting technology is and will continue to be a major activity at Hanford as only a limited amount of directly applicable R&D will be available from other sites.

The major benefit to be achieved through an extensive and continuing fuel program is attainment of the full capabilities entailed in the basic fuel concept at much reduced costs. The initial N-Reactor fuel design represents an estimate of what is required for adequate performance. While the design is intentionally conservative, some features may not fully provide the level of performance required to sustain relatively unhampered reactor operation. Production-scale irradiation experience will provide the feed-back required to give direction to a continuing program to correct any excesses or deficiencies in the initial fuel design. Reduction of unwarranted conservatism in the design will lower fuel fabrication costs; correction of deficiencies will lower irradiation costs through increased time operated efficiency. In addition to design optimization, direct savings in fuel fabrication costs will result from developing improved processing methods that will permit higher process yields at the same or higher quality levels.

Establishment of an economic design point relative to the initially-goaled operating conditions will not in itself attain the objective of achieving the full capability of the coextruded fuel

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M-1- N-Reactor Fuel Development

14. (continued)
concept.

To meet the functional fuel requirements for the more rigorous exposure conditions that pertain to potential future modes of reactor operation, optimization of the physical design of the fuel element and improvement in the irradiation properties of the materials will be required. Exposure levels of 3000-4000 MWD/T at reactor powers up to 4800 MW would necessitate reducing uranium swelling and mitigating the effects of both swelling and thermal strains on fuel cladding. Development of such fuel is not expected to materially change local fabrication costs. However, the availability of a longer-lived fuel will enable the fuel-contributed portion of production costs to be significantly reduced.

The long-range objective of this program is the provision of technology which will enable the reduction of the cost of fabrication of the N-Reactor fuel to between \$3 and \$4 per pound, (not including off-site fabrication costs), the provision of fuel having characteristics consistent with the production of 1000 kg Pu equivalents per year in the N-Reactor, and a fuel that will support both the current mode of reactor operation and future modes necessitating longer exposures and/or higher specific powers. Attainment of the cited objective depends both on the R&D herein proposed and on other related activities of a manufacturing and operating nature, and related work in physics, thermohydraulics. The successful completion of this program is thus an essential part of the development of the N-Reactor to a point of economic superiority.

15. Scope

Fabrication of the first load fuel elements was essentially completed in CY 1963. At the conclusion of the low level power demonstration and the final operational tests about May, 1964, power ascension will be initiated. During FY 1965 fuel performance data will be obtained by which the established first load fuel design can be judged and a basis for improvement in performance and fuel manufacturing economy can be derived. In addition, capability for continuing production testing of new improved or less costly fuel designs and for assessing fuel performance

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at much extended exposures will have been established. The scope of the program to evaluate the performance of the first load of fuel elements recognizes the arbitrariness that was exercised when that design was frozen. There were scant data on swelling, the relative change of inner vs. outer diameters related to clad strength, and their relation to the operating characteristics of the hydraulic system. The above scope complements those of the separate programs to test improved or less costly designs and develop fuel designs for much extended exposure and power level.

The evaluation of the performance of the first load will follow stages of test, evaluate, redesign, test, evaluate, etc. The development of less costly and longer-lived fuel elements will include: testing of improved designs and new materials, evaluation of new processing methods, and improving specific processing yields.

16. Relationship to Other Programs

This program is related to: 1) the process technology programs that directly support N-fuel element manufacture on-site and the provision of adequate material components from off-site sources that are converted to on-site fuel, 2) reactor programs in support of nuclear engineering materials and reactor coolant technology, 3) reactor programs related to operational aspects of the fuel in the areas of thermal-hydraulic performance, fuel rupture monitoring, and the mechanical aspects of charge-discharge operations.

17. Technical Progress in FY 1964

The major technical progress in the evaluation of the current fuel element was highlighted by (a) data showing continued adequacy for swelling and general performance from the KER loop irradiation test program for exposures to 2100 MWD/T which exceeds the N goal by 50 percent, (b) continued study of the rate of uranium core loss from purposely defected irradiated fuel elements that were cooled down at rates simulating actual reactor conditions, (c) further capsule irradiations that defined local clad thickness variation to avoid clad failure.

