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**A RESEARCH REPORT FOR
ROCKWELL HANFORD OPERATIONS**

**Potential Value of
Cs-137 Capsules**

April 1985

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

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A RESEARCH REPORT FOR
ROCKWELL HANFORD OPERATIONS

POTENTIAL VALUE OF Cs-137 CAPSULES

C. H. Bloomster
D. R. Brown
G. A. Bruno
R. F. Hazelton
P. L. Hendrickson
A. J. Lezberg
G. L. Tingey
G. L. Wilfert

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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

We determined the value of Cs-137 compared to Co-60 as a source for the irradiation of fruit (apples and cherries), pork and medical supplies. Cs-137, in the WESF capsule form, had a value of approximately \$.40/Ci as a substitute for Co-60 priced at approximately \$1.00/Ci. The comparison was based on the available curies emitted from the surface of each capsule. The \$.40 value was approximately the same for each irradiation application. If the value is expressed in terms of total curies contained in the WESF capsule, the value drops to \$.24/Ci since 40% of the curies are absorbed internally.

We developed preliminary designs for fourteen irradiation facilities; seven were based on Co-60 and seven were based on Cs-137. There were three sizes of fruit irradiators, two sizes for pork, and two sizes for medical supplies. These designs provided the basis for estimating capital and operating costs which, in turn, provided the basis for determining the value of Cs-137 relative to Co-60 in these applications.

We evaluated the effect of the size of the irradiation facility on the value of Cs-137. Facility size did not affect the value of Cs-137 except for the smallest facility which was an order-of-magnitude smaller than the other facilities. The indifference value of Cs-137 in the smallest irradiator increased to \$1.12/Ci. The high indifference value for cesium in the smallest plant can be linked to the size of the irradiation chamber and source replenishment. A cesium source irradiation chamber costs about 25% less than a cobalt irradiation chamber. Although this cost advantage for cesium exists for all of the plant sizes, the advantage is magnified for a small plant because the irradiation chamber becomes a much larger part of the total plant capital cost. Cesium also has an advantage in small plants due to the fixed costs associated with the transportation and installation of replacement sources. Full transportation and cask rental charges must be paid regardless of the number of curies purchased. Similarly, installation costs vary little with the quantity of curies handled. Although small shipments of cesium are also relatively expensive, the cost effect is less because cesium sources are replenished every fifth year, while cobalt sources are replenished annually.

The cost of irradiation is low compared to the value of the product. Irradiation of apples for disinfestation costs \$.01-.02 per pound. Irradiation

for trichina-safe pork costs \$.02 per pound. Irradiation of medical supplies for sterilization costs \$.07-.12 per pound.

The cost of the irradiation source, either Co-60 or Cs-137, contributed only a minor amount to the total cost of irradiation, about 5% for the fruit and hog cases and about 20% for the medical supply cases. Thus, the demand for the isotopes should be relatively inelastic, that is, demand should be relatively unaffected by price.

Potential markets for medical supplies and pork are very large. If the entire market potential is realized, the resulting demand for Cs-137 reaches about 700 megacuries by year 2000. The largest potential demand for Cs-137 is medical supplies (469 MCi), followed by pork (204 MCi), followed by Northwest apples and cherries (1.2 MCi). However, the only existing market is for medical supplies. Current FDA regulations do not permit the irradiation of pork or fruit. The largest potential market for irradiated fresh cherries and apples (for disinfestation) is Japan, but Japan does not currently permit the import of irradiated cherries or apples.

In the WESF capsule design about 60% of the total curies are available for irradiation of products; 40% are absorbed internally. Increasing the percentage of curies available for irradiation would directly increase the value of Cs-137 in terms of total curies, but would have little effect on the value in terms of net curies available.

We analyzed the sensitivity of the irradiation costs and Cs-137 value to several key assumptions. The medium-sized fruit irradiator was selected for these analyses. Municipal financing, compared to private financing, reduced irradiation costs about 20% and increased the value of Cs by about \$.06/Ci. Similarly, reducing the real rates of return on debt and equity from the high current values to the long-term historic average reduced irradiation costs about 10% and increased the value of Cs-137 about \$.06/Ci. Allowing a salvage value credit for the unused curies at the end of plant life had a negligible impact on irradiation costs, but increased the value of Cs-137 by \$.08/Ci. Increasing the facility life to 30 years from 15 years reduced irradiation costs about 10% but had little impact on the value of Cs-137. Doubling the Co-60 source cost had little impact on irradiation costs, but, as expected, nearly doubled the value of Cs-137. Escalating the price of Co-60 10% per year (this is the projection by AECL) had little impact on irradiation costs, but increased the value of Cs-137 by \$.05 per Ci. We would expect these

same sensitivity results to apply to the large fruit irradiator and to the two pork irradiators. However, we would expect the medical irradiators to be more sensitive than the other irradiators to the salvage value and Co-60 source value, because of the greater contribution of source costs to production costs in this application.

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INTRODUCTION

The purpose of this study is to determine the value of encapsulated Cs-137 for commercial irradiation applications, specifically the value of the capsule produced by the Waste Encapsulation and Storage Facility (WESF). The value of Cs-137 is determined by its potential substitutability for Co-60. Since Co-60 and Cs-137 are perfect technological substitutes for each other in irradiation applications, the value of Cs-137 can be expressed as a ratio to the value of Co-60. This ratio, called the indifference value, yields an identical cost of irradiation for each isotope. Canada's AECL supplies Co-60 pins commercially to the U.S. market; the current price is near \$1/curie (Ci).

One objective of the study was to determine whether the value of Cs-137 was affected by the type of application. Three irradiation applications were selected for analysis: (1) disinfestation of apples and cherries produced in the Northwest, (2) elimination of trichina in pork, and (3) sterilization of medical supplies. Only medical supplies are currently being irradiated commercially using Co-60.

Another objective was to determine the effect of the capacity of the irradiation facility on the relative value of Cs-137. Three sizes of fruit irradiation facilities and two sizes each for the pork and medical supplies were selected to determine the impact of economies or diseconomies of scale on the cost of irradiation and the value of Cs-137.

Another objective was to assess factors that affect the potential market for irradiated products in each of these applications. This would provide a basis for assessing the potential demand for Cs-137 and Co-60 for these applications. Many other applications for irradiated products have been proposed which might add to the demand, but this study is limited to medical supplies, pork, and apples and cherries produced in the Northwest.

A final objective was to assess the impact of current and probable federal and state regulations on the market for irradiated products.

The potential value for Cs-137 as a substitute for Co-60 is that value for which the cost of irradiation using Cs-137 is identical to the cost of irradiation using Co-60. This is known as the indifference value. The desired value for Cs-137 is the indifference value of the curies emitted from the surface of the capsule produced by the Waste Encapsulation and Storage Facility (WESF). The curies emitted from the surface and available for irradiation is

the proper measure of value for an irradiation source. This capsule, 2.6-inch diameter by 20.8-inches long, was designed for storage and not an irradiation source. About 40% of the total curies are absorbed internally in this capsule design; 60% are emitted from the surface and can be used for irradiating products.

A recent report by CH₂M-Hill⁽¹⁾ compared Co-60 and Cs-137 isotopes. For one illustrative application, this report estimated the value of Cs-137 in the WESF capsule at \$.24/Ci based on the total curies contained in the capsule, or about \$.40/Ci emitted from the surface, compared to a price of \$1.00/Ci for Co-60. The report also developed systematic relationships between the initial cost of Co-60 and the initial costs of Cs-137 at several Co-60 to Cs-137 source utilization ratios. The CH₂M-Hill study did not include differences in the cost of the irradiation facilities and in transportation costs in their analysis that are included in our study. Also, the economic assumptions differed between the two studies. Nonetheless, with one exception our study estimated values for Cs-137 that were about the same as the CH₂M-Hill study.

ANALYTICAL PROCEDURE

The analytical procedure in this study was as follows:

1. Conceptual designs were developed for each type and size of irradiator using Co-60 as an irradiation source. There were three sizes for apples, two sizes for pork, and two sizes for medical supplies - seven conceptual designs total.
2. Seven conceptual designs were also developed for each identical type and size of irradiator using Cs-137 as the irradiation source.
3. Life-cycle costs were estimated for each Co-60 facility. The present value of the life-cycle costs for each facility was determined using discounted cash flow analysis.
4. For each identical Cs-137 facility, the value of Cs-137 that yielded the same present worth of the life-cycle costs was determined.
5. The unit cost of irradiation was determined for each facility by dividing the annualized production cost by the production rate.

The principal assumptions and ground rules adopted for this study are listed below.

ASSUMPTIONS AND GROUND RULES

1. Operating Entity

The reference case will assume a commercial operation of the irradiation facility.

The financial characteristics of the operation will assume 70% equity and 30% debt. Current tax rates, depreciation schedules and investment tax credits will be followed. Real rates of return of 12% on equity and 6% on debt will be assumed.

2. Costs

Costs will be estimated in constant 1984 dollars. The analysis will be based on real (non-inflated) costs.

Unit costs, \$/Ci Cs-137, will be determined from the annualized life-cycle costs.

3. Escalation and Inflation

Labor rates will be assumed to escalate at 1% per year. This is the "real" rate above the inflation rate.

Energy costs will be assumed to escalate at 2% per year.

The inflation rate will be assumed to be 6% per year.

4. Co-60 Price

This is the price quoted and projected by AECL, the current primary supplier of Co-60. It is based on the curies emitted from the surface of each pin.

5. Cs-137 Form

The starting point will be the WESF capsule having zero cost. Cesium value will be based on the curies emitted from the surface of each capsule.

6. Location

The fruit irradiation facility is assumed to be located in Yakima, Washington.

The pork and medical irradiation facilities are assumed to be located in Chicago, Illinois.

