Mr. Range

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Radioisotope Program Notes
for
USAEC Budget Review Committee Meeting
June 7, 1971

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A. F. Rupp

The Radioisotope Program is comprised of two parts: (1) Production, financed by income from sales and inventory accounts and (2) Research and Development, financed mainly by the Division of Isotopes Development (08) Program, Division of Space Nuclear Systems (04 - isotopic power) plus small amounts of work for other agencies or semi-private institutions. Referring to Fig. 1, it will be noted that the Radioisotope Production Program peaked about 1962 and the Research and Development Program in 1967. Until about 1962, when DID was established, the Radioisotope Program received no program research and development funds; we carried our research and development program informally as a business expense.

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FOLDER Budget-Review Committee Program-Notes June 1971

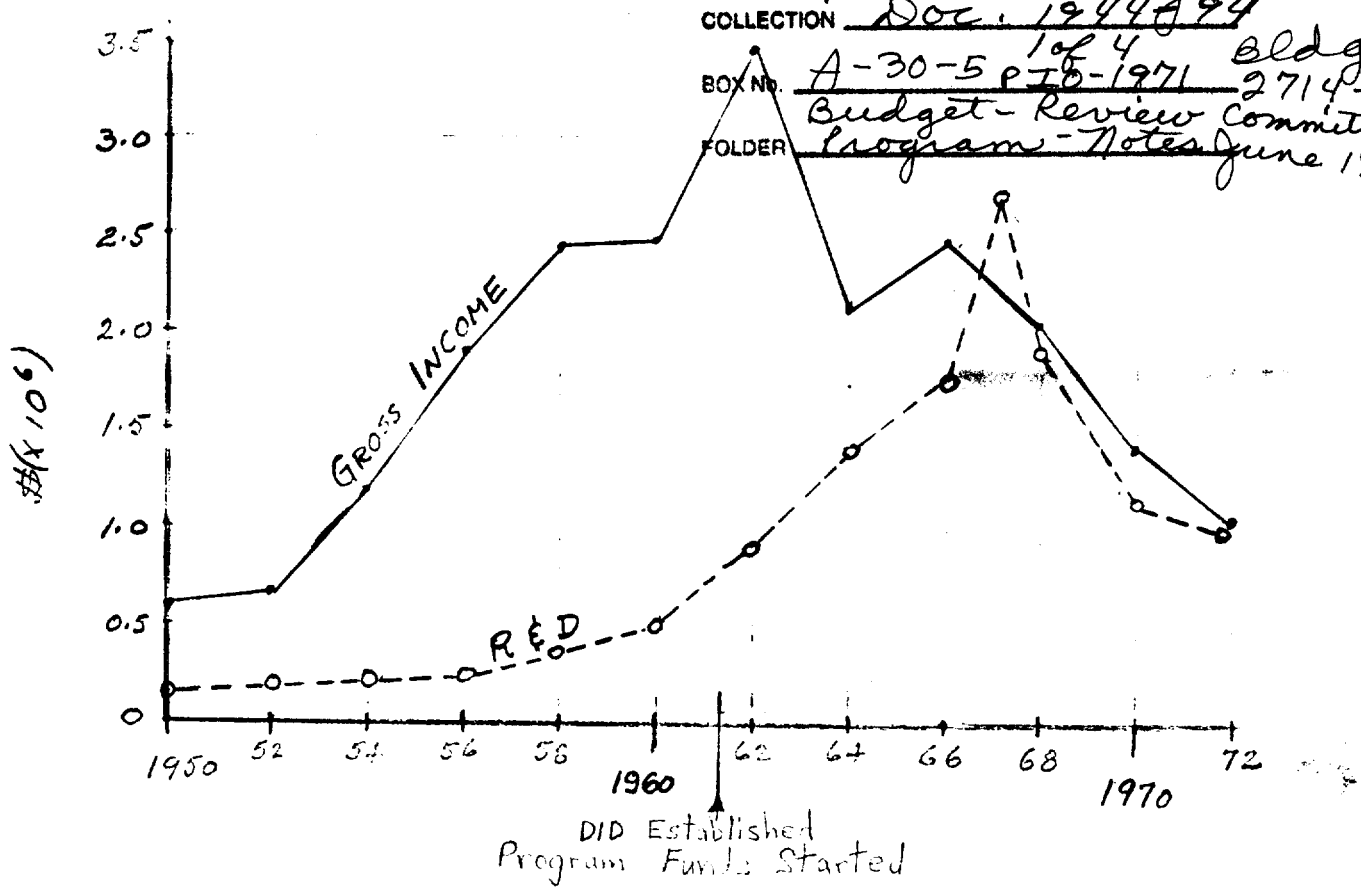

Fig. 1. Radioisotope Program Funds 1950-1972.

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AEC policy requires that we withdraw from radioisotope production. The following table shows that we soon will have withdrawn from practically all the business; we now produce only research radioisotopes or fill special requests approved by AEC. This is illustrated in Figs. 2 and 3.

Withdrawn Radioisotopes

Isotope	Withdrawn	Isotope	Withdrawn
Antimony-122	Proposed	Iron-59	4/18/65
Antimony-124	5/2/66	Lanthanum-140	5/2/66
Antimony-125	4/18/65	Mercury-197	5/2/66
Arsenic-76	5/2/66	Mercury-203	5/2/66
Arsenic-77	5/2/66	Molybdenum-99	5/2/66
Barium-131	Proposed	Nickel-63	Proposed
Barium-133	Proposed	Osmium-191	Proposed
Bismuth-210	Proposed	Palladium-109	Proposed
Bromine-82	5/2/66	Phosphorus-32	5/2/66
Calcium-45	4/18/65	Promethium-142	Proposed
Cadmium-109	5/2/66	Potassium-42	5/2/66
Cadmium-115	5/2/66	Rhenium-186	Proposed
Cadmium-115m	5/2/66	Rubidium-86	Proposed
Carbon-14	Proposed	Samarium-153	Proposed
Cerium-141	6/23/64	Scandium-46	Proposed
Cesium-131	Proposed	Selenium-75	4/18/65
Cesium-134	6/23/64	Silver-110m	5/2/66
Chlorine-36	Proposed	Silver-111	Proposed
Chromium-51	6/23/64	Sodium-24	5/2/66
Cobalt-58	6/23/64	Strontium-85	10/15/64
Cobalt-60	3/68	Sulfur-33	5/2/66
Copper-64	5/2/66	Tantalum-182	Proposed
Copper-67	Proposed	Tellurium-125m	Proposed
Gallium-72	Proposed	Thallium-204	Proposed
Gold-198	5/2/66	Thulium-170	Proposed
Gold-199	5/2/66	Thulium-171	Proposed
Iodine-125	10/1/63	Tin-113	4/18/65
Iodine-130	Proposed	Tungsten-185	Proposed
Iodine-131	10/1/63	Tungsten-187	Proposed
Iridium-192	3/68	Tungsten-188	Proposed
Iridium-194	Proposed	Zinc-65	4/18/65
Iron-55	6/23/64		