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(d) the completion of the data storage and analysis programs for the fuel element manufacturing variables and attributes that will be automatically computed and analyzed on the 7090 IBM computer, (e) the special loading of 97 columns of measured and weighed fuel elements to monitor the in-reactor performance of the first fuel load.

The major items of technical progress on the evaluation of the advanced fuel element program were; (a) the initial successful irradiation of a single-tube prototype for high-temperature performance, (b) the mechanical and thermal processing behavior, suitability to fuel element manufacturing, and in-reactor evaluation of the dilute uranium alloy used by the British, (c) further evaluation of the in-reactor performance of specially-shaped fuel elements, (d) an economic analysis of the cost of the single tube as an advanced fuel element in N-Reactor.

The major progress in reducing fuel element costs and/or attaining improved design features in the current fuel element included: (a) demonstration of the in-reactor stability of a shaped end cap in both the as-brazed and the as-unbonded condition, (b) the development and evaluation of a thermo couple element as a crud monitor.

18. Expected Results in FY 1965

The major areas of expected progress in FY 1965 are: 1) the initiation of a vigorously sustained fuel performance evaluation program based on characterization of the fuel element attributes both before and after irradiation and the correlation of the changes in attributes expressed as a function of the irradiation and fabrication process variables, 2) the development of reasonably conclusive definition of any deficiencies in the design of the first load fuel elements, 3) the initiation of production testing of design changes directed towards improved

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fuel capability and towards reducing fuel manufacturing costs.

Major FY 1965 goals relative to fuel evaluation are: 1) to complete and demonstrate adequate capability of the fuel examination facility, 2) to complete the development of IBM programs for fuel data handling and engineering analysis, 3) make substantial progress toward a performance analysis of first load fuel.

Major FY 1965 goals relative to design definition are: 1) irradiate a series of fuel charges to assess cladding requirements in terms of minimum nominal clad thickness, magnitude of local clad variations, and optimum distribution of fuel volume increases by varying inner to outer clad ratios, 2) irradiate several uranium alloys with potential for reduced swelling susceptibility, 3) initiate extended exposure tests to explore for threshold limits of strain from swelling for both the clads and the end closure, 4) conduct irradiation tests to determine if the mid-point inner fuel tube supports are required, the locking clips can be eliminated, and whether the vibrational environment evidenced in reactor operation requires a less rigorous fuel criterion with regard to avoid fretting.

Major FY 1965 goals relative to backup fuel capability and cost reduction are: 1) to irradiate significant numbers of fuel with completely bonded and partially bonded shaped end closures, 2) to develop and test an improved unbonded closure concept, 3) irradiate fuel with reduced clad thickness, 4) conduct exploratory irradiations to support ex-reactor data indicating that acceptance criteria for product attributes and characteristics are too conservative.

Expected Results in FY 1966

The major goals for the fuel element development program in FY 1966 will be to: 1) conduct a multifaceted evaluation program for the irradiated fuel element performance and establish a

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"norm" of quality to which continuing changes in both the design and the method of manufacturing the fuel elements can be compared, 2) demonstrate through in-reactor test, a single tube fuel element concept that will operate with full confidence of superior performance as an alternate mode of achieving greater economy of operation, 3) demonstrate a breadth and depth of technical competence to explain the mechanisms by which swelling is controlled and such that no other deformation process-limits the use of metallic uranium fuel at higher levels of power and exposure.

20. Description and Explanation of Major Materials, Equipment, and Off-site Contracts

N fuel R&D is characterized by high material costs (Zircalov and other reactive metal alloys), the commitment of a large minimum unit of representative manufacture for tests, the production size coextrusion of each clad fuel tube geometry, non-typical equipment for handling reactive and radioactive materials, and high expense related to the examination of irradiated fuel.

Facilities for irradiated fuel handling and evaluation will be provided and operated as part of this program. These facilities include equipment for special pickup of irradiated fuel to avoid damage upon discharge, equipment for measuring the dimensions of irradiated fuel elements, a device to weigh the fuel to determine the change in density (swelling) and instruments to measure clad thickness and bonding.