7. Operating Rate

The facilities are assumed to operate at 80% of capacity.

8. Useful Life

For the reference financial analysis the facilities are assumed to have a useful life of 15 years, consistent with commonly accepted guidelines for manufacturing facilities. The structural parts of the facility should have a much longer useful life.

REFERENCE

1. CH₂M Hill. Ca 1983. Comparison of Radioactive Isotopes Cobalt-60 Versus Cesium-137. Albuquerque, N.M.

IRRADIATOR DESIGNS

The preliminary designs for the facilities to irradiate apples, pork, and medical supplies are presented in this section to aid in estimating the indifference price for cesium-137 as compared with that for cobalt-60.

The primary components of an irradiator are a source of gamma radiation, concrete shielding, a target conveyor system, storage for the radiation source when it is not in use, a system to remove heat generated by the radiation source, and process control and personnel safety equipment. Major factors affecting irradiator design are the minimum radiation dose required to treat a product as well as the allowable maximum, the energy released by radiation source decay, product package density, package dimensions, product throughput, and package thermal constraints.

The codling moth, which infests apples and other fruits, can be destroyed by a radiation dose less than 40 krad,^(a) but for this study, the minimum dose was assumed to be 40 krad. This disinfestation may allow export of apples to the Orient. Pork can be made trichina-safe by irradiating it at a minimum dose of 25 krad. The Food and Drug Administration (FDA) restricts the maximum radiation dose for these and other foods to 100 krad; thus, the maximum dose needs to be considered in a design. Medical supplies require a radiation dose of 2.5 Mrad for sterilization. These doses are used as design parameters for the facilities described herein.

Compared with cesium-137, a disintegration of cobalt-60 gives both higher gamma emissions (2.0 vs. 0.85) and higher radiation energy (2.5 vs. 0.56 MeV). This affects both the total activity required for irradiation of a product (less for cobalt-60) and the amount of shielding needed (more for cobalt-60) for an irradiation facility.

FACILITY DESIGN PROCESS RATES

The following throughputs for apples, pork, and medical supplies were used to develop the preliminary designs for possible commercial-size facilities:

(a) For conversion to SI units, 100 rad = 1 Gy (1 Gray).

PRELIMINARY DESIGN DATA

Key preliminary irradiator design data for the three products are summarized in Tables 1, 2, and 3. The designs are developed in detail in Appendix A.

TABLE 1. Apple Irradiator Key Preliminary Design Data

	Apple Throughput, lb/day (lb/h)		
	Case I.A.	Case I.B.	Case I.C.
	82,000	800,000	2,500,000
	(3,417)	(33,300)	(104,000)
Minimum radiation dose, krad	40	40	40
Irradiator capacity, Mrad-lb/h(a)	137	1,333	4,170
Package density, g/cm ³	0.3	0.3	0.3

1. Cobalt-60 Irradiator

Activity required, Ci (net)	49,000	205,000	736,000
Dose uniformity, D_{max}/D_{min}	1.7	1.3	1.8
Source utilization efficiency, %	24	55	48
Source heat generation, Btu/h	2,800	12,000	42,000
Irradiation chamber area dimensions, ft	9 x 20	11.5 x 30	13 x 30
Concrete shielding thickness, ft	5	5	6
Total area dimensions, ft	25 x 40	27.5 x 40	36.5 x 52

2. Cesium-137 Irradiator

Activity required, Ci (net)	212,000	1,080,000	3,450,000
Number of WESF capsules	8	36	115
Dose uniformity, D_{max}/D_{min}	1.7	1.4	1.8
Source utilization efficiency, %	25	48	47
Source heat generation, Btu/h	7,260	32,700	104,000
Irradiation chamber area dimensions, ft	9 x 20	14 x 30	13 x 30
Concrete shielding thickness, ft	3.8	4	4.5
Total area dimensions, ft	22.5 x 36.3	28 x 47	35.5 x 49.5

Cesium-137 to cobalt-60 ratio, Ci/Ci	4.3	5.3	4.7
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(a) Irradiator capacity (Q) is determined from the product mass flow rate (w) and the minimum dose (D_{min}), i.e., $Q = w \times D_{min}$.

TABLE 2. Pork Irradiator Key Preliminary Design Data

	Hog Carcasses Throughput Number/Day (lb/h)	
	Case II.A. 2,000 (14,000)(a)	Case II.B. 4,000 (28,000)(a)
Minimum radiation dose, krad	25	25
Irradiator capacity, Mrad-lb/h	354	708
Package density, g/cm ³	1.0	1.0

1. Cobalt-60 Irradiator

Activity required, Ci (net)	317,000	634,000
Dose uniformity D_{max}/D_{min}	1.8	1.8
Source utilization efficiency, %	9.5	9.5
Source heat generation, Btu/h	18,000	36,000
Irradiation chamber area dimensions, ft	10.5 x 30	13.5 x 30
Concrete shielding thickness, ft	5.8	6
Total area dimensions, ft	28 x 52.3	31.5 x 53

2. Cesium-137 Irradiator

Activity required, Ci (net)	1,550,000	3,100,000
Number of WESF capsules	52	104
Dose uniformity, D_{max}/D_{min}	1.9	1.9
Source utilization efficiency, %	8.9	8.9
Source heat generation, Btu/h	47,200	94,400
Irradiation chamber area dimensions, ft	13.5 x 30	13.5 x 30
Concrete shielding thickness, ft	4.5	4.5
Total area dimensions, ft	28.5 x 48.5	28.5 x 48.5
Cesium-137 to cobalt-60 ratio, Ci/Ci	4.9	4.9

(a) Assumed 170 lb/hog carcass.

TABLE 3. Medical Supplies Irradiator Key Preliminary Design Data

	Medical Supplies Throughput, lb/day (lb/h)	
	Case III.A. 18,000(a) (750)	Case III.B. 54,000(b) (2,250)
Minimum radiation dose, Mrad	2.5	2.5
Irradiator capacity, Mrad-lb/h	1,880	5,625
Package density, g/cm ³	0.2	0.2

1. Cobalt-60 Irradiator

Activity required, Ci (net)	627,000	1,680,000
Dose uniformity D_{max}/D_{min}	1.7	1.5
Source utilization efficiency, %	25	29
Source heat generation, Btu/h	36,000	96,000
Irradiation chamber area dimensions, ft	12.5 x 33	12.5 x 33
Concrete shielding thickness, ft	6	6.3
Total area dimensions, ft	31.5 x 57	32 x 57.8

2. Cesium-137 Irradiator

Activity required, Ci (net)	2,720,000	6,600,000
Number of WESF capsules	92	220
Dose uniformity, D_{max}/D_{min}	1.7	1.5
Source utilization efficiency, %	27	33
Source heat generation, Btu/h	83,500	200,000
Irradiation chamber area dimensions, ft	16.5 x 33	16.5 x 33
Concrete shielding thickness, ft	4.5	4.5
Total area dimensions, ft	33.5 x 52.5	32.5 x 52.5

Cesium-137 to cobalt-60 ratio, Ci/Ci	4.3	3.9
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(a) With 8,000 h operation annually, this is equivalent to 6,000,000 lb/yr; at 7,000 h/yr, 5,250,000 lb/yr.

(b) With 8,000 h operation annually, this is equivalent to 18,000,000 lb/yr; at 7,000 h/yr, 15,750,000 lb/yr.

<u>Apples</u>	82,000 lb/day (3,417 lb/h)
	800,000 lb/day (33,300 lb/h)
	2,500,000 lb/day (104,000 lb/h)
<u>Pork</u>	2,000 hog carcasses/day (14,000 lb/h)
	4,000 hog carcasses/day (28,000 lb/h)
<u>Medical supplies</u>	18,000 lb/day (750 lb/h)
	54,000 lb/day (2,250 lb/h)

IRRADIATOR DESIGN PROCEDURE

The Brookhaven National Laboratory (BNL) developed several design procedures for irradiators and irradiator design concepts in the 1960's and early 1970's. Rizzo et al. of BNL (1968, 1972) describe practical irradiator design concepts and give details on the static equivalent system (SES) design procedure used in the preliminary designs of this work. The irradiator type chosen for this study is the continuous-motion, single-direction, multipass irradiator. In this type of irradiator, the target is moved in either a vertical or horizontal direction past the radiation source plaque through the irradiation chamber. The target is moved one or more passes by each side of a source plaque. The static equivalent system (SES) is a static representation of the irradiator geometry that yields results exactly equal to the results that would be obtained from the equivalent dynamic system (Rizzo et al. 1972). Computer-calculated tabulated dose distribution data used with the SES design procedure are given by Galanter (1971a, b) for rectangular cobalt-60 and cesium-137 source plaques.

The facility layout, conveyor system, source plaque storage for each irradiator design are patterned on information supplied by Bradburne (1972) in his publication on gamma irradiation systems.

The shielding thickness of concrete of an irradiator and the depth of water above a source in a water storage pool are based on personnel radiation-dose rates of no more than 0.25 mR/h at the outer surface of a concrete wall of the irradiation chamber and 5 mR/h above the water pool. Computer codes ISOSHLD-II and SLAB (written by Pacific Northwest Laboratory) were used to calculate these dimensions which affect overall facility designs.

ECONOMIC ANALYSIS OF IRRADIATOR SYSTEMS

Fourteen different plant designs were evaluated to determine the indifference value of Cs-137 relative to Co-60. The indifference value for Cs-137 is the price at which a plant owner would be indifferent between purchasing Cs-137 and Co-60. The purchase decision must consider differences in plant design, source transportation, and source installation, as well as the cost per Ci purchased.

