C-1 COPRODUCT DEVELOPMENT FOR N-REACTOR

Excerpts from
N-Reactor Department Research and
Development Budget For FY-1967
And Revision of Budget For FY-1966

April 19, 1965

Staff, N-Reactor Department

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PREPARED BY THE GENERAL ELECTRIC COMPANY, CONTRACTOR FOR

U. S. ATOMIC ENERGY COMMISSION

RICKLAND OPERATIONS OFFICE

Additional Justification for Operating Costs

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<thead>
<tr>
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<tr>
<td>5. Method of Reporting</td>
<td>Semiannual</td>
<td>6. Working Locations:</td>
<td></td>
</tr>
<tr>
<td>7. Person in Charge</td>
<td>M.C. Leverett</td>
<td>8. Project Term</td>
<td>1964</td>
</tr>
<tr>
<td>Principal Investigators</td>
<td>J.W. Riches</td>
<td>From</td>
<td>1967</td>
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<thead>
<tr>
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<tr>
<td>(a) Scientific and Technical</td>
<td>23</td>
<td>1</td>
<td>8</td>
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<tr>
<td>(b) Other</td>
<td>170</td>
<td>1</td>
<td>8</td>
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<tr>
<td>Total</td>
<td>220</td>
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10. Costs

<table>
<thead>
<tr>
<th>(a) Direct Labor (Including Continuity of Service)</th>
<th>1965</th>
<th>1966</th>
<th>1967</th>
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<tbody>
<tr>
<td>Materials, Technical Services, Subcontracts</td>
<td>475,000</td>
<td>252,000</td>
<td>192,000</td>
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<td>Battelle-Northwest</td>
<td>417,000</td>
<td>60,000</td>
<td>50,000</td>
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<tr>
<td>Total Direct</td>
<td>892,000</td>
<td>302,000</td>
<td>242,000</td>
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<tr>
<td>(c) Indirect Expenses</td>
<td></td>
<td></td>
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<tr>
<td>Total Operating Cost</td>
<td>150,000</td>
<td>104,000</td>
<td>60,000</td>
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<tr>
<td>Total Operation Cost</td>
<td>1,042,000</td>
<td>796,000</td>
<td>450,000</td>
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<tr>
<td>(d) Equipment</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(e) Irradiation Unit Cost</td>
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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 Multiproduct Operation of the N-Reactor," By Staff, Research and Engineering Section, NRD, September 9, 1963


HW-77198, "Production Studies - N-Reactor," April 4, 1963, N-Reactor Staff


HW-81327, "Production Test NR-8 Coproducer Demonstration Test (1.25)," May 4, 1964, T. W. Evans

14. Need for Program, Payoff, and Benefits

Continuing production studies reveal that the production of weapon 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, coproduct 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 $7 per gram equivalent when compared to other modes of operation of N-Reactor that yield only weapon 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. Analyses 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 target to permit the specification of a production fuel and target design. The incremental cost of this program is estimated to be $1,055 million in FY-1965, $0.796 million in FY-1966 and $0.450 million in FY-1967 for a total of $2.3 million.

The principal benefits to be derived from this expenditure of research and development funds are lower unit costs for both tritium and weapon grade plutonium. When the reactor reaches equilibrium operation as a dual-purpose reactor producing process steam for credit, it will be a highly competitive producer of plutonium and tritium 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 must be performed to define engineering limitations for heat generation and boiling burnout for new geometries and higher heat fluxes, to establish 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 02-Base Case Research and Development Program will be utilized throughout. Knowledge gained from programs sponsored by the Division of Research and Division of Reactor Development also will contribute to the success of the Coproduct Program.

17. Technical Progress in FY-1965

Experience with heavier single tube fuel has demonstrated the feasibility of fabricating coproduct driver elements. Over 1000 driver elements for two production tests of 1.25 and 1.95 percent enriched coproduct assemblies have been made. Pilot lots of heavier single tube elements with standard uranium and new uranium alloys have also been fabricated.

Fabrication of Al-Li target elements likewise demonstrated the feasibility to produce target elements in pilot plant quantities. Nearly 2000 ft. of Al-Li target elements were fabricated for the PCTR tests and 1.25 and 1.95 percent enriched irradiation tests.

Production capability to 2.5 kg of tritium was largely demonstrated with near completion of the 36 tube production test of 1.25 percent U-235 coproduct elements. Chemical analyses of the fuel and target elements to determine actual product yields will carry into FY-1966.

Analysis of swelling data from the irradiation testing of single tube fuel containing iron silicon (150 ppm iron and 100 ppm silicon) and iron-aluminum uranium (300 ppm aluminum and 400 ppm iron) alloys provided further
confidence that the more severe operating conditions associated with coproduct operation can be safely accommodated. This fuel operated satisfactorily at temperatures in excess of 525 °C and to exposures of 2500 MWD/T. Selected tubes from the 36 tube 1.25 percent U-235 coproduct test will remain in the reactor to provide fuel driver and target performance at exposures in excess of goal and core temperatures up to 530 °C. A proof loading of about 18 tubes of 1.95 percent enriched assemblies operating at uranium temperatures up to 580 °C and to an average exposure of 1700 MWD/T will be loaded in the reactor about April 1965. This loading will use the basic fuel design chosen for the full reactor load.