Nuclear Metals, Inc. will be retained as expert consultants and to perform specialized research and development in support of the program.

The reduced level of services reflects the change over from fuel testing in in-reactor loops funded from R&D to testing in N-Reactor where tests elements will contribute to production from the reactor.

21. Proposed Future Related Construction Projects

None.

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PROGRAM

1. Contractors: General Electric Company		Contract No. AT-(45-1)-1350	Task No.
2. Project Title: Co-Product Development for N-Reactor		189 No.	3. Budget Activity No.
4. Date Prepared: February 3, 1964	5. Method of Reporting: Monthly	6. Working Locations: 100 - 300 Areas	
7. Person in Charge: M. C. Leverett Principal Investigators: J. W. Riches		8. Project Term: Continuing From: To:	

9. Man Years:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Scientific and Technical	7	22	14
(b) Other	3	5	4
Total	<u>10</u>	<u>27</u>	<u>18</u>
10. Costs:	<u>FY 1964</u>	<u>FY 1965</u>	<u>FY 1966</u>
(a) Direct Labor (Including Continuity of Service)	220,000	610,000	335,000
(b) Materials, Technical Services, Subcontracts	200,000	544,000	260,000
Total Direct	<u>440,000</u>	<u>1,154,000</u>	<u>595,000</u>
(c) Indirect Expenses	75,000	196,000	105,000
Total Operating Cost	<u>515,000</u>	<u>1,350,000</u>	<u>700,000</u>
(d) Equipment	0	0	0
(e) Irradiation Unit Cost	0	0	0

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Co-Product Development for N-Reactor

11. Reactor concept - pressurized water cooled, Graphite moderated
12. Materials- zircaloy components, enriched uranium fuel, and aluminum-lithium target alloys
13. Dates and Titles of Publications

HW-78864, "A Program for Multi-Product Operation of the N-Reactor," September 9, 1963,
by Staff, Research and Engineering Section, N-Reactor Department.

HW-79289, "Co-Product Program - N-Reactor," October 17, 1963, R. L. Dickeman.

HW-79306, "Production of Special Nuclear Materials in N-Reactor," October 21, 1963,
D. L. Condotta and E. G. Pierick.

14. Need for Program, Payoff, and Benefits

Continuing production studies reveal that the production of weapons grade plutonium and tritium is an economically attractive mode of operation for N-Reactor. With the successful completion of the proposed research and development program, co-product production in N-Reactor could begin in January 1967. Approximately 5 kg of tritium could be produced at a reduction in unit total cost of up to \$6 per gram equivalent when compared to other modes of operation of N-Reactor that yield only weapons grade plutonium.

Achieving this production level and unit cost requires a fuel and target design that will subject the materials to more severe temperature and exposure conditions than for the tube-in-tube design. Analysis of existing knowledge and experimental results obtained to date are very encouraging. However, there is a continuing need for additional experimental verification of the limiting conditions for both fuel and driver to permit the specification of a production fuel and target design. The incremental cost of this continuing

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program is estimated to be \$2.4 million. The proposed schedule of expenditure is FY-1965 - \$1.35 million; FY-1966 - \$0.7 million and FY-1967 - \$0.35 million.

The principal benefits to be derived from this expenditure of research and development funds are lower unit costs for both tritium and weapons grade plutonium. The co-product mode of operation would make N-Reactor the most economical production reactor in the AEC complex.

15. Scope

The scope of the research and development program encompasses work in physics, reactor engineering, materials and fuels areas necessary to define a fuel and target design and reactor operating characteristics compatible with production economy and nuclear safety. Both experimental and analytical work will be performed to define engineering limitations for heat generation and boiling burnout for new geometries and higher heat fluxes, to establish optimum nuclear characteristics of exposure transients and temperature coefficients compatible with available control strengths under normal and accident conditions, to develop fuel materials capable of high temperature, long exposure operation and target materials compatible with production and nuclear hazards requirements.