Capital and O&M costs were estimated for each of the fourteen cases. The leveled cost of irradiation per pound of throughput was first calculated for each of the seven Co-60 cases using known market prices for cobalt (see "Cobalt and Cesium Supply and Cost", below). The indifference value for Cs-137 was established for each of the corresponding cesium cases via a trial-and-error procedure. The price per net curie of cesium was varied until the cost of irradiation was identical to the corresponding cobalt case.

CAPITAL AND O&M COST ESTIMATES

The objective of the cost estimating task was to develop standard, unitized costs for each component to allow for equitable comparisons of the costs for each plant design and accurate determination of the indifference value of Cs-137 relative to Co-60. The cost estimating effort began by first identifying the components to be included. This was accomplished via a review of the literature completed in conjunction with the irradiator design task. Irradiation facility components can be broken into three broad categories: direct costs, indirect costs, and operating and maintenance (O&M) costs. Individual components are listed in Table 4 along with their cost controlling variable(s) and unit costs. Unit costs were established by consulting cost engineering handbooks, related literature, equipment vendors, and other sources.

Quantity requirements were taken directly from the design data for components relating to the source and the irradiation chamber. Labor requirements varied with the plant throughput. Operating manpower was required for loading and unloading trucks, storing and retrieving boxes from warehouses, and loading and unloading conveyors. Other activities included control room monitoring, radiation monitoring, equipment maintenance, and supervision. Ancillary building space was established by the number of employees and plant throughput. Warehouse space was set equal to 3 days storage capacity on both

TABLE 4. Irradiation Facility Cost Estimating Components

COMPONENT	CONTROLLING VARIABLE(S)	UNIT COST OR RATE (\$ or %)
DIRECT COSTS		
Source	Ci	
	Source Type	
Source Rack	sq. ft.	600
Source Rack Hoist	fixed	4,000
Concrete Irradiator	cu. yd.	290
Irradiator Earthwork	cu. yd.	7.5
Irradiator Electrical, Lighting, and Fire Pro- tection Systems	sq. ft.	13
Land	acres	40,000
Site Preparation	acres	10,000
Surface Coverings		
gravel	acres	6,000
pavement	acres	35,000
concrete	acres	85,000
Product Conveyor	ft.	70
	chain pull (lbs.)	5
Source Storage Pool		
concrete walls	cu. yd.	290
S.S. liner	sq. yd.	310
water treatment	fixed	10,000
Building Ventilation	SCFM	$\$20(\text{SCFM}) + \$50(\text{SCFM}) \cdot 65$
Instrumentation & Control	fixed	100,000
Utility Room	sq. ft.	45
Control Room	sq. ft.	45
Office	sq. ft.	55
Restroom	sq. ft.	55
Lunchroom	sq. ft.	55

TABLE 4. (Continued)

COMPONENT	CONTROLLING VARIABLE(S)	UNIT COST
DIRECT COSTS		
Equipment & Maintenance Shop	sq. ft.	35
Health Physics Lab	sq. ft.	75
Warehouse	sq. ft.	25
Refrigerated Warehouse	sq. ft.	35
Emergency Generator	fixed	5,000
Truck Scales	fixed	30,000
Forklifts	plant size/# lifts	15,000
Misc. Site Facilities	direct cost	1%
INDIRECT COSTS		
Design and Engineering	direct cost	10%
Construction Management and Fees	direct cost	15%
Contingency	direct cost	25%
O&M COSTS		
Source Replacement	Ci	
	Source Type	
Labor		
loader/unloader	plant size/mhrs	15
oper/maint/RM	plant size/mhrs	15
supervisor	plant size/mhrs	20
Miscellaneous Supplies, Tools, Parts, & Operating Costs	direct cost	2.5%
Local Taxes & Insurance	direct cost	2%

the receiving and shipping sides of the operation. The land requirement was controlled by building size with allowances for vehicular traffic. The surface covering for the non-building area of a site was split between gravel, pavement, and concrete, in descending order of relative coverage. The remaining components were either fixed as constants or were set equal to a certain fraction of the direct costs.

Capital and O&M costs are summarized in Table 5. The figures identify the large economies-of-scale available in building an irradiation facility. A detailed breakdown of the costs by component is given in Appendix B.

COBALT AND CESIUM SUPPLY AND COST

The major portion of the world's Cobalt-60 supply comes from Canada. It is supplied by Atomic Energy of Canada Limited (AECL) from their NRV and NRX research reactors and from four reactors at the Pickering A Nuclear Power Generating Station of Ontario Hydro. Since 1951, AECL has supplied a total of 118 million curies of Co-60 for industrial irradiator use. The AECL Marketing Manager of Industrial Irradiators was contacted for information on Co-60 supply and cost. The supply and cost information can be summarized in five categories: Co-60 unit cost, delivery associated cost, transportation cost, installation cost, and disposal costs.

Co-60 is supplied on a curie basis. A price breakdown in U.S. dollars for Co-60 quantities, based on delivery prior to July 1, 1985, is given by AECL as follows:

50,000 Curies -	149,999 Curies -	\$1.02/Ci
150,000 Curies -	349,999 Curies -	\$0.99/Ci
350,000 Curies -	749,999 Curies -	\$0.97/Ci
750,000 Curies -	1,349,999 Curies -	\$0.95/Ci

A 10% yearly price increase was indicated by AECL. This price schedule is for net curies available as measured on the outside of the Co-60 source pencil (No. C-188) assembly.

Costs associated with delivery of the Co-60 include the rental of a special shipping cask. AECL uses a F-168 shipping container (cask) which measures 54 inches (137.16 cm) square at the pallet base by 62 inches high (157.48 cm) including the pallet base. The cask gross weight, including lead-steel shielding, equals 11,200 pounds. The maximum cask capacity is 200,000 curies of Co-60. The rental fee charged by AECL is \$1,300 per use.

TABLE 5. Capital and O&M Cost Summary
(All Costs in Thousands of 1984 Dollars)

Plant Description	Plant Capital			O&M		
	Source*	Land	Other	Source*	Labor	Misc.
82,000 pounds apples/day; Co-60 Source	64.8	50.0	1120	16.0	350	18.7
82,000 pounds apples/day; Cs-137 Source	249	50.0	1053	32.6	350	17.5
800,000 pounds apples/day; Co-60 Source	218	150	4583	35.7	1296	76.4
800,000 pounds apples/day; Cs-137 Source	435	150	4591	52.5	1296	76.5
2,500,000 pounds apples/day; Co-60 Source	743	340	12684	108	3644	211
2,500,000 pounds apples/day; Cs-137 Source	1468	340	12628	169	3644	211
340,000 pounds hogs per day; Co-60 Source	330	70	5013	53.0	876	83.6
340,000 pounds hogs per day; Cs-137 Source	671	70	5002	85.3	876	83.4
680,000 pounds hogs per day; Co-60 Source	634	100	9247	93.0	1296	154
680,000 pounds hogs per day; Cs-137 Source	1238	100	9228	146	1296	154
18,000 pounds medical sup- plies/day; Co-60 Source	628	40.0	1109	92.1	245	18.5
18,000 pounds medical sup- plies/day; Cs-137 Source	1199	40.0	1119	141	245	18.6
54,000 pounds medical sup- plies/day; Co-60 Source	1634	50.0	1459	218	350	24.3
54,000 pounds medical sup- plies/day; Cs-137 Source	2957	50.0	1552	329	350	25.9

*The source replacement cost occurs every year for Co-60 and every fifth year for Cs-137. The source costs shown for Cs-137 represent the indifference value of Cs-137 that was determined for each application.

Transportation charges for shipping a loaded F-168 cask from Ontario, Canada were obtained from the AECL transportation department. Charges are based on a hundred pound weight to Chicago, Illinois and Yakima, Washington, U.S.A. These charges are summarized as follows:

<u>To Chicago</u>	<u>To Yakima</u>
\$1813 total charge	\$3539 total charge

These total charges are independent of the number of curies of Co-60 being transported. Thus, the least cost for transportation per curie occurs when a maximum load of 200,000 curies is being shipped. The transportation cost per curie for Co-60, then, is proportional to the percent of maximum load being shipped.

There is also a charge by AECL to install a shipment of Co-60 pencils in an irradiator facility. An average charge, as given by AECL, for an initial installation job requiring 2-3 days time is \$10,000. This charge includes travel and living expenses as well as labor costs. It is assumed that installation costs would be independent of total curies installed or replaced since assembling the crew and gaining access to the source storage pool would be the most time consuming and costly tasks. Pencil replacement should take a relatively small amount of time once access to the storage pool has been achieved.

Upon depletion of the activity of the Co-60 pencils, the spent pencils are removed from the irradiator source plaque and disposed by AECL. AECL returns the spent pencils back to their Ontario, Canada facilities for ultimate burial. There is a one time charge of \$2,000 per 15 years. This charge covers administrative costs associated with spent pencil accountability and disposal. There are no transportation charges associated with removal/disposal per se since a shipping cask delivering a new Co-60 supply simply returns home with the spent pencils. Cask rental and shipping charges are already covered for the shipment.

The supply and cost information for Co-60 is summarized as follows:

Co-60 unit cost	see price schedule in text
Delivery cost (shipping and rental)	\$1300/use
Transportation cost	
- to Chicago	\$1813
- to Yakima	\$3540
Installation and replacement charge	\$10,000
Disposal cost (one time per 15 years)	\$2000

The indifference value or unit cost of Cs-137 is determined by equating the annualized life-cycle cost of a Co-60 irradiation facility to that of a Cs-137 facility. These unit costs are calculated in "Levelized Cost Analysis", below.

There are presently 77 megacuries of Cs-137 held in storage. About 1500 Cs-137 capsules are available. Each capsule contains 30,000 to 70,000 curies with an average of 50,000 curies. Due to the thick metal cladding and self absorption, only about 60% of the Cs-137 gamma activity is available for use as measured on the outside surface of the capsule.