Experiments in the Physical Constants Test Reactor (PCTR) on the 1.95 percent enriched fuel were completed and provided essential empirical checkpoints for infinite multiplication ($k_{in}$) and thermal utilization ($f$) for both a wet and dry lattice. Initial analysis showed close agreement between PCTR results and the FLEX 3 computer code. Experiments to measure buckling ($B_e$) and control strengths in an exponential pile for the wet and dry lattice were made. These experiments were performed using the basic fuel design chosen for the full reactor load in an N-Reactor graphite lattice. Preliminary results verified that the margin of control strength under both normal and accident conditions is adequate for 1.95 percent enriched coproduct fuel.

A preliminary safeguards analysis for a full load of coproduct in N-Reactor of 1.95 percent enrichment was carried out. A series of experiments designed to determine the behavior of the target alloy under various accident conditions were underway. Early results on unirradiated targets revealed that when targets are heated to temperatures of 1100 °C the molten aluminum-lithium alloy is normally contained by the Zircaloy jacket. When jacket failure has occurred, the aluminum-lithium alloy reacts with the Zircaloy jacket forming a highly refractory compound that contains the lithium within the target. Irradiated target elements were also subjected to a similar temperature cycle, causing rupture of the clad and expulsion of about 2/3 of the aluminum-lithium alloy from the target. Analysis of the target core materials dislocated during the tests revealed that the ratio of lithium-6 to aluminum remained relatively constant indicating that vaporization of lithium from the alloy should not be a problem. Detailed analysis of the distribution of lithium-6 in the reactor following a loss of water accident was initiated. The excess reactivity that would result should the aluminum-lithium content of the reactor be depleted could exceed the local control strength. To avoid this depletion, a target with a non-melting
poison core is being tested. Also, alternate fuel designs and loading patterns are being investigated to avoid the potential problems of excess reactivity resulting from target melting.

Critical mass exponential experiments were completed for the coproducer fuel element with and without target poison in various water lattices to verify calculations. No insurmountable safeguards problems are expected in satisfying nuclear safety criteria for either pre-irradiated or post-irradiated phases of material handling.

Considerable work has been expended narrowing the range of coproducer fuel designs for the first full load coproducer fuel. Generalizations have been developed as follows: a) once the quantity of tritium to be produced by N-Reactor has been established, the corresponding enrichment level of the fuel to produce this quantity becomes fixed. b) After specific uranium enrichment has been chosen, increasing the weight of fuel per foot decreases the unit product cost. c) The maximum fuel weight is limited by the maximum allowable core temperature, by heat dissipation requirements, by control strength available, by driver-target effective cross sections, by nuclear safety requirements, and by reactivity behavior. The effect of these limits are in the last phase of evaluation for coproducer fuel designs that will produce about 4 to 5 kg of tritium per year.

18. Expected Results 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 coproduct elements will be designed. Fuel performance data from three large scale production tests (PT-8, 13, and 36) will be obtained during the first half of FY-1966. Analysis of these data and of fuel fabrication experience will permit selection of a fuel composition which will be adequate for use in the coproducer driver element. Particularly significant is the proof loading of about 20 tubes of 1.95 percent enriched assemblies (PT-13) that will be operated to uranium temperatures up to 580 °C and to average exposures beyond 1700 MWD/T. Single tube loadings of 0.947 percent enriched fuel (PT-36) will be irradiated to test uranium alloys for swelling resistance. Test columns of prototypical fuel will be irradiated to evaluate the validity of calculated limits such as peak uranium temperatures, clad thickness variation and target designs.
Rates and degree of migration of molten target alloy under accident conditions will be defined. In excessive reactor reactivity gains are prognosticated as based on migration experiments, appropriate changes in target design, loading patterns, or materials of construction will be made to eliminate problems.

Evaluation of the results of the two in-reactor test blocks will be completed providing experimental data on reactivity behavior and product yields. A final hazards summary report will be prepared, describing the physics behavior of a full reactor load of coproduct fuel under normal and accident conditions and assessing the adequacy of available reactor safety systems. Should the final fuel design deviate significantly from the prototypical design already investigated, PCTR tests will be undertaken to verify calculated physics parameters. A method of providing fringe enrichment to enhance pile flattening efficiency will be developed. If required, a PCTR test will be carried out to verify calculated reactivity parameters of fringe enrichment columns. Plans will be made for the in-reactor experimental physics program which will provide the operational bases for full power operation with a full reactor loading of the target-driver fuel elements.

Both boiling burnout experiments and two phase pressure drop studies of the coproducer fuel will be completed. Data from these experiments will assist in determining essential operating safety limits under coproduct operation and will also be used in studies made in support of safeguards analysis.

19. Expected Results FY-1967

Program emphasis during FY-1967 will be largely determined by the results of the testing programs initiated during FY-1965 and FY-1966. It is expected that analytical work will be required in the areas of reactor physics and thermal hydraulics to permit interpretation of the results of earlier testing programs. Through engineering analysis and test programs, the problems associated with operating coproduct fuel at 120 percent of the design power will be assessed. Test fuel columns charged to evaluate engineering limits will reach goal exposure and the results interpreted with respect to feasibility for more rigorous service for the fuel and target assembly.
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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.

21. Proposed Future Related Construction Projects

Plant and equipment modifications are needed to convert N-Reactor to coproduct 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 percent 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 dissolver 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 Acquisitig and Construction Budgets for FY-1966, 1967, and 1968. The total cost is estimated to be about $2,000,000.
END

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