16. Relationship to Other Programs

The work described in this report is in direct support of N-Reactor. Data relative to N-Reactor developed under the O2-Base Case-Research and Development Program will be utilized throughout. The results relative to metallic fuel development derived from this program and the AEC sponsored Heavy Water Moderated Power Reactor Program should be of mutual benefit. Knowledge gained from programs sponsored by the Division of Research and Division of Reactor Development also will contribute to the success of the Co-Product Program.

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17. Technical Progress in FY-1964

Two results were obtained with major significance for the ultimate success of the program:

1. Tolerable swelling of a prototypic fuel made from ingot grade uranium (no iron or silicon additions) was obtained for irradiation conditions of 1200 MWD/T at a peak core temperature of 600 C.
2. No significant migration nor loss of tritium was measured at 300 C in in-reactor gas release tests nor in aluminum-lithium target elements irradiated at N-Reactor coolant temperatures to an exposure of GVR 30 to 35 which is twice the exposure planned for production.

Prototypical fuel elements were fabricated from standard N-uranium (150 ppm iron and 100 pm silicon added) and the swelling resistant British composition (800 ppm aluminum and 400 ppm iron added) to measure their behavior under irradiation conditions simulating those to be encountered during co-product production in N-Reactor. A broad spectrum of uranium alloy samples are being irradiated in capsules to test swelling theories and define the best alloy for co-product service.

Prototypic fuel and target elements were designed for test irradiation. Uranium enrichments of 1.25 and about 2.0 per cent U-235 will be tested to encompass the range of tritium production best suited for N-Reactor. Sufficient fuel and target elements were fabricated for 1.25 per cent U-235 test to permit charging a 36 tube square pattern from which both production data and material behavior data will be obtained to simulate production of 2.5 kg tritium per year in N-Reactor.

Conversion ratios for both plutonium and tritium were calculated for a broad range of fuel and target designs and reactor operating conditions to permit the selection of a production design as data are accumulated to specify materials, engineering and physics limitations more exactly.

18. Expected Results in FY-1965

During FY-1965, the performance of several uranium alloys will be measured under irradiation conditions

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typical of co-production operation of N-Reactor. It is expected that an alloy resistant to swelling at core temperatures up to 600 C and exposures up to 1700 MWD/T will be demonstrated. The relationship between the high temperature swelling of uranium under irradiation and the microstructure and other metallurgical properties will be determined.

Production capability to 2.5 kg of tritium will be demonstrated upon the successful completion of 36 tube production test of 1.25 per cent U-235 co-product elements. It is expected that solutions will be found to the more vigorous materials and fuels problems associated with economical production of 5 kg of tritium through irradiation of about 10 fuel columns of co-product elements containing uranium of about 2 per cent enrichment.

Boiling burnout experiments with short heated sections of selected co-producer designs will be completed by the middle of the fiscal year. Construction of an electrically heated test section equipped with prototypic inlet and outlet connectors and fittings will be complete and ready for testing by the end of FY-1965. As they become available, the results of boiling burnout analysis will be factored into production fuel and target design and hazards analyses.

Detailed calculations of control strengths, temperature and exposure transients, base reactivity, and reactivities for abnormal conditions will be based upon experimental results from the PCTR. Measurements in the PCTR of k_0 and f for prototypical 1.95% fuel elements will be done on the wet and dry lattice both with and without the target element in place. The fuel temperature coefficient of k_0 will be measured for the dry lattice. Measurements of Δk for simulated slumped fuel elements or targets are planned to provide information for hazards evaluation. Measurements of bucklings and control strengths in the expotential piles will be started during this year. Kinetics studies and other information required for final hazards analysis will be in progress.

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19. Expected Results in FY-1966

Based upon analyses of irradiation test results and physics and engineering experiments and calculations the fuel and target for the first production load of co-product elements will be designed. Practical and economic fabrication and heat treating processes will be developed for the new uranium alloy and the aluminum-lithium target alloy. Pilot quantities of production elements will be thoroughly tested both out of reactor and under irradiation to further verify the design.

Experiments will be made, with a half-column test section representing a selected co-producer design, to determine two-phase flow performance under steady-state and transient conditions simulating tube leaks, pluggings and other abnormal situations. Results of these experiments will be interpreted in terms of actual process tube performance.