The Department of Energy (DOE) initially plans to rent a G.E. 700 cask in which to transport the first shipments of Cs-137 capsules. This cask has a gross weight of 36,000 pounds. The cavity of the cask (Cs-137 carrier) measures 15 inches (38.1 cm) in diameter and 40 inches (101.6 cm) high and has a capacity of about 1,350,000 curies of Cs-137 (27 capsules). The rental charge of this G.E. 700 cask is assumed to be \$1300 per use. DOE supposedly will have its own BUSS cask available later on. There will be no rental charge for its use.

DOE is responsible for Cs-137 encapsulation and for packaging the capsules into the shipping casks. There is no charge for this service. Also, the acquisition by users of the Cs-137 is to be on a lease-type arrangement.* In this way, DOE will assume responsibility for later disposal of the spent Cs-137 capsules. There is no disposal cost for the user.

Transportation costs from Richland, Washington to Yakima, Washington and to Chicago, Illinois were obtained from PNL Lab Safety. Typical costs are based on a hundred weight measure and are summarized as follows:

<u>To Yakima</u>	<u>To Chicago</u>
\$547 total charge	\$3485 total charge

DOE will not be involved in installing the Cs-137 capsules into irradiation facilities. Installation will be the responsibility of the Cs-137 purchaser. Installation and replacement costs are estimated at \$10,000 per job which is the same as the AECL installation charge.

*NOTE: Our analysis assumes the initial purchase of the Cs-137. The indifference value could be affected, either increased or decreased, depending on the terms of the lease.

The supply and cost information for Cs-137 is summarized as follows:

Cs-137 unit cost	determined in "Levelized Cost Analysis"
Delivery cost (cask rental)	\$1300/use
Transportation cost	
- to Yakima	\$547
- to Chicago	\$3485
Installation charge	\$10,000
Disposal cost	zero

LEVELIZED COST ANALYSIS

The calculation of levelized costs yields a cost per pound of throughput for cobalt systems and allows determination of the cost per curie of cesium that would yield the same cost per pound of throughput for cesium systems, i.e., it allows determination of the indifference value of cesium relative to cobalt. The levelized cost of irradiation is calculated according to principles outlined in Doane (1976) and Applegren (1982). This methodology is often referred to as the "required revenue" approach, because the cost per pound calculated is equivalent to the revenue per pound a plant owner would have to receive to exactly cover all capital and operating expenses plus allow for a return on equity investment.

Levelized costs were calculated in both real (constant) and nominal (current) dollar terms. A real dollar analysis excludes the effects of general inflation which a nominal dollar analysis includes. Either method is equally appropriate for comparisons of one levelized cost to another. A real dollar analysis is often preferred because its levelized cost is more directly comparable to costs we see in the marketplace today.

The levelized costs were calculated assuming commercial ownership of the irradiation facilities. Debt and equity rates, component escalation rates, and other financial factors incorporated into the levelized costing methodology are specified in Table 6. The resulting levelized irradiation costs and corresponding indifference values for cesium are identified in Table 7. Details of the year-by-year cash flows, by major components, are presented in Appendix C.

The figures given in Table 7 present some interesting results. The levelized irradiation costs confirm the economies-of-scale indicated in Table 5. The cost of irradiation, per pound, drops with increasing plant capacity

TABLE 6. Financial Inputs to Levelized Cost Calculations

General Inflation	6%
Capital Escalation	6%
Source Escalation	6%
Labor Escalation	7%
Miscellaneous O&M Escalation	6%
Land Escalation	6%
Debt Cost	12%
Equity Cost	18%
Debt Ratio	0.3
Federal and State Taxes	50%
Local Taxes and Insurance	2%
Investment Tax Credit	10%
Depreciable Life	5 yrs
Depreciation Schedule	ACRS - 5 yr
Construction Period	1 yr
Salvage Value	0
Capacity Factor	80%
Facility Life	15 yrs

TABLE 7. Levelized Irradiation Costs and Cesium Indifference Values

<u>Plant Description</u>	<u>Levelized Cost \$/Lb</u>		<u>Cesium Indifference Value, \$/Net Ci</u>
	<u>Real</u>	<u>Nominal</u>	
82,000 pounds apples/day	.024	.035	1.12
800,000 pounds apples/day	.010	.014	.39
2,500,000 pounds apples/day	.009	.012	.42
340,000 pounds hogs/day	.019	.027	.42
680,000 pounds hogs/day	.016	.022	.39
18,000 pounds medical supplies per day	.123	.176	.43
54,000 pounds medical supplies per day	.071	.101	.44

for each of the three commodities evaluated. The irradiation chamber itself possesses extreme economies-of-scale. For instance, while the production ratio of the large and small apple plants is 30, the irradiation chamber cost ratio is only 1.8!

For most of the cases, the indifference value for cesium is approximately \$.40/net curie. The minor fluctuations around this figure can be attributed to step function differences in design (e.g., rounding irradiator wall thickness to the nearest 1/4 foot), small differences in the cobalt/cesium source utilization efficiency ratio for plants of different sizes and commodities, step function differences in the cost of transporting and installing the source, and quantity discount schedules for the initial purchase of cobalt. Cobalt and cesium irradiation facilities do have different design requirements and costs, but advantages gained from one component tend to be cancelled by disadvantages from another. Lower shielding requirements for cesium lead to lower costs for its irradiation chamber and storage pool, but cesium source requires more capsules and generates more thermal energy which increases the cost of the source rack and ventilation system relative to a cobalt system.

The high indifference value for cesium estimated for the small apple plant can be linked to the size of the irradiation chamber and source replenishment. A cesium source irradiation chamber costs about 25% less than a cobalt irradiation chamber. Although this cost advantage for cesium exists for all of the plant sizes, the advantage is magnified for a smaller plant because the irradiation chamber becomes a much larger part of the total plant capital cost. Cesium also has an advantage in small plants due to the fixed costs associated with the transportation and installation of replacement sources. Full transportation and cask rental charges must be paid regardless of the number of curies purchased. Similarly, installation costs accrue largely from crew travel expenses and set-up charges, both of which vary little with the quantity of curies handled. The result is an effective (installed) cost of replacement curies for the small cobalt apple plant of over \$2.50/Ci. Although small shipments of cesium are also relatively expensive, the cost effect is more benign because cesium sources are replenished every fifth year, while cobalt sources are replenished annually.

SENSITIVITY ANALYSES

In addition to the fourteen plant designs evaluated under the conditions specified in Table 6, levelized irradiation costs were calculated for cases

with a source salvage value, municipal financing, 30 year plant life, higher initial cobalt cost, higher cobalt cost escalation rate, and lower commercial financing costs. Source salvage value was given for the curie content remaining at the end of the 15 year plant life. The remaining curies were valued at the purchase price. Long-term historic rates of return on debt and equity are much lower than the corresponding rates in the current market. The sensitivity of the levelized irradiation cost and cesium indifference value to the price of cobalt was calculated for cobalt prices double that of current market conditions and for cobalt prices that escalated at 10% per year (4% real escalation).

The sensitivity analysis for the 30 year plant life case involved some complicating factors. The source racks for the base case irradiation plants were all designed for a 15 year life. Space was allowed on the racks for the addition of pins or capsules as decay took place. Extending operations past 15 years would require either replacing the entire source and repeating the periodic pin/capsule additions or periodic replacement of the oldest pins/capsules in the rack. Our analysis assumed the latter. Because the pins/capsules removed contain unused curies, the amount of curies added in the last 15 years exceeds the amount added in the first 15 years by the amount of curies contained in the pins removed. Replacement is complicated by the constantly changing curie content of the pins/capsules that are replaced. The schedule of curie additions for both cobalt and cesium systems is shown in Table 8 as a percent of the initial source total. Note that this replacement policy requires a significant increase in the amount of cesium replaced. In actual practice, a cesium system would probably be designed with a 30-year rack life so that cesium capsules would not have to be replaced "before their time". Also note that this analysis did not include any equipment replacement during the 30 year period.

The results of the sensitivity analyses are presented in Table 9. As expected, including a credit for source salvage has little effect on the levelized cost of irradiation because the credit occurs far in the future and the radiation source is only 5-10% of the total capital cost. Including a source salvage value does benefit the cesium plant more than the cobalt plant, however, causing the indifference value of cesium to rise. This phenomena occurs because the salvage value credit for cesium is larger than that for cobalt. The salvage value is higher because the initial source cost for Cs-137 is larger. Thus, the indifference cost of the Cs-137 source must rise to match

TABLE 8. Curie Replacement Schedule for 30 Year Plant Life

<u>Year</u>	<u>Cobalt</u>	<u>Cesium</u>
1	12.346	
2	12.346	
3	12.346	
4	12.346	
5	12.346	10.83
6	12.346	
7	12.346	
8	12.346	
9	12.346	
10	12.346	10.83
11	12.346	
12	12.346	
13	12.346	
14	12.346	
15*	14.34	37.21
16	14.06	
17	13.82	
18	13.62	
19	13.45	
20	13.30	29.44
21	13.18	
22	13.14	
23	13.15	
24	13.16	
25	13.16	21.77
26	13.17	
27	13.18	
28	13.19	
29	13.20	

NOTE: These figures represent the percent of initial source that must be purchased at the end of each year to replenish the source activity level.

*Source rack is assumed to be filled at end of 15 years. Thereafter, new Co-60 pins or Cs-137 capsules replace existing pins or capsules in source rack.