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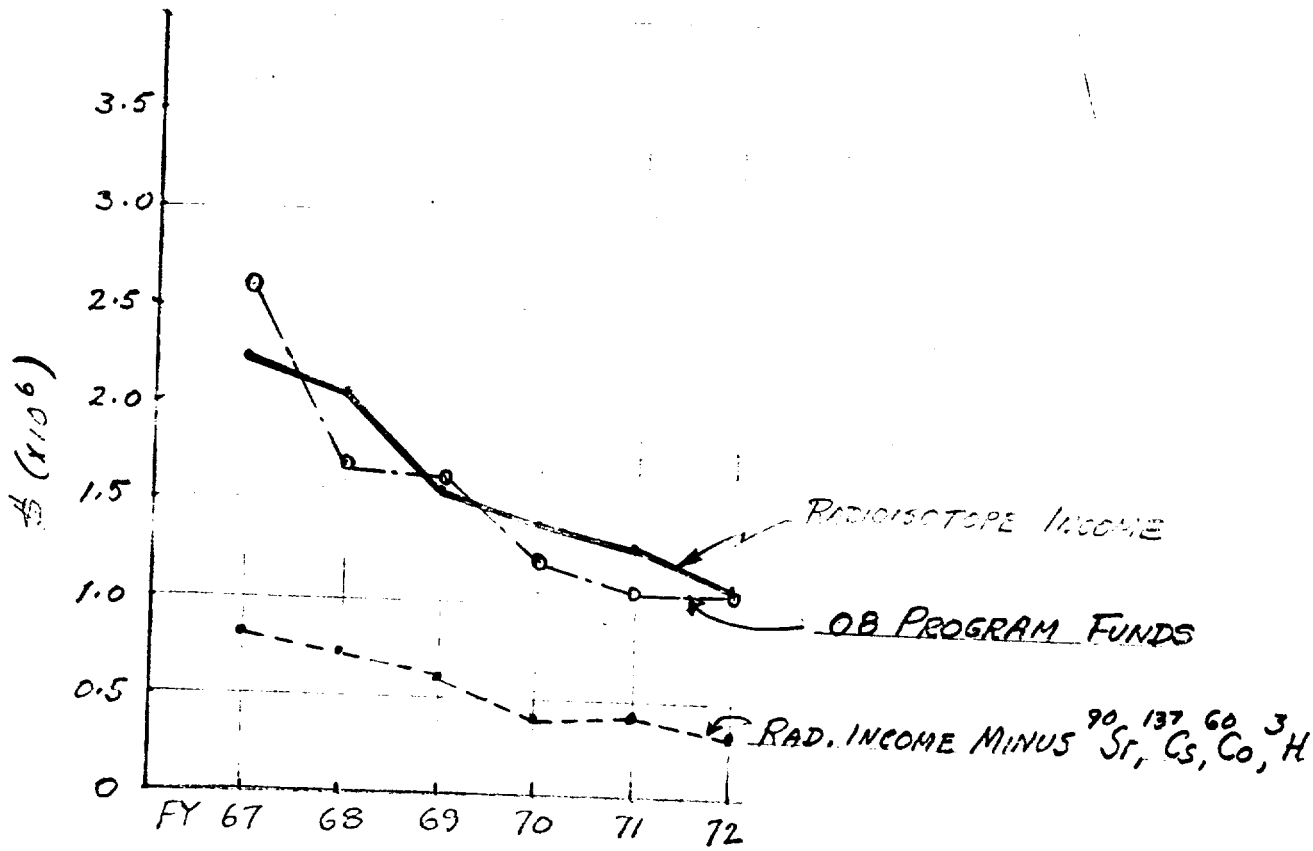

Fig. 2.

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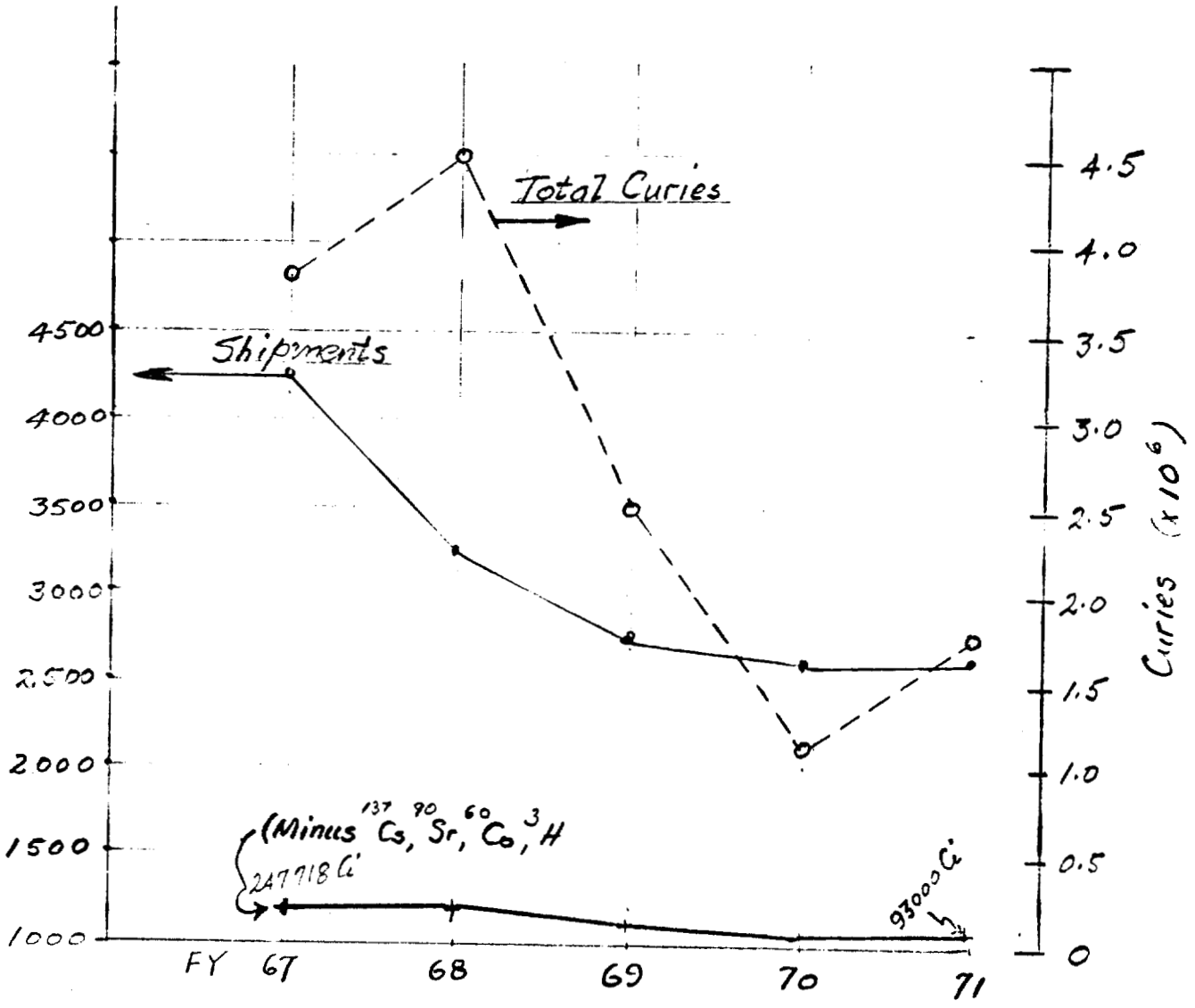

Fig. 3. Radioisotope Shipments and Curies.