The measurements of buckling and control strengths in the exponential piles will be completed and analyzed. The calculations of control margins for both normal and abnormal operating conditions will be completed and compared with the laboratory experiments for normalization. Detailed calculations of temperature and exposure transients will be completed. Further work on kinetics and control studies will be completed for hazards evaluation and analysis. Plans will be made for the in-reactor experimental physics program which will provide the operational bases for resumption of full power operation with a full reactor loading of the target-driver fuel elements.

20. Description and Explanation of Major Materials and Offsite Contracts

Research and development in support of a new material or fuel concept is characterized by high materials and services costs because of the need to work with production size components and to perform tests and examinations on highly radioactive materials.

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21. Proposed Future Related Construction Projects

Modest plant and equipment modifications are needed to convert N-Reactor to co-product operation. In the fuels plant, new or revised cleaning, assembly, welding, and inspection equipment will be required for the target element. The single tube driver with about 2 per cent enrichment will require some equipment modifications because of the change in size and weight and to assure nuclear safety. The reactor plant will require equipment to separate the target from the driver and to remove the zirconium jacket from the target, minor modifications to fuel handling equipment and the acquisition of casks and cask cans for shipment of the target. Because of the higher enrichment, the separations plant will require new desolver inserts, processing tanks, and calciner. Modification of the on-site cask cans may be required. These plant and equipment items will be included in the Plant Acquisition and Construction Budgets for FY 1965, 1966, and 1967. The total cost is estimated to be about \$1,800,000.

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PROGRAM

1. Contractors General Electric Company		Contract No. At-(45-1)-1350	Task No.
2. Project Title: Co-Product Development for N-Reactor (Alternate)		189 No.	3. Budget Activity No.
4. Date Prepared: February 3, 1964	5. Method of Reportings Monthly	6. Working Locations 100 - 300 Areas	
7. Person in Charge: M. C. Leverett Principal Investigators: J. W. Riches		8. Project Term Continuing From To:	

9. Man Years:	<u>FY 196 4</u>	<u>FY 196 5</u>	<u>FY 196 6</u>
(a) Scientific and Technical	7	17	17
(b) Other	3	3	3
Total	<u>10</u>	<u>20</u>	<u>20</u>
10. Costs:	<u>FY 196 4</u>	<u>FY 196 5</u>	<u>FY 196 6</u>
(a) Direct Labor (Including Continuity of Service)	220,000	455,000	455,000
(b) Materials, Technical Services, Subcontracts	200,000	400,000	393,000
Total Direct	<u>440,000</u>	<u>855,000</u>	<u>848,000</u>
(c) Indirect Expenses	75,000	145,000	152,000
Total Operating Cost	<u>515,000</u>	<u>1,000,000</u>	<u>1,000,000</u>
(d) Equipment	0	0	0
(e) Irradiation Unit Cost	0	0	0

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Co-Product Development for N-Reactor (Alternate)

The program described in "Co-Product Development for N-Reactor," page 58, was developed to establish technical feasibility of the co-producer program for N-Reactor by the end of CY 1964 and full reactor loading by January 1967. The basis for this program is an analysis prepared at the request of Commissioner Ramey and transmitted to the Commission on October 25, 1963.⁽¹⁾

A somewhat less accelerated program proposal ⁽²⁾ provided the Commission in September 1963, was programmed to support initial full reactor loading during CY 1967 rather than by January 1967; this required an expenditure pattern of \$1.0 million in FY 1965, \$1.0 million in FY 1966, and \$0.4 million in FY 1967. In either case, the incremental research and development required to mature the co-product mode of operation is estimated to be \$2.4 million.

We urge the Commission to make the additional dollars available to permit accomplishing the program on the accelerated schedule.

(1) Letter: W. E. Johnson to AEC-RL00, Attention: J. E. Travis, HW-79374, October 25, 1963, (Secret).

(2) M. C. Leverett, "A Program for Multi-Product Operation of the N-Reactor," HW-78864, 9-9-63, (Secret).

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