TABLE 9. Sensitivity Analysis Results

(Levelized Costs are in Real Dollars as Opposed to Nominal Dollars)

<u>Plant Description</u>	<u>Sensitivity Change</u>	<u>Levelized Cost, \$/lb</u>		<u>Cesium Indifference Value, \$/Net Ci</u>	
		<u>w/Change</u>	<u>Base Case</u>	<u>w/Change</u>	<u>Base Case</u>
800,000 pounds apples per day	salvage value credit	.010	.010	.47	.39
800,000 pounds apples per day	municipal financing	.008	.010	.45	.39
340,000 pounds hogs per day	municipal financing	.016	.019	.48	.42
18,000 pounds medical supplies per day	municipal financing	.100	.123	.48	.43
800,000 pounds apples per day	30 year plant life	.009	.010	.40	.39
800,000 pounds apples per day	double cobalt source cost	.010	.010	.74	.39
800,000 pounds apples per day	escalate cobalt price @ 10%/yr	.010	.010	.44	.39
800,000 pounds apples per day	lower debt and equity rates	.009	.010	.45	.39

the irradiation cost of the cobalt plant. On the other hand, if the initial cobalt source capital cost had been greater than that for cesium, including a salvage credit would have benefitted the cobalt plant more than the cesium plant and dropped the cesium indifference value. More simply put, a source salvage credit at market prices provides a greater benefit to the plant with the larger initial source capital cost.

The lower financing charges associated with municipal financing result in reduced levelized irradiation costs for each of the commodities and also raises the cesium indifference value. Municipal financing lowers the fixed-charge-rate (FCR) from 21.3% to 13.2% and lowers the capital recovery factor (CRF) from 16.6% to 13.2%. (The capital cost portion of the levelized cost is directly proportional to the FCR and the O&M cost portion of the levelized cost is directly proportional to the CRF.) Cobalt, with its high source replenishment costs, benefits most from lowering the CRF. Cesium, with its higher initial capital cost, benefits most from lowering the FCR. Since the FCR drops more with municipal financing than the CRF, the benefit to cesium is greater and its indifference value rises.

The levelized cost of irradiation drops in real terms with a 30-year plant life because of the longer period allowed to utilize the investment in plant equipment. The additional source replacement costs identified in Table 8 have little impact because they occur far in the future and are still small compared to capital and labor costs.

Neither doubling the initial cobalt price or allowing it to escalate at 10% per year has a significant impact on the levelized cost of irradiation. This points out the relatively small portion of costs attributable to the source for the 800,000 pounds/day apple plant. If cobalt prices were doubled for a medical supplies plant, however, the cost effect would be much more dramatic because of the greater importance source costs play for that type of facility. Increasing the cost of cobalt does have a directly proportional impact on the indifference value of cesium if the fixed costs of transportation and installation are netted out.

The base case real debt and equity rate assumptions approximately represent market conditions of the last couple of years. If the required real rate of return on debt and equity were equal to their long run historical averages (1.7% real return on debt; 6.7% real return on equity), the cost of irradiating apples would drop by about 10% and the cesium indifference value would rise by

about 15%. The impact of lower commercial financing costs is similar to switching to municipal financing for the same reasons outlined above, i.e., lower financing charges directly lower the levelized cost by reducing the FCR and CRF. Again, because the FCR drops more than the CRF, the benefit to the more capital intensive cesium facility is greater and the cesium indifference value rises. Details of the year-by-year cash flows for each of the sensitivity cases are shown in Appendix D.

FACTORS AFFECTING THE MARKET FOR IRRADIATORS

The use of cesium as a gamma source for irradiators to irradiate medical supplies and food products is receiving increasing interest in the U.S. Cesium-137 is considered to be an alternative gamma radiation source to cobalt-60, which is currently being used in irradiators worldwide. The demand for irradiators is expected to increase significantly over the next several decades. Although the exact demand for irradiators in the U.S. is unknown, some of the factors that will influence the extent that irradiators are used in the U.S. are discussed in this chapter. The future of gamma irradiators in the U.S. depends on several factors, including regulatory issues, cost competitiveness, and public acceptance. In the following discussion, these factors are discussed as they relate to four markets selected for review: sterilized medical supplies, trichina parasite control in pork, and disinfestation of Northwest cherries and apples.

BACKGROUND

The effect of ionizing energy on living and nonliving materials has been the subject of extensive research for over 30 years.⁽¹⁾ Much of the research has been devoted to determining the amount of radiation required to accomplish insect control, maturation inhibition, parasite and microbial control, and sterilization. Research also has been conducted to determine whether living and nonliving materials become radioactive if exposed to low-dose up to about 100 Krad (1 kGy),^(a) medium dose about 100-1,000 Krad (1-10 kGy), or high-dose about 1,000-5,000 Krad (10-50 kGy) exposures.

An international base of research is being used currently to address questions on the appropriate uses of radiation. To date, the consensus has been that the applied dose of radiation should be the minimum necessary to achieve the desired effect without exceeding the appropriate standards.⁽²⁾ Therefore,

(a) The System International (SI) unit for expressing the amount of absorbed radiation dose is the Gray [joules/kilogram (Gy)]. The older term is rad. The equivalent value in rads is 100 rad = 1 Gy. The prefix kilo (k) represents a thousandfold.

much research is being conducted to find and apply the appropriate dose level and to determine where radiator facilities have cost or other benefits over competing methods of accomplishing insect control, maturation inhibition, parasite and microbial control, and sterilization.

Ionizing energy for irradiation may be obtained from electron beams that are machine generated (accelerators), from x-ray machines, or from gamma rays released from radioactive materials such as cobalt-60 and cesium-137. All three types of irradiation sources have advantages and disadvantages. For example, electron beam sources do not require high levels of shielding. This technique of providing irradiation is most appropriate for low-density items with a maximum thickness of 2 to 4 inches. Gamma radiation has the greatest penetration ability, while x-rays have the second best. However, gamma and x-ray irradiation must be carried out behind shielding.

COMMERCIAL USE OF IRRADIATED MEDICAL SUPPLIES AND FOOD PRODUCTS

Medical supplies sterilized by irradiation are being used in significant quantities in the U.S. today. On the other hand, the consumption of irradiated foods in the U.S. has been very limited. In the following sections commercial use and public acceptance of irradiation in these areas is discussed.

Medical Supplies

Irradiation is already used extensively worldwide for sterilizing medical products. In the U.S. an estimated 35 to 40% of all disposable medical items are sterilized by ionizing energy.⁽³⁾ The use of ionizing energy to sterilize medical items has increased during the past five years. Before that time, only 5% of the sterilized medical supplies were sterilized by radiation. Instead, gas fumigation using ethylene oxide (ETO) gas was the common sterilization method. In 1977, after the Environmental Protection Agency (EPA) released the results of toxicity tests that showed that ETO was mutagenic, the medical supply industry began to evaluate alternatives.

Recently, the U.S. Occupational Safety and Health Administration (OSHA) has changed their regulations to decrease the integrated daily worker exposure level from 50 parts of ETO per million parts of air (ppm) to 0.5 ppm. This

significant reduction in worker exposure could be very expensive to implement. Because the medical supply industry had evaluated radiation for sterilization, there is now a significant shift toward medical products sterilized by gamma radiation.⁽⁴⁾

In the medical supply industry, radiation for sterilization has been supplied by both electron beam machinery and by gamma rays supplied by cobalt-60. Electron beam processing is characterized by low penetration and high dose rates, whereas gamma ray processing is characterized by high penetration and low dose rates. Medical products with densities of less than 30 pounds per ft³ can be irradiated with electron beams if the products typically have cross sections of less than 2 inches for DC machines and 4 inches for high-voltage linear accelerators. Gamma irradiators are preferable to electron beam machines because the gamma irradiators can process cartons and pallets of medical materials.⁽⁴⁾

Food Products

Since the mid 1970s, several national and international committees have been convened to review the research data and information available on the effect irradiation has on food wholesomeness. The exposure of food to irradiation has been widely referred to as irradiated food. In 1980, a joint committee composed of the Food and Agriculture Organization (FAO) of the United Nations, the International Atomic Energy Agency (IAEA), and the World Health Organization (WHO) was convened to review the research conducted on irradiated foods. It was believed that the recommendations of these experts could influence various countries to adopt a common approach to legislation and regulation of irradiated foods. As a result of this review, the Joint Expert Committee felt that sufficient data are now available to conclude that all major classes of foods irradiated up to an average dose of 1,000 Krad (10 kGy) pose no toxicological problems and can be used by humans without further testing for wholesomeness.⁽²⁾ The Committee made the following conclusions:

- Irradiation of any food commodity up to an overall average dose of 1,000 Krad (10 kGy) presents no toxicological hazard; therefore, toxicological testing of foods so treated is no longer required.

- Irradiation of food up to an overall average dose of 1,000 Krad (10 kGy) introduces no special nutritional or microbiological problems. The committee did emphasize that if any change occurred in the irradiated food's role in the diet, that food item should be examined.
- Future research is needed in various areas to increase existing knowledge about the effects of irradiation on food and to facilitate future evaluations. Some of the research activities recommended include the following:
 - establish the technological and economic feasibility of irradiating food on a larger scale and the suitability of irradiating a wider variety of foods
 - perform further wholesomeness studies of certain foods irradiated at higher doses

Several countries, including the U.S., are considering the Joint Expert Committee's recommendations as well as the soon to be published Codex General Standards for Irradiated Food derived from the reports of the Joint Expert Committee.⁽⁵⁾ At this time, more than 20 countries have regulations approving one or more uses of food irradiation for commercial or experimental purposes. Under Codex rules, member countries review and evaluate the proposed Codex standards against their own individual food laws. These standards can be accepted without change, accepted with change, or not accepted.⁽⁵⁾

Approximately 40 irradiated foods have been approved by health authorities in at least 28 countries. Countries such as the Netherlands, France, Russia, and Japan have been using food irradiation on a variety of food commodities for many years. Internationally, irradiated food products with the widest acceptance include potatoes, onions, garlic and strawberries. In total, 2,000 tons of food products are irradiated each year.