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About 1967 the responsibility for isotopic power research and development (except basic radioactive materials and sales technical services) was transferred from 08 Program to 04 Program. There was a short spurt of activity that peaked in 1968 (Fig. 4). A description of the isotopic power program is given later in these notes under "Isotopic Power Programs."

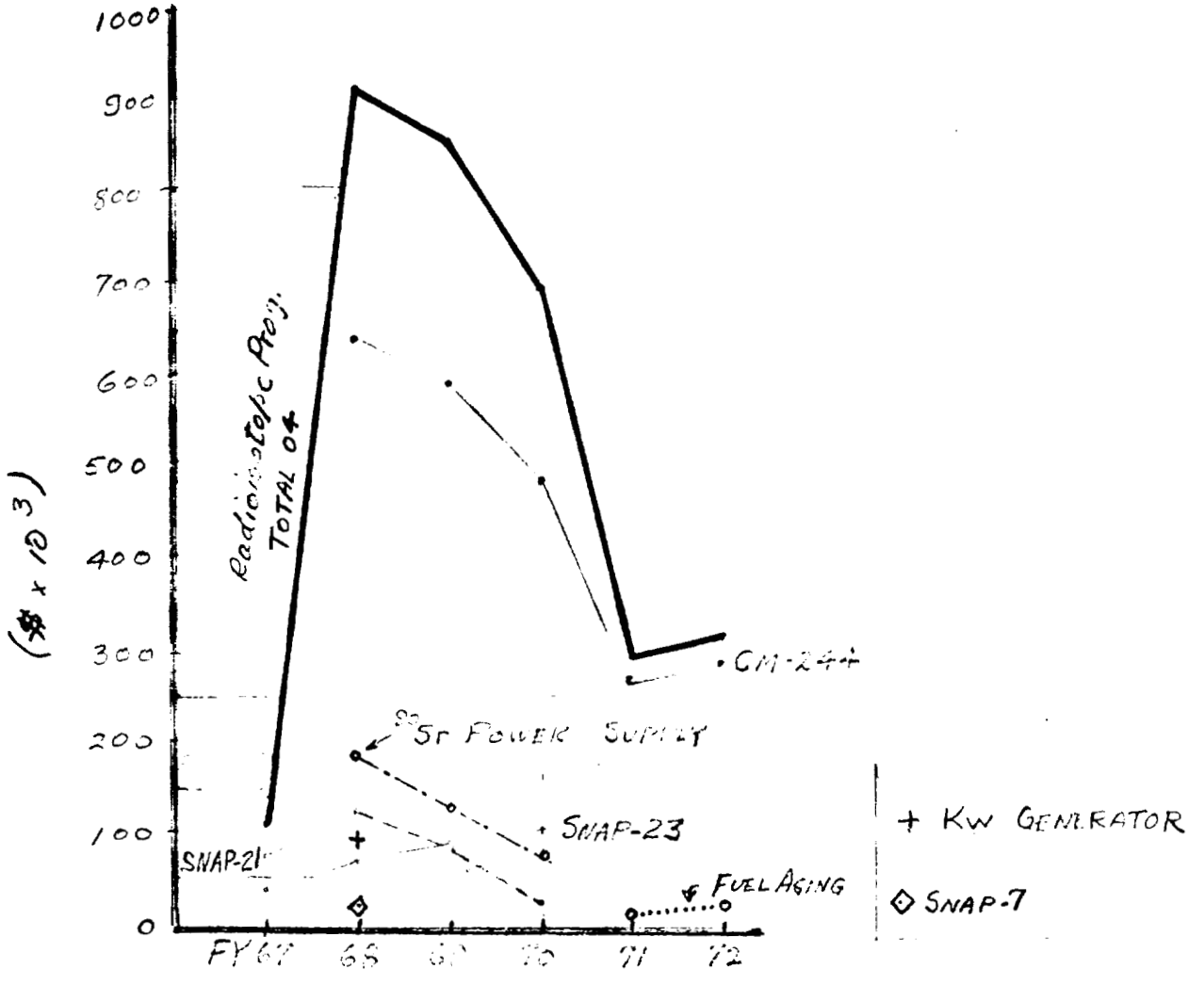

Fig. 4. 04 Funds, Radioisotope Program.

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Radioisotope Production

Radioisotope Production Functions

Radioisotopes are produced at ORNL in reactors (ORR and HFIR) and the ORNL 86-Inch Cyclotron. Fission products ^{137}Cs and ^{90}Sr are shipped from Hanford to ORNL's Fission Product Development Laboratory where chemical processing and source fabrication procedures convert them to radiation and heat sources. Radioisotopes produced by reactor or cyclotron irradiation require preparation of target material, encapsulation for irradiation, and chemical processing following irradiation. In some cases a valuable reactor-produced material (^{36}Cl) or enriched isotope is used as target material and must be recovered for recycling. The radioisotope sales and related business activities for ORNL and other AEC sites (except ^{252}Cf) are administered by ORNL.

Fission Product Development Laboratory

The Fission Product Development Laboratory (FPDL) began operations in 1958 to demonstrate the separation of ^{90}Sr, ^{137}Cs, ^{144}Ce, ^{106}Ru, ^{99}Tc, and ^{147}Pm from fuel reprocessing waste and to provide useful forms of these radioisotopes for development of applications. When fission product waste was no longer available at ORNL, a technique was developed cooperatively with Hanford to ship purified ^{90}Sr and unpurified ^{137}Cs to ORNL for further processing. Since beginning operation, FPDL has processed 7.0×10^6 Ci of ^{90}Sr and 4.5×10^6 Ci of ^{137}Cs to produce heat and radiation sources.

The FPDL consists of 15 heavily shielded cells in the main cell block and auxiliary cells for storage, sampling, analytical work, and scrubbing of effluent air. The ^{137}Cs and ^{90}Sr feed streams are chemically processed to form $^{137}CsCl$, $^{90}SrTiO_3$, or ^{90}SrO. Further mechanical operations performed in manipulator cells include hot pressing to form dense pellets, encapsulation by welding, and quality assurance inspection of the containers.

The present production capacity of FPDL is 2×10^6 Ci of ^{90}Sr and 1×10^6 Ci of ^{137}Cs annually and has been sufficient to supply customers' requirements in a wide range of source designs and specifications. Future

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requirements forecast by the Navy indicate a total of 35 x 10^6 Ci of ^{90}Sr must be processed to fabricate heat sources from FY 1972 through FY 1977. The FPDL production rate can be increased to 10 x 10^6 Ci of ^{90}Sr annually to meet these forecast requirements by converting to four-shift, seven-day-per-week operation. The necessary shipments from Hanford can be made in existing HAPO-type casks. Forecast ^{137}Cs demand indicates a processing rate of 200,000 Ci annually will be sufficient during this period.