The first approved use of irradiation in the United States was gamma radiation for preserving canned bacon in February 1963. In August of 1963, the FDA approved electron beam radiation of canned bacon. These regulations were rescinded in 1968 because a later examination of the raw data for the animal

feeding studies showed major deficiencies in the way some of the experiments were designed and conducted. However, in 1963 the FDA also permitted the use of irradiation for the control of insect infestation of wheat and wheat products. The use of irradiation of potatoes for sprout control inhibition has been allowed in the U.S. since 1964. Although these regulations still exist today, irradiation treatments for insect disinfestation in wheat and wheat flour and potato sprout control are not being used by the U.S. grain industry because cheaper alternatives are available.⁽⁶⁾ The only food commodity presently being irradiated for commercial consumption in the U.S. is spices. About 5% of the spices used by consumers and food processors in the U.S. have been irradiated to rid them of bacteria and insects.

Concerns that May Limit the Commercial Use of Gamma Irradiation

Irradiated foods have received much closer scrutiny than medical supplies and have a higher degree of public concern because irradiated foods may be ingested in large quantities on a recurring and long-term basis. Thus, the primary concerns the public has with the use of gamma radiation for irradiating medical and food supplies centers principally on the effects irradiation has on the wholesomeness of food.⁽³⁾ The three principal concerns are as follows:

- Is there a possibility of inducing radioactivity in food that is irradiated with gamma radiation?
- Is there a possibility of long-term toxicological effects of the radiolytic products formed in foods as a result of irradiation?
- Is there an adverse effect on the nutritional quality of the treated food?

Considerable research has been conducted in this country and others addressing these concerns. In addressing the concern about inducing radioactivity in foods, the Joint Expert Committee points out that the energy level of the radiation applied to food needs to be limited to prevent the possible formation of induced radioactivity in food. The energy level permitted for food irradiation should not exceed 1) 10 million electron volts (MeV) for electron beams and 2) 5 MeV for gamma rays and x-rays. Machine produced electron

beams can be generated at energy levels above 10 MeV, and thus machine irradiation could produce radioactivity in food. Gamma radiation from cobalt-60 and cesium-137 has energy levels of 2.503 and 0.662 MeV, respectively, and thus are well below the 5 MeV limit.

Exposure of food to high doses of ionizing radiation can cause chemical changes called "radiolytic products" in food. The concentration of radiolytic products in a food item generally increases with increasing radiation dose but can be modified by factors such as temperature, air and water. Calculations of radiolytic products based on radiation chemistry indicate that low irradiation doses yield a total of about 30 ppm radiolytic products.⁽³⁾ The type of radiolytic products produced depend on the chemical composition of the food. Approximately 90% of the radiolytic products identified have been found as natural components of food. The remaining 10% of the radiolytic products (3 ppm) are chemically similar to known natural food compounds.⁽⁷⁾ Because the natural composition of foods is not usually characterized at the ppm level, some radiolytic products assumed to be unique may in fact be natural components of food. Even if these 10% of the radiolytic products are unique, they constitute only 3 ppm in foods irradiated at low doses. Because more than 10 different kinds of radiolytic products are likely to be formed when a food item is irradiated, the concentration of any one type of radiolytic product will be less than 1 ppm. At this low level of concentration, it was concluded by the FDA that food irradiated at low doses is safe for human consumption.

After reviewing the available data on the nutrition of irradiated foods, the FDA also concluded that the available data demonstrates that food irradiated at low doses will have the same nutritional value as comparable food that has not been irradiated.

REGULATORY FACTORS CONTROLLING FOOD IRRADIATION

Many regulatory factors will influence the market for food irradiators. For example, the Food and Drug Administration (FDA) is currently proposing regulations that will increase both dose limits and the number of foods that can be irradiated. Another factor that may influence food irradiation is state regulations. These factors are discussed in the following section.

Regulation by the Food and Drug Administration

The principal regulatory agency that will have a role in food irradiation is the FDA. The FDA is a part of the U.S. Department of Health and Human Services. The mission of the FDA is protection of human health from impure and unsafe foods, drugs, and cosmetics.

Enabling Legislation

The basic statutory authority for the FDA is the Federal Food, Drug and Cosmetic Act of 1938,⁽⁸⁾ and later amendments. The Act generally prohibits the introduction into interstate commerce of any adulterated food, the adulteration of any food in interstate commerce, the receipt and delivery or proffered delivery of any adulterated food in interstate commerce, and the manufacture of adulterated food.⁽⁹⁾ The amendment to the Act that is most relevant to food irradiation is the Food Additives Amendment of 1958.⁽¹⁰⁾ Under the 1958 Amendment, the use of a new food additive is prohibited until the sponsor establishes its safety and FDA issues a regulation specifying conditions of safe use. The use of radiation for food processing falls within the definition of food additive.⁽¹¹⁾ Moreover, a food is considered to be adulterated if it has been intentionally subjected to radiation, unless the use of radiation was in conformity with FDA regulations.⁽¹²⁾ All food irradiation therefore must conform to FDA regulations.

Legislation (H. R. 5605) has been introduced into the Congress that would define food irradiation as a process rather than an additive. The bill would also provide federal assistance for continued development and commercialization of food irradiation.

The FDA also has regulatory authority over food package labeling under the Food, Drug, and Cosmetic Act and the Fair Packaging and Labeling Act.⁽¹³⁾ The Agency has interpreted some of the labeling prohibitions in its enabling legislation to permit positive consumer education programs through labeling.⁽¹⁴⁾

Regulatory Actions

In February 1984 the FDA issued proposed regulations covering food irradiation.⁽¹⁵⁾ Subject to various conditions, the proposed regulations authorize the use of ionizing radiation for treating food. Among the conditions are the following:

1. Irradiation for growth and maturation inhibition of fresh fruits and vegetables and for insect disinfection is not to exceed 100 Krad (1 kGy).
2. Microbial disinfection of various spices and seasonings is not to exceed 3,000 Krad (30 kGy).
3. Irradiated food shipped for further processing must be labeled "treated with ionizing radiation - do not irradiate again."
4. Ionizing radiation is limited to a) gamma rays from sealed units of cobalt-60 or cesium-137, b) x-rays generated from machine sources at energy levels not to exceed 5 MeV, and c) electrons generated from machine sources at energy levels not to exceed 10 MeV.

The FDA did not include any requirements in the proposed regulations for labeling of packages that contain irradiated foods sold to consumers. The Agency noted the conflict between providing consumer information and the possibility that any label would be confusing and misleading for many consumers. Comments on the labeling issue were invited. The existing FDA regulations (see below) do require that package labels state that the food has been treated with ionizing radiation.⁽¹⁶⁾

The proposed regulations also include requirements that the minimum radiation be used for the desired effect, that the radiation treatment be administered during a scheduled process devised by radiation processing experts, and that the processor maintain radiation records until the shelf life of the irradiated food is exceeded by one year.

The FDA received nearly 4,000 comments on the proposed regulation before the May 16, 1984, comment deadline.⁽⁵⁾ The Agency is currently reviewing the comments. No specific time period for acting on the proposed regulations has been set.

For irradiation of certain foods the FDA also has existing regulations that appear at 20 CFR 179. The regulations permit gamma radiation of the following:

1. garlic powder and certain spices up to 1,000 Krad (10 kGy) for control of micro-organisms
2. wheat and wheat flour up to 50 Krad (.5 kGy) for control of insect infestation
3. white potatoes up to 15 Krad (.15 KGy) to inhibit sprout development.

Irradiation of wheat, wheat flour, and potatoes has received little commercial application to date because chemicals are cheaper and easier to use.⁽⁴⁾

Regulations also exist for treating wheat and wheat flour with low-dose electron beam radiation, ultraviolet radiation for the processing and treatment of foods and potable water, and radiofrequency radiation for the heating of food. In all cases, retail and wholesale packages must be labeled to show that the food has been treated with ionizing or gamma radiation. Regulations also cover the types of food packing materials that may be subject to irradiation up to 1,000 Krad (10 kGy) during processing.

Finally, FDA has regulations at 21 CFR 1002 that may be applicable to machine-generated radiation. The regulations cover recordkeeping and reports on accidental radiation occurrences.

Potential State Regulation

Although no state regulations covering food irradiation currently exist,⁽¹⁷⁾ states have many regulations that do cover foods and those regulations play an important regulatory role.⁽¹⁸⁾ It is entirely possible that in

the future, states could attempt to regulate certain aspects of food irradiation including types of eligible foods, maximum possible radiation, and labeling requirements.

The most likely regulatory role a state might take would appear to be in the area of labeling. For example, a state might require retail packaging to disclose if a food has been subject to irradiation if the FDA does not adopt such a requirement. Groups and individuals opposed to food irradiation for health reasons might be expected to lobby strongly for such disclosure. Although the outcome of such a state labeling requirement in the courts cannot be predicted with certainty, prior case law suggests that an affirmative FDA decision not to require labeling would preempt inconsistent state requirements. A federal district court in Wisconsin, for example, struck down an attempt by that state to require disclosure of the proportions of imitation and natural cheese in pizzas.⁽¹⁹⁾ The FDA regulation did not require specific natural/imitation proportions or disclosure of proportions other than an ingredients declaration. In another case, the FDA had adopted a regulation regarding labeling of aerosol products that permitted the statement to appear anywhere on the package. An attempt by Minnesota to mandate the required statement to appear on the front of the product was also struck down.⁽²⁰⁾ The court found that the pervasive FDA regulation in the field overcame Minnesota's local interest in consumer protection.

A state might also seek to permit food irradiation, but at a lower exposure level than permitted by the FDA. This type of requirement is also very vulnerable to a preemption argument and an argument that such a limitation would be an unacceptable burden on interstate food commerce.