Additional production capacity can be achieved by modifications to FPDL equipment and fabrication of additional shipping casks that would increase the processing rate to 10 x 10^6 Ci of ^{90}Sr and 5 x 10^6 Ci of ^{137}Cs annually. The capital cost of these modifications and casks is estimated to be $1,600,000 and the operating cost of the modified plant is estimated to be $2,000,000 annually compared to $900,000 annually in the present operating mode. Thus, in one decade 100 megacuries of ^{90}Sr and 50 megacuries of ^{137}Cs could be processed to packaged forms at a total operating cost of $20,000,000 and capital cost of $1,600,000.

Once the source material ($^{90}SrTiO_3$ or $^{137}CsCl$) is made, the cost of fabricating a source unit is very dependent on source design, capsule material, and specifications required by the customer. In the case of ^{90}Sr heat sources the capsule material is Hastelloy C-276, and the cost of machined capsule prior to any hot cell operations is a substantial part of the source fabrication costs. The cost breakdown of a recent quotation illustrates this point:

Basic Machined Capsule	$1870	27%
Encapsulation Costs (hot cells)	4950	73%
Total	$6820	

The encapsulation costs can be further broken down according to hot cell and support operations as shown in Fig. 5. The effect of quality assurance requirements on total source cost can be seen in the percentage (24%) assigned to this operation.

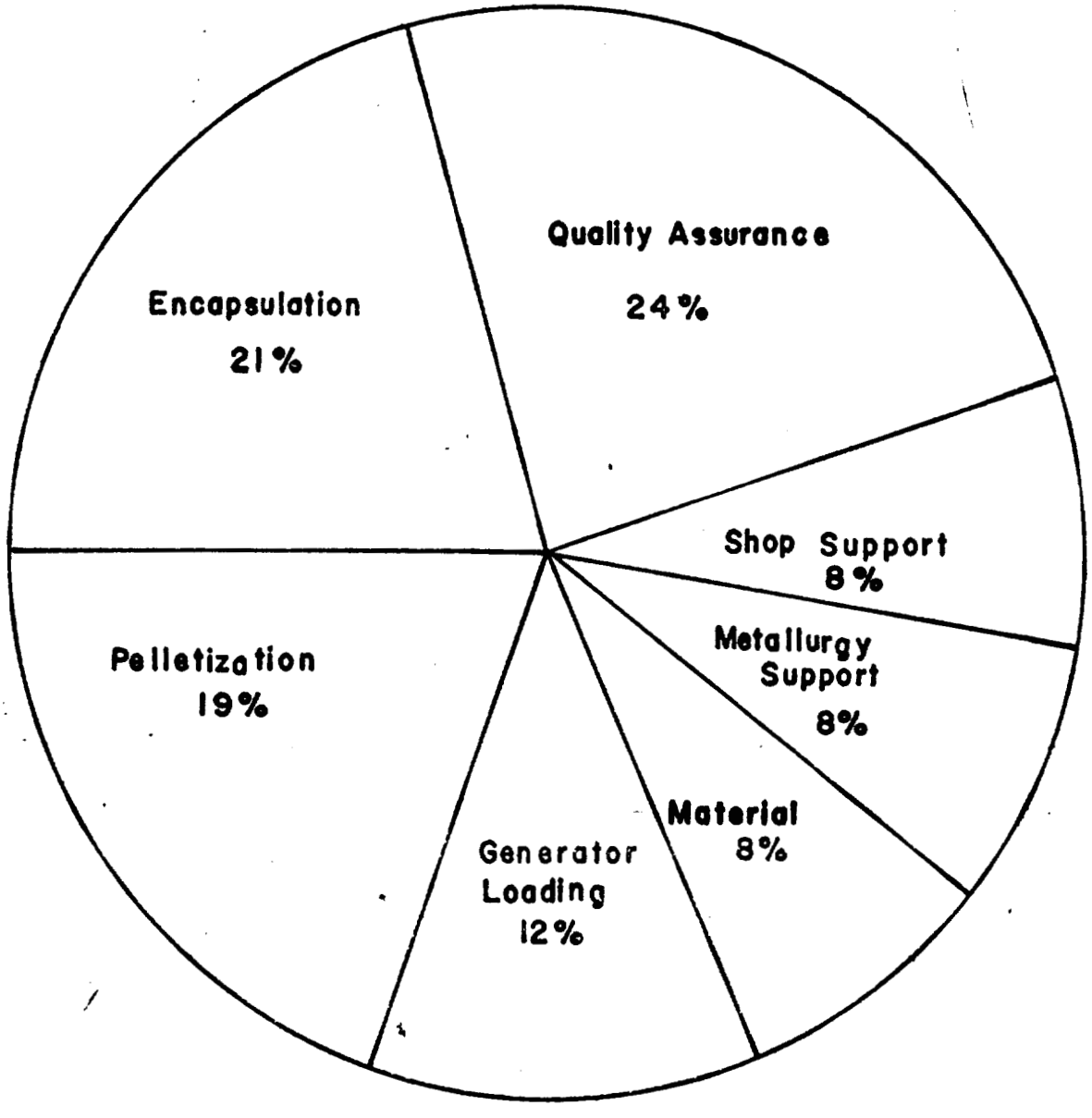

Fig. 5. Source Fabrication Cost.

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Radioisotope Development

Division of Isotopes Development (08) Programs

The ORNL development programs funded by the AEC Division of Isotopes Development include the general divisions of Reactor Products, Accelerator Products, Fission Products, Source Development, Radioisotope Safety, Technology Utilization, and Oceanographic and Natural Resources Study. Task summaries of work in these programmatic divisions in the FY 1971 through FY 1973 period are given in Attachment 1.

Isotopic Power Programs

At present the only isotopic power program at ORNL is the Curium-244 Fuel Development Program funded by the AEC Division of Space Nuclear Systems. Prior to FY 1971 a Strontium-90 Fuel Development Program was funded by the AEC Division of Reactor Development and Technology. The trend in budget for the total ORNL isotopic power programs is given below for FY 1968 through FY 1972 (the curves in Fig. 4 show budgets for Radioisotopes Program only).

Program	Budget ($ in thousands)				
	FY 68	FY 69	FY 70	FY 71	FY 72
Curium-244 (DSNS)	1,028	950	690	350	350
Strontium-90 (DRD&T)	660	390	340	-	-
Total	**1,688**	**1,340**	**1,030**	**350**	**350**

The cessation of funding for the Strontium-90 Isotopic Power Program has resulted in stoppage of development work with incomplete data on ^{90}SrO for full approval of its use in isotopic power generators. The ^{90}SrO fuel form is much desired because its higher power density results in lighter shields than is the case for $^{90}SrTiO_3$. In addition, no work has been done in the $^{90}SrF_2$ form which will be available from the Hanford Waste Management Plant as a potential fuel form. Budget estimates for continuation of ^{90}Sr isotopic power fuel development are currently being formulated by the Division of Isotopes Development with input from ORNL.