Any state attempt to ban the distribution of irradiated food after FDA approval would likely be struck down. Under the Supremacy Clause in Article VI of the U.S. Constitution, federal law prevails over conflicting state law. Similarly, a state decision to authorize food irradiation without FDA approval would be barred because the Food Additives Amendment prohibits irradiation until FDA issues a regulation specifying safe use.

A probable area of state regulation is inspection and enforcement at food irradiation facilities. There is considerable precedent for state/federal

sharing of inspection and enforcement of food laws.⁽²¹⁾ States also may have enforcement authority that FDA does not. An example is the ability to embargo or detain food products that do not meet applicable regulations. A state that is one of the 27 agreement states under Section 274 of the Atomic Energy Act will also have regulatory authority over any radioisotope source at the processing plant and the radiation exposure to those working at the plant.

International Regulation

There has been considerable international activity on food irradiation. In 1981, the World Health Organization (WHO) published a report on the subject.⁽²⁾ The report was prepared by an Expert Committee on behalf of the United Nations Food and Agriculture Organization (FAO), the International Atomic Energy Agency, and WHO. The committee concluded that irradiation of any food commodity up to an overall average dose of 1,000 Krad (10 kGy) presents no toxicological hazard, so the testing of foods so treated need not be required.⁽²²⁾ This level of exposure is 10 times the level that the FDA is proposing.⁽¹⁵⁾ A FAO/WHO Codex Alimentarius Commission standard for irradiated food is due to be issued soon.⁽⁵⁾ However, any such standard will not be binding on the FDA.

Several individual countries also have food irradiation standards and regulations for a variety of foods.⁽²³⁾ These regulations began as early as 1960. The Netherlands has been particularly active in authorizing food irradiation.

REGULATORY FACTORS THAT COULD PROMOTE COMMERCIAL IRRADIATORS

Any regulatory action to reduce the use of pesticides, fumigants, and sterilants increases the possibility of irradiation as a replacement process.

The chemical ethylene oxide (ETO) is used as a sterilizing agent for medical instruments and as a fumigant for various items, including spices and dairy packaging. A prior Occupational, Safety, and Health Administration (OSHA) rule required employers to ensure that employees were not exposed to an ETO concentration that exceeded 50 ppm determined as an 8 hour time-weighted average. On June 22, 1984, OSHA promulgated a new and significantly lower standard of

0.5 ppm.⁽²⁴⁾ As a result, it is expected that the medical supply industry, which is already using irradiators to sterilize medical supplies, will continue to move rapidly toward irradiation as their principal means of sterilization.

The chemical ethylene dibromide (EDB) has been extensively used to preserve food in the past, but is now in jeopardy of being phased out. EDB is currently used for disinfestation of fruits and vegetables for meeting quarantine requirements for the Mediterranean fruit fly, the Mexican fruit fly, the Caribbean fruit fly, the Queensland fruit fly, the melon fly, the mango weevil, and others. It has also been used for fumigating grains. Under the Federal Environmental Pesticide Control Act, a pesticide must be registered by the Environmental Protection Agency (EPA) before it can be sold. EPA has recently taken several steps that will restrict the use of EDB. On February 6, 1984, the registration of products containing EDB and labeled for use to fumigate stored grain and grain milling equipment was suspended.⁽²⁵⁾ EPA cited concerns that EDB can potentially increase cancer risks, increase the risk of genetic damage, and cause adverse reproductive effects. On April 23, 1984, EPA revoked the exemption from tolerable bromide residues when using EDB as a post-harvest fumigant on barley, corn, oats, popcorn, rice, rye, sorghum, and wheat.⁽²⁶⁾ Finally, on May 25, 1984, EPA issued a notice that revokes the tolerance for residues of inorganic bromides in or on citrus fruits and papayas that have been fumigated after harvest with EDB.⁽²⁷⁾ Other alternatives, both chemical and nonchemical, to EDB exist. Irradiation is one nonchemical alternative being considered.

Methyl bromide is another chemical that is used extensively on those agricultural commodities that can tolerate its use. For example, methyl bromide may be used on dried fruits, tree nuts, vegetables, apples, cherries, etc. The fumigant is effective against naval orange worm, codling moth, Indian meal moth, and other such moths. Because some of these commodities are stored for extended periods and are therefore repeatedly gassed, bromide residue builds up. Several countries are seriously concerned about the potential carcinogenicity of this chemical. Thus, reduction of methyl bromide may increase export markets. It has been suggested that irradiation of these commodities

after packaging for the export market would eliminate a final gassing with methyl bromide and could effectively reduce bromide residues.

Research has been conducted on the effectiveness of irradiation in inactivating trichina parasites in ground and fresh pork. The tests have proved successful and have indicated that a low dose of about 30 Krad (.3 kGy) is required. Thus, irradiation of pork is viewed as a way to reduce the potential of contracting trichinosis, while at the same time increasing consumer demand for pork.⁽¹⁵⁾

Other Regulatory Factors

An irradiation facility can be isotope based or machine based. If it is isotope based, it will be subject to NRC regulations. The applicable regulations are principally in 10 CFR Part 20 - Standards for Protection Against Radiation, and Part 30 - Rules of General Applicability to Domestic Licensing of Byproduct Material. Additionally, OSHA has regulations for worker protection from ionizing protection at 29 CFR 1910.96. Neither NRC nor OSHA has regulatory authority over the products subject to irradiation, except to assure that products remain free of radioactive contamination.⁽²⁸⁾

Twenty-seven states have entered into an agreement with the NRC to assume regulatory authority over isotopes used to produce gamma radiation byproduct materials. The radioisotopes most likely to be used in irradiators, cobalt-60 and cesium-137, are classified as byproduct material. The regulations applicable to irradiation facilities will be the same whether a state or NRC exercises regulatory authority.

MARKET POTENTIAL FOR IRRADIATORS

Four potential markets for isotope irradiators have been selected for specific review:

- irradiation of disposable medical products for sterilization
- irradiation of pork to destroy trichina
- irradiation of Northwest cherries for disinfestation
- irradiation of Northwest apples for disinfestation.

Although electron beam and x-ray radiation may be used in each of these markets, isotope irradiators using cobalt-60 or cesium-137 sources are considered to be the chief source of ionizing radiation.

Presently in the U.S., about 35 commercial irradiator facilities are licensed by the NRC to use gamma radiation sources. All of the irradiators currently use cobalt-60 as the irradiation source. The main commodity now being irradiated is medical supplies.

Irradiation of Medical Products

The largest single use of gamma irradiation is for sterilizing disposable medical products. Gamma-based sterilization has grown from only 5% of the medical sterilization market 7 years ago to between 35 and 40% today.⁽³⁾ With restrictions being placed on the use of ETO, irradiation of disposable medical products could double by the end of the decade. Generally, medical products are packaged into large cartons and sterilized by gamma processing. Present installed capacity for medical supply sterilization is estimated to be approximately 40 million ft³ per year. If the percent of products sterilized by ionizing radiation increases by 100% by 1990 because of the restrictions of ETO and the amount of supplies grow at 1 or 2% per year, the need for irradiator capacity could double. (Depending on the radiator utilization factor of today's irradiators, future demand for irradiator capacity could double.)

The shift toward gamma radiation for sterilization of disposable medical products is already creating some concern for suppliers of gamma sources. The Atomic Energy of Canada, Limited (the principal supplier of cobalt-60) has put its customers on an allocation basis for isotope procurement. This situation creates pressure for medical supply industry to reconsider the use of electron beam technology for sterilizing low-density items and to pursue the development of cesium irradiators.

Irradiation of Pork

The FDA regulations being proposed at this time are for irradiation of commodities to be irradiated up to 100 Krad (1 kGy) a dose level adequate to inactivate trichinae. Mr. Miller of FDA has stated that no provisions were

included in the FDA proposed rules to allow commercial irradiation of pork.⁽⁵⁾ Pork is not currently being irradiated.

In recent years, pork consumption in the U.S. has accounted for about 35 to 40% of the red meat consumed. Per-capita consumption over the last 30 years has been fairly constant at about 60 pounds. The trichina stigma is believed to be limiting the demand for pork. The Committee on Trichina Safe Pork for the National Pork Producers Council has recommended that the Council pursue a policy to provide a nationwide supply of trichina-safe pork. If pork were trichina free, it is expected that a 2% increase in the domestic demand for pork would occur in the short run and an additional 1% increase in domestic demand would occur in the long run.⁽²⁴⁾ The demand for trichina-free pork would increase for the following reasons:

- People would believe that the product is safer.
- More cooking options to accommodate a wider variety of personal tastes would be available.
- The use of chemical additives would be reduced.
- Positive publicity about irradiated pork would focus attention on other healthy features of pork.
- An increase in export market activities would occur.

In recent years, the incident of trichinosis in hogs has declined from about 9.5 infected animals per 1,000 (0.95%) in the 1930s to 1.25 per 1,000 (0.125%) in the 1960s. It is estimated that in 1982 some 82 million hogs were slaughtered in the U.S. Using a 0.125% infection rate, the number of hogs slaughtered annually that have trichinosis is calculated to be about 100,000.

Several techniques for the destruction of trichina are available. Heating, refrigerating, curing, and irradiation are techniques that could be used to ensure that pork which reaches the market is trichina free. In addition, several methods have been proposed for identifying trichina-infected swine. A potential problem with the identification methods, however, is that it may be less reliable than treatments to destroy trichina.