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The Curium Isotopic Power Program, originally concerned with ^{242}Cm, is currently based on ^{244}Cm. The purpose of this program is to develop, characterize, demonstrate the feasibility of, and develop the availability of ^{244}Cm as an isotopic power fuel. Curium-244, an alpha emitter having an 18.4-year half-life will have a potential availability in multi-kilowatt quantities as a by-product of power reactor operation beginning in FY 1975. Curium-244 is presently considered the only potential back-up fuel to ^{238}Pu for aerospace applications. In future years, ^{244}Cm can exceed ^{238}Pu in availability from power reactor operations and can be two to five times less costly than ^{238}Pu on a thermal watt basis. Curium-244 isotopic power fuel will be required to satisfy demand for dependable power in earth satellites performing functions such as weather observation, communication, and DOD space missions. The fuel is particularly useful in applications needing high power density to achieve high temperatures, to minimize shielding and converter weight by permitting smaller systems than obtainable with ^{238}Pu, and to maximize safe containment of the fuel by inclusion in a metal matrix. Beginning in the second half of FY 1971, the program has been oriented to develop fuel for silicon-germanium thermoelectric converters of the Multi-Hundred Watt type with the objective of fabricating a flight-qualified heat source in FY 1975. Curium-244 will be shipped from Savannah River Laboratory to ORNL at the rate of 1 kg/year beginning in FY 1973 so that sufficient fuel for three Multi-Hundred Watt Converters [2200 W(th) each] will be accumulated by the end of FY 1975. In the second half of the 1970 decade, it is anticipated that ^{244}Cm will be recovered from power reactor fuel by commercial operators for the fabrication of additional power sources.

The program includes development of fuel forms of all types of power conversion systems with specific emphasis on Multi-Hundred Watt and Isotope Brayton applications.

The program objectives are as follows: (1) selection of a curium fuel form and encapsulating materials, (2) development of processes for compound preparation, (3) development of source form fabrication techniques, (4) determination of chemical and physical properties of the compound source form and capsule, (5) investigation of shielding requirements,

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(6) development of encapsulation techniques, (7) development of quality control procedures, (8) prototype fabrication and testing, and (9) preparation of comprehensive reports.

Coordination with other programs involved in advanced isotopic space power technologies is provided, including interfacing with the AEC Division of Biology and Medicine in their studies on ^{244}Cm radiation effects in mammals.

The program also provides consultation on potential uses of ^{242}Cm as a source of power and as a means to accelerate aging effects in $^{238}PuO_2$ fuel forms. The capability to process multi-gram quantities of ^{242}Cm to the $^{242}Cm_2O_3$ fuel form is provided in the Source Fabrication Facility.

The breakdown of tasks to be worked on during the FY 1972 through FY 1973 period is tabulated below.

	Begin	End
CURIUM-244 OXIDE CHARACTERIZATION		
Baseline Compatibility	Before FY 1971	June 1972
Helium Release	Before FY 1971	October 1971
Heat Capacity of $^{244}Cm_2O_3$	July 1970	March 1972
Phase Transition in $^{244}Cm_2O_3$	Before FY 1971	October 1970
Viscosity, Heat of Fusion, Surface Tension, and Emissivity	July 1972	June 1973
CERMET AND INTERMETALLIC FUEL FORMS DEVELOPMENT AND CHARACTERIZATION		
Basic Development of Cermet Fabrication Methods	January 1971	July 1973
Investigation of Feasibility of Intermetallic Fuel Compounds	January 1971	June 1972
Baseline Compatibility of Cermets and Intermetallics	January 1972	June 1974
Shielding and Radiation Studies	July 1972	June 1974
Advanced Development of Intermetallic Fuel Compounds	July 1972	June 1975
ENVIRONMENTAL EFFECTS		
Solubility and Leach Rate of $^{244}Cm_2O_3$	October 1970	December 1971
Solubility and Leach Rate of Cermets	July 1972	December 1973

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	Begin	End
ENVIRONMENTAL EFFECTS (continued)		
Vapor Transport of $^{244}Cm_2O_3$	Before FY 1971	December 1970
Air Oxidation Cermet Fuel Forms	January 1972	June 1974
Fuel Form Impact Testing (Screening Phase)	July 1971	December 1973
CURIUM-244 FUEL APPLICATIONS		
Multi-Hundred Watt Curium Source Design Study	July 1970	December 1972
Prototype Multi-Hundred Watt Curium Fueled Source	July 1972	June 1975
$^{244}Cm_2O_3$ Heat Source Test [1000 W(th)]	Before FY 1971	December 1972
Curium-244 Supply and Economics	October 1971	Beyond FY 1973

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ATTACHMENT 1

08 PROGRAM TASK SUMMARIES

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Date April 23, 1971

REACTOR PRODUCTS 08 01 01	Begin	End	Annual Manyears	Estimated Total Cost of Task
EXPLORATORY DEVELOPMENT OF PRODUCTS AND TECHNIQUES				
Lanthanum-137	FY 70	FY 73	0.2	$40,000

Status: ^{137}La (6×10^4 y) is suitable for resonant absorption applications of the Mössbauer technique using the 9-hr ^{137}Ce parent as the exciting source. Procedures have been developed for irradiating enriched $^{136}CeO_2$, separating the ^{137}La decay product of ^{137}Ce by low pressure ion exchange, and recovering the enriched target. Future work will include optimization of separation and irradiation procedures and the supply of ^{137}La to cooperative researchers for evaluation.

Platinum-195m	FY 72	FY 75	0.5	$100,000

Status: ^{195m}Pt (4.1 d) is the optimum platinum radionuclide for investigating the mechanism involved in the therapeutic effect of certain platinum compounds on specific tumors. Determination of production cross sections, characterization of product activities, and preparation of radionuclide compounds for medical researchers will begin in FY 72. Future work will include pilot production of ^{195m}Pt and development of additional compounds for cooperative medical research programs.

Barium-135m	FY 70	FY 77	0.3	$120,000

Status: ^{135m}Ba (28.7 h), because of its gamma ray of 268 keV and its chemical similarity to calcium, is an excellent diagnostic bone-scanning agent. Preparations of ^{135m}Ba having a specific activity of 35 mCi/mg barium have been made and supplied to three medical institutions for evaluation. Future work will include continued supply to medical institutions, optimization of production techniques, and assessment of nuclear recoil as a technique for preparation in low flux reactors.

Multiple Neutron Capture Products	FY 65	Continuing	0.4	~$250,000

Status: Long-term (years) irradiations in very high neutron fluxes are used to produce the desired radionuclides. Targets have been irradiated for the production of ^{32}Si (~650 y) by the $^{31}P(n,\gamma)^{32}P(n,p)^{32}Si$ and $^{30}Si(2n,\gamma)^{32}Si$ reaction paths, and ^{188}W (69 d) by the $^{186}W(2n,\gamma)^{188}W$ reaction path. Future work will include ^{46}Ca, ^{60}Fe, ^{182}Hf, ^{41}Ar, ^{126}Sn, and ^{194}Os.

Table of Reactor-Produced Radionuclides	FY 72	FY 73	0.2	$20,000

Status: Calculations of reactor radionuclides will be made to revise and expand the Reactor Yield Calculations originally published as ORNL-IIC-8 (1966).

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REACTOR PRODUCTS 08 01 01	Begin	End	Annual Manyears	Estimated Total Cost of Task
HFIR Production Capabilities	FY 66	Continuing	0.3	~$200,000

Status: Targets have been developed to withstand the severe radiation and temperature environment of the HFIR. Future work will include the utilization of additional irradiation positions in the HFIR to expand the study of production capabilities.

Responsive Exploratory Radioisotope Development	Continuing	Continuing	0.6	-

Status: Work in this category comprises the effort expended in response to requests to the Isotopes Development Center involving exploratory development which is not specifically programmed. In FY 71 work included preparation of ^{97}Ru for a medical cooperative program evaluation and activation of a chromic oxide aerosol for an ORNL lung carcinogenesis program. Future work in this category will be responsive to the needs of research in radioisotope applications.

PHOSPHORUS-33	FY 67	FY 75	0.5	$225,000

Status: ^{33}P (25 d) is useful in autographic studies in the biochemical and physical sciences, for long-term studies in agricultural and environmental work, and double-labeling [with ^{32}P (14.3 d)] of chemical compounds. Production technology was developed to prepare curie batches of ^{33}P containing less than 5% ^{32}P using the $^{36}Cl(n,\alpha)^{33}P$ reaction. Future work will include continued pilot production and improvement and simplification of the process procedure to improve the product and assure routine process reliability.

POTASSIUM-43	FY 68	FY 77	0.4	$200,000

Status: ^{43}K (22.5 h) has been shown through medical cooperative programs to be an excellent tool for studying blood flow through the heart and for diagnosing myocardial infarctions. Procedures have been developed for reactor preparation by the $^{43}Ca(n,p)^{43}K$ reaction on isotopically enriched ^{43}CaO targets and for separation of the ^{43}K by an ion-exchange technique and recovery of the ^{43}CaO target for further reactor irradiations. Future work will include studies to scale up production rates to make possible full-scale clinical evaluation and to obtain additional production data for economic evaluation of the process.

THULIUM-170	FY 68	FY 72	1.3	$325,000

Status: ^{170}Tm (128.5 d) has potential for application as an isotopic power source by virtue of its high power density and stable Tm_2O_3 compound. The physical and chemical properties of $^{170}Tm_2O_3$ such as reactor cross sections for production of ^{170}Tm, densification of Tm_2O_3 by hot pressing, thermal conductivity, solubility in distilled and sea water, and compatibility with metal and alloy containers have been investigated. Future work will include measurement of the vapor pressure of Tm_2O_3, completion of the compatibility experiments, and completion of a summary of the AEC sponsored work on this task.

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REACTOR PRODUCTS 08 01 01	Begin	End	Annual Manyears	Estimated Total Cost of Task
CHLORINE-36	FY 66	FY 75	0.1	$50,000

Status: ^{36}Cl (3×10^5 y) is the only radioisotope of chlorine with a sufficiently long half-life for general tracer applications and is the preferred reactor target for production of ^{33}P by the $^{36}Cl(n,\alpha)^{33}P$ reaction. Exposure of KCl targets to high neutron fluences has demonstrated the potential for preparation of 65-70% isotopic abundance material. Future work will include measurement of the reactor cross section of ^{36}Cl and continued long-term reactor irradiations to produce ^{36}Cl suitable for ^{33}P production.

EUROPIUM-155	FY 72	FY 73	0.2	$20,000

Status: ^{155}Eu (5 y) is useful as a low energy (80-102 keV) gamma source if produced free of ^{152}Eu and ^{154}Eu. Reactor irradiation of high-purity enriched ^{154}Sm has been made to study the production of ^{155}Eu as a decay product of ^{155}Sm. Future work will include determination of reactor cross sections and chemical process to optimize the yield and purity of the ^{155}Eu.

GADOLINIUM-153	FY 69	FY 76	1.0	$400,000

Status: ^{153}Gd (240 d, 100-kev photon) has many potentially important and varied applications such as in medicine for scanning the heart, lungs, and bones; in industry for control devices; and in secondary x-ray analytical instruments. Methods to produce ^{153}Gd have been developed, procedures standardized, and source fabrication methods investigated. Future work will involve preparation of an inventory to supply present and near future requests and measurement of source output characteristics.

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ACCELERATOR PRODUCTS 08 01 02	Begin	End	Annual Manyears	Estimated Total Cost of Task
EXPLORATORY DEVELOPMENT OF PRODUCTS AND TECHNIQUES				
Cesium-129	FY 68	FY 75	0.1	$40,000

Status: ^{129}Cs (32.3 h) decays by electron capture to yield moderate energy photons suitable for scanning or imaging for medical diagnostic studies of blood flow, myocardium infarctions, and tumor imaging. Procedures have been developed for production by the $^{129}Xe(p,n)^{129}Cs$ reaction. Future work will include preparation of high purity ^{129}Cs from an enriched ^{129}Xe target and supply to medical cooperative participants for clinical evaluation.

Bismuth-206	FY 72	FY 75	0.3	$60,000

Status: ^{206}Bi (6.24 d) decays by electron capture and positron emission to yield relatively high-energy photons (800-900 keV) normally difficult to scan with present systems, but recent scanning system improvements make possible the use of this radionuclide to delineate brain tumors now poorly visualized by available radionuclides. Investigations have shown the $^{207}Pb(p,2n)^{206}Bi$ reaction most suited to prepare a product of acceptable purity. Future work will include further development of the $^{207}Pb(p,2n)$ target reaction and chemical purification of ^{206}Bi products for supply to medical cooperative participants for evaluation.

RADIONUCLIDES FOR BONE SCANNING

Neodymium-140	FY 72	FY 73	0.2	$20,000

Status: ^{140}Nd (3.37 d) is potentially useful in the form of a chelate for deposition in the bone to locate lesions by detection of the 511-keV annihilation radiation from its daughter product ^{140}Pm (3.39 m). Only very preliminary work has been done on the preparation by the $^{141}Pr(p,2n)^{140}Nd$ reaction and chemical recovery by ion-exchange techniques. Future work will include development of more efficient ^{141}Pr cyclotron targets, improved separation procedures by high-pressure ion-exchange equipment, and supply of ^{140}Nd products to medical cooperative participants for evaluation.

Barium-133m	FY 71	FY 73	0.1	$15,000

Status: ^{133m}Ba (38.9 h) can be produced in high specific activity and could be a desirable alternative to reactor-produced ^{135m}Ba (28.7 h) which has been shown to be useful as a bone-scanning agent but has practical production limitations due to the high toxicity of barium. A process has been developed for production by the $^{133}Cs(p,n)^{133m}Ba$ reaction and subsequent chemical separation. Future work will include further production experience and supply of ^{133m}Ba products to medical cooperative participants for clinical evaluation.

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ACCELERATOR PRODUCTS 08 01 02	Begin	End	Annual Manyears	Estimated Total Cost of Task
Lead-203	FY 71	FY 73	0.1	$15,000

Status: ^{203}Pb (52.1 h) has potential application as a bone-scanning agent having low patient radiation dose decay characteristics. A process was developed for the preparation by the $^{203}Tl(p,n)^{203}Pb$ reaction and chemical separation of the product. Future work will include supply of ^{203}Pb products to medical cooperative participants for evaluation and investigation of the $^{204}Pb(p,2n)^{203}Bi \xrightarrow{EC,\beta^+} {}^{203}Pb$ production reaction to determine if production rates can be increased.

CYCLOTRON TARGET DEVELOPMENT	FY 72	Continuing	0.2	~$75,000

Status: Cyclotron target design optimization is important to the utilization of high-current, high-energy internal beams where large-scale production and efficient use of machine time can lead to economic production of radionuclides of high radionuclidic purity by use of isotopically enriched targets. Future work will include development and testing of efficient, economical targets for the (p,2n) reaction for the preparation of ^{140}Nd, ^{203}Pb, ^{206}Bi, and ^{67}Ga.

SPALLATION PRODUCTION	FY 72	Continuing	0.5	-

Status: The near future availability of high-intensity, high-energy (200 keV) proton beams at the BLIP facility, Brookhaven National Laboratory, will be utilized to produce radionuclides for physical, biological, and medical research that are not readily produced by either conventional accelerators or nuclear reactors. Future work will include irradiation of targets in BLIP and development of chemical processes for the preparation of ^{26}Al, ^{32}Si, ^{42}Ar, ^{72}Se, ^{82}Sr, ^{83}Rb, ^{118}Te, ^{172}Hf, ^{188}Pt, ^{194}Hg, and ^{202}Pb.

GALLIUM-67	FY 70	FY 76	0.5	$175,000

Status: ^{67}Ga (78.2 h) application to diagnostic medicine has been spurred by clinical evidence obtained, through the DID-ORNL medical cooperative program, that it has a high uptake in lymphoid tumors in both animals and humans. Pilot production by the $^{68}Zn(p,2n)^{67}Ga$ reaction and chemical separation of high-purity products have been demonstrated and ^{67}Ga products supplied to approximately 20 medical cooperative program participants. Future work will include continued pilot production to supply the intensified clinical evaluation program and improved accelerator targets will be tested and evaluated aimed at increased yields and lower unit costs.

INDIUM-111	FY 70	FY 76	0.2	$70,000

Status: ^{111}In (2.81 d) has been suggested for medical applications in studies such as spinal-cerebral cisternography, aerosol lung studies, brain scanning, and tumor localization because of its suitable half-life and low-energy photons ideally suited for external detection by scanning equipment in common use. A procedure has been developed for the preparation from enriched isotopic targets by the $^{111}Cd(p,n)^{111}In$ reaction and chemically purified products distributed to medical groups for evaluation. Future work will include continued pilot production to supply users this special research material.

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ACCELERATOR PRODUCTS 08 01 02	Begin	End	Annual Manyears	Estimated Total Cost of Task
RUBIDIUM-84	FY 71	FY 72	0.1	$10,000

Status: ^{84}Rb (33 d) is useful for myocardial scanning with positron cameras to detect heart function defects. An improved accelerator target of enriched ^{84}Kr has been developed to increase the production rate by the ^{84}Kr(p,n)^{84}Rb reaction and increase the radioisotopic purity of the product. Future work will determine the target depletion rate and develop improved target gas handling methods.

CARBON-11	FY 71	FY 77	0.2	$70,000

Status: ^{11}C (20.4 m) is a valuable radionuclide for diagnostic and experimental studies involving blood flow rates, ventilation capacity, and other physiological information. The feasibility of producing multicurie amounts of ^{11}C by the ^{11}B(p,n)^{11}C reaction has been demonstrated. Future work will involve accelerator equipment development and production experiments aimed at establishing a cooperative medical evaluation program.

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FISSION PRODUCTS 08 01 03	Begin	End	Annual Manyears	Estimated Total Cost of Task
PRODUCTION AND MATERIALS STUDIES				
Fission Products from Power Reactor Fuel Reprocessing	FY 71	Continuing	1.0	-

Status: Valuable radioactive and stable nuclides are formed in the reactor fuels that can be recovered in fuel reprocessing plants for beneficial applications; four such materials are ^{85}Kr, stable xenon, ^{137}Cs, and ^{90}Sr. Xenon has been purified to less than 1 μCi of ^{85}Kr per liter for anesthesia testing. Cesium-137 recovery and purification technology was reviewed and related to private reactor fuel reprocessing facilities to assess potential for future supply. Future work will include development of method for recovery of ultra-pure xenon and study of methods for recovery and purification of fission products as applied to private power reactor fuel reprocessing.

Fission Product Development Laboratory Operations Assistance	Continuing	Continuing	1.5	-

Status: The FPDL operation provides megacurie quantities of ^{137}Cs and ^{90}Sr as $^{137}CsCl$, $^{90}SrTiO_3$, $^{90}Sr_2TiO_4$, and ^{90}SrO in encapsulated source forms for use in the development of irradiation and isotopic power systems. Development of process techniques (compound formation, pellet fabrication, welding, weld inspection) is a continuing effort to provide specialized product forms of highest reliability. Technical assistance is provided to organizations developing applications for ^{137}Cs and ^{90}Sr, including determination of critical data, such as compatibility, where needed for definition of reliable and safe operation of systems utilizing these source materials.

CESIUM-137 GAMMA SOURCE DEVELOPMENT

Cesium Compound Development	FY 70	FY 77	0.5	$200,000

Status: Cesium-137 (30 y) is now used principally for gamma-ray sources in the form of encapsulated $^{137}CsCl$; however, some potential future applications may require a ^{137}Cs source compound with greater thermal stability and low solubility in water. Methods are being developed for the preparation and characterization of $CsNbO_3$, $CsTaO_3$, and various phosphate compounds. Future work will include selection of one or two promising cesium compounds and development of pilot-scale production processes and further characterization of their properties.

CsCl Source Form Development	FY 72	FY 75	0.5	$100,000

Status: Coating of $^{137}CsCl$ particles with inert materials offers a possible means of increasing the thermal and solubility resistance of $^{137}CsCl$ source forms. Future work will include development of coating techniques and evaluation of the fuel forms.

KRYPTON-85 ENRICHMENT

Pilot Production of Enriched Krypton-85	FY 67	FY 75	1	$400,000

Status: The enrichment of the ^{85}Kr radioisotope in fission krypton from ~5% to 15-50% enhances its usefulness by making possible the design of more compact sources. A thermal diffusion pilot has been operated for the past 3 years to demonstrate this

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FISSION PRODUCTS 08 01 03	Begin	End	Annual Manyears	Estimated Total Cost of Task

KRYPTON-85 ENRICHMENT

Pilot Production of Enriched Krypton-85 (continued)

method of enrichment and to provide sufficient quantities of enriched ^{85}Kr for use in developing applications. Operation of this plant will continue to obtain engineering data that will be necessary if a full-scale plant is built and to build up the inventory of enriched material for applications development.

Test Column Operation	FY 71	FY 75	0.25	$63,000

Status: The separation forces involved in isotopic separation by thermal diffusion are very weak and small changes in operating conditions such as pressure, temperature, etc. may produce a large effect on the time required to achieve a separation. Two single tube test columns have been installed to investigate these effects and provide design data for future production type units. These columns will be operated with both stable and radioactive krypton to determine if the presence of radioactive gas ions affects separation efficiency.

KRYPTON SOURCE DEVELOPMENT

Krypton-85 Heat Source	FY 72	FY 74	0.3	$50,000

Status: Krypton-85 is of interest as a heat source for small power production units because it will be available in large quantities at low cost from reactor fuel reprocessing operations and it has a low biological hazard potential compared to other radioisotopes used for this purpose. A heat source capable of operation at 600°C will be designed, built and loaded with stable krypton, and tested in a tested in a furnace. Based on the results of this experiment and compatibility tests, a source containing radioactive krypton will be designed and built.

Krypton-85 Light Source	FY 72	FY 73	0.2	$20,000

Status: The use of ^{85}Kr stimulated phosphors in small light sources would be an advantage because of the potential for greater light intensity and a longer useful life than some of the other radioisotopes used for this purpose. Foils will be impregnated with ^{85}Kr by ion bombardment and then coated with various phosphors. The light intensity and release of ^{85}Kr will be measured as a function of time and temperature.

Krypton-85 Beta Battery	FY 72	FY 73	0.1	$10,000

Status: Long-lived, high voltage, low current batteries can be made by collecting the electrons emitted during the beta decay of a radioisotope. Foils will be impregnated with ^{85}Kr by ion bombardment and wrapped in a spiral configuration with an insulator and electron collector foil. The electrical characteristics will be measured as a function of time.

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FISSION PRODUCTS 08 01 03	Begin	End	Annual Manyears	Estimated Total Cost of Task
STRONTIUM-90 SILICATE BETA SOURCES	FY 67	FY 71	1.6	$400,000

Status: Strontium-90 (^{90}Sr, 28 y; ^{90}Y, 64.4 h) beta sources are useful for medical irradiators in eye and skin cancer treatment, for various industrial gaging and control devices, and for thin film irradiators. Methods to synthesize strontium silicate glass beads and to encapsulate these beads in metal matrix were developed to increase the safety and radiation output of these sources. The development program has provided methods to fabricate ^{90}Sr beta sources that are structurally rugged, have high output, and can be produced in a wide variety of geometrical shapes.

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SOURCE DEVELOPMENT 08 01 04	Begin	End	Annual Manyears	Estimated Total Cost of Task
RADIATION SOURCE DEVELOPMENT				
Gamma and Beta Sources	FY 67	FY 77	0.75	$375,000

Status: Encapsulated sources have formed the basis for a growing segment of the private nuclear industry. Methods have been developed to fabricate sources that have energy spectra output characteristics needed to meet the needs of the space technology, national defense, and industry. Future development will involve methods to upgrade safety characteristics and to obtain radiation output data needed to maintain the industrial growth in the utilization of gamma and beta sources.

Secondary X-Ray Sources	FY 69	FY 79	0.5	$250,000

Status: Secondary x-ray sources are used in devices to analyze for trace elements in process streams and in situ devices such as the analysis of rock dust, coal dust mixtures in the safety management of coal mines. Investigation of methods to increase the yield of secondary x rays and to measure their spectral characteristics have been carried out for various targets, using ^{147}Pm, ^{241}Am, and ^{85}Kr as the activating source material. Future work will continue this investigation to encompass additional radionuclides and to produce fabrication technology and data needed to extend the application of fluorescent x rays, especially to medical diagnosis and measurement of heavy metal pollutants in water.

Alpha Sources and Alpha Excited Secondary X-Ray Sources	FY 69	FY 79	0.25	$125,000

Status: Alpha sources have wide application in the calibration of instruments for the nuclear industry. Plated sources of ^{242}Cm and ^{244}Cm have been prepared and very thin window materials of nickel, aluminum, and gold studied. Future investigations will continue to develop methods for increasing the safety characteristics of alpha sources and the measurement of output characteristics of primary and secondary radiations.

RADIOISOTOPE SAFETY				
Radioisotope Source Safety Testing	Continuing	Continuing	1.5	–

Status: The design of radioisotope sources is largely dictated by safety considerations. Source capsules of various types are subjected to mechanical and temperature tests to obtain information for manufacturers, users, and regulatory groups concerning the containment limitations of the design. Routine testing of both sealed and unsealed sources will continue and studies of the effects of manufacturing defects will be used to recommend quality assurance procedures.

Radioactive Material Shipping Containers	Continuing	Continuing	0.1	–

Status: For the safety of the public, shipping containers must be designed to withstand the effects of transportation accidents without releasing any of the radioactive contents. Shipping container designs are reviewed and prototypes tested to verify their containment integrity.

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SOURCE DEVELOPMENT 08 01 04	Begin	End	Annual Manyears	Estimated Total Cost of Task
RADIOISOTOPE CHARACTERIZATION, QUALITY CONTROL, AND STANDARDS	Continuing	Continuing	1	-

Status: The efficient utilization of radionuclides requires the best possible information on modes and energies of decay and half-life of each nuclide as well as the accurate analysis of each preparation. Analytical techniques for quality control of radioisotope products have been developed; data on 60 nuclides were prepared for a paper in Nuclear Science and Engineering, and intercomparison studies of numerous radioisotope standards have been made. Future work will be similar and will continue to include responses to consumer questions and process problems.

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TECHNOLOGY UTILIZATION 08 01 05	Begin	End	Annual Manyears	Estimated Total Cost of Task
ISOTOPES INFORMATION CENTER	Continuing	Continuing	5	-

Status: The Isotopes Information Center activities comprise surveying the available nuclear-applications-oriented literature, accessioning relevant material, and dissemination of information on request and by special reports. Information sources published as the ORNL-IIC series are typified by Special Sources of Information on Isotopes (ORNL-IIC-12) and Isotope User's Guide (ORNL-IIC-19). Future work will include continuation of the information service to isotope users and the staff function to DID for reporting, editorial assistance, and information activities.

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RADIOISOTOPES SYSTEMS DEVELOPMENT 08 03 03	Begin	End	Annual Manyears	Estimated Total Cost of Task
OCEANOGRAPHIC AND NATURAL RESOURCES STUDY				
Sand Transport Study	FY 68	FY 73	1	$300,000

Status: Sand transport is a national problem since beach erosion, harbor maintenance, and coastal land development are affected by this natural phenomenon, and little is known concerning the fundamental mechanism of transport. Methods for tagging sand particles with radionuclides were developed at ORNL; and an underwater radiation survey system, capable of synoptic measurement of tagged sand in the swash zone, the breaker zone, and deep water of the ocean, has been developed cooperatively with the U. S. Army Corps of Engineers. Future development extending the technology to encompass the measurement of volume transport rates of sand moving along the coasts is planned.

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