Pork can be heat treated to kill trichina organisms by heating pork muscle tissue to 137°F.(29)

In treatment of pork by refrigeration, temperatures of -30°F and below kill trichina organisms instantly. Thus, trichina can be destroyed in pork if the center of the unit is refrigerated to -30°F. If pork is refrigerated to temperatures above -30°F, the treatment of trichina by refrigeration varies with the size of the unit of pork being refrigerated and with temperature.(24) Time-temperature-unit relationships are shown in Table 10. The unit of pork is based on the thickness of the meat or container size. Unit 1 refrigeration time is based on units with dimensions not exceeding 6 inches in thickness. Unit 2 refrigeration time is based on thicknesses between 6 and 27 inches.

TABLE 10 Temperature-Time Relationships for
Trichina Kill by Refrigeration

Temperature °F	Unit 1 <6" Thick (days)	Unit 2 6 to 27" Thick (days)
5	20	30
-10	10	20
-20	6	12

Pork can also be treated for trichina through curing. The amount of salt required and the duration and temperature of the curing process depends upon the size of the ground or chopped meat package.

Research has shown that at doses of 30 Krad (.3 kGy) encysted trichina larvae died in the enteric phase without reaching maturity. Irradiation of market-weight split pork carcasses indicates that doses as low as 8 Krad (.08 kGy) provide sterility in first-generation larvae while 15 Krad (.15 kGy) prevents emergence of the encysted larvae.

Irradiation of pork for trichina control has been evaluated as one of the more cost-effective methods of assuring trichina-free pork. Assuming that irradiators could be located near or next to slaughter plants and would be used as the only method of controlling trichina in 94% of the hogs slaughtered in

the U.S., then approximately 77,000,000 carcasses of hogs would need to be irradiated annually to meet the current demand for pork.

Hog production occurs throughout the U.S., with the heaviest concentrations being in the Midwest where about two-thirds of all hogs are produced. Slaughtering of hogs is concentrated in 84 large plants slaughtering over 250,000 head of swine per year (Table 11). These 84 plants account of about 90% of all the hogs slaughtered at federally inspected plants. If the 17 plants with volumes of between 100,000 and 250,000 hogs were included with the above plants, 94% of the hogs slaughtered in federally inspected plants are slaughtered in 101 of the 1344 slaughtering plants in the U.S.

TABLE 11. Number of Federally-Inspected Plants and Head Slaughtered by Plant Size in 1982

<u>Plant Size by No. of Hogs Slaughtered</u>	<u>Number of Plants</u>	<u>Cumulative Number of Plants</u>	<u>Head Killed (Thousands)</u>	<u>Cumulative Percentage of Head Killed</u>
<1,000	900	1,344	290	100
1,000 - 9,999	232	444	710	99.6
10,000 - 99,999	111	212	3,800	98.7
100,000 - 249,999	17	101	2,900	94.0
250,000 - 499,999	32	84	11,000	90.4
500,000 - 999,999	18	52	13,000	75.9
1 Million - 1.499 Million	28	34	34,000	59.7
>1.5 Million	<u>6</u>	6	<u>13,000</u>	16.2
Totals	1,344		79,000	

Source: American Meat Institute.

Irradiation of Northwest Cherries and Apples

A current proposal by the FDA would permit the irradiation of fresh fruit at doses not to exceed 100 Krad (1 kGy). These irradiation doses would disinfect fruit of certain insects, although they apparently would not control smaller microorganisms that are partially responsible for fruit spoilage.⁽³⁰⁾ Commercial prospects for the irradiation of Northwestern cherries and apples at

doses not exceeding 100 Krad (1 kGy) are therefore likely to be limited to the use of irradiation as an alternative to other quarantine treatments for insect control, such as chemical fumigation. Current markets for Northwest cherries and apples are discussed below. Quarantine requirements applicable to interstate and foreign shipments of these fruits also are addressed, and current methods of controlling insects are compared with irradiation treatment.

Cherries. Sweet cherries are a major crop in several areas of Washington (Yakima Valley, Wenatchee area, and Columbia Basin) and Oregon (The Dalles-Hood River area, Milton-Freewater area and Willamette Valley). The two states together grow most of the sweet cherries in the Northwest. Table 12 presents historical data on the production of sweet cherries in the Northwest. Since 1979, total utilized production in Oregon and Washington combined has ranged from 80,100 tons to 122,900 tons per season. Washington-grown cherries regularly account for the largest total harvests and are sold for fresh use nearly three times as often as for processing. In Oregon, the ratio of fresh to processed use of sweet cherries is approximately the same ratio but reversed. The major processing technique used for sweet cherries processed in Oregon is bringing to make maraschino cherries.

The acreage in cherry orchards and the number of bearing trees in Washington cherry orchards have increased somewhat since 1978. Washington cherry orchard acres and number of trees are shown for 1982 and 1978 in Table 13. The 1983 cherry harvest was unusually large, however, and does not imply an overall trend of greatly increased production.

Fruit irradiation is more likely to be directed at fresh than at processed cherries. For this reason, data on tart cherries, which are a smaller crop than sweet cherries and mostly used for processing, are not shown. Further analysis therefore concentrated on fresh, sweet cherries marketed by Northwestern growers. Total fresh cherry shipments over the last five years are also shown in Table 14.

The market destinations of Northwest fresh cherry shipments are shown in Table 14. Most of the cherries are consumed domestically, with approximately equal portions going to the West Coast (Washington, Oregon, California, Nevada and Hawaii) and North Central (Ohio, Kentucky, Missouri, Illinois, Wisconsin)

TABLE 12. Production of Sweet Cherries Grown in the Northwest:
1979-1983, with Estimates for 1984 (tons)

Sweet Cherries	1979	1980	1981	1982	1983	1984(d)
<u>Washington(a)</u>						
Total Production	67,600	52,000	46,400	66,000	89,000	65,000
Total Utilized Production(e)	67,600	48,300	44,400	50,800	80,900	NA(f)
Fresh	47,500	37,200	31,800	36,100	63,500	NA
Processed	20,100	11,100	12,600	14,700	17,400	NA
<u>Oregon(b)</u>						
Total Production	38,000	33,000	40,000	35,000	45,000	37,000
Total Utilized Production(e)	38,000	31,800	37,000	35,000	42,000	NA
Fresh	8,600	7,400	6,600	11,500	9,500	NA
Processed	29,400	24,400	30,400	23,500	32,500	NA
<u>Washington and Oregon</u>						
Total Production	105,600	85,000	86,400	101,000	134,000	102,000
Total Utilized Production(e)	105,600	80,100	81,400	85,800	122,900	NA
Fresh	56,100	44,600	38,400	47,600	73,000	NA
Processed	49,500	35,500	43,000	38,200	49,900	NA
<u>Northwest (including Washington, Oregon, Idaho, Utah and Montana)(c)</u>						
Total Fresh Cherry Shipments	56,900	43,500	38,700	47,300	73,300	NA

(a) Compiled from Washington Crop and Livestock Reporting Service 1983, 1984a, 1984b.

(b) Compiled from: USDA Statistical Reporting Service (1982, 1983, 1984). Non-Citrus Fruits and Nuts Report. Washington, D.C.

(c) Compiled from Washington Cherry Marketing Committee (1983, 1982, 1981). "Fresh Cherry Shipments: Northwest and California." Seasonal Summary. Yakima, Washington.

(d) 1984 Estimates: Washington Crop and Livestock Reporting Service. 7/20/84. Washington Agri-Facts.

(e) When total production and total utilized production differs, the most likely implication is that unharvested production accounts for the difference. Reasons for not harvesting the crop are poor crop quality (due to weather or disease) or economics (price too low to justify harvesting expense). The difference may also be due to cherries that are harvested but not used (Terri Holland, Oregon State Department of Agriculture, 8/10/84, personal communication).

(f) Not available.

states. Japan is the major importing country, excluding Canada. Significant amounts of cherries are also exported to Hong Kong and London.

The short duration of the shipping season is a salient characteristic of Northwest cherry shipments. Three-quarters of total shipments may be shipped in the space of three weeks (Washington Cherry Marketing Committee 1983). This

TABLE 13. Washington Cherry Orchard Trends

<u>Year</u>	<u># Farms</u>	<u>Acres</u>	<u>Number of Trees</u>		
			<u>Total</u>	<u>Non-Bearing</u>	<u>Bearing</u>
1982	2,066	14,277	1,381,000	337,000	1,045,000
1978	1,829	13,211	1,197,000	157,012	1,040,000

Source: USDA Statistical Reporting Service (1982). Census of Agriculture: State of Washington.

time frame implies that any capital equipment required to pack or ship fresh cherries must be able to handle large volumes of fruit during the peak season.

Apples. In value of production, apples rank among Washington's top five agricultural commodities. More apples are grown in the state (3 billion pounds in 1983) than anywhere else in the Northwest. Production and disposition of apples grown in Washington State from 1979 to 1983 are shown in Table 15. For comparative purposes, historical data for Oregon are also shown.

Exports of Washington state apples are shown in Table 16. Since 1980, Washington has exported from 12 to 16% of its total crop each year, with an annual average of 409 million pounds. Major importing countries include Taiwan, Saudi Arabia and Hong Kong.

The overriding concern of the Washington state apple industry is the effect a major increase in production will have on economic returns to apple growers. Such an increase is predicted to occur soon and extend into the 1990s due to increased acreage of bearing trees and increased yields per acre. Washington apple orchard trends and projections of crop size at four-year intervals are shown in Table 17. By the early 1990s, over 3,556 million pounds (82 million 42 lb packed boxes) are projected to be available for fresh sales, a 71% increase over 2,081 million pounds (48 million 42 lb packed boxes) averaged annually in the 1979-1983 seasons.⁽³¹⁾ Although the projections are not exact, analysis of historical data by A. Desmond O'Rourke of Washington State University (1984) suggests that actual production is unlikely to exceed the projections by more than 15% in 26 out of 32 years and unlikely to fall below the projections by more than 15% in 27 out of 32 years.

TABLE 14. Market Destination of Sweet Cherries Grown in the Northwest: 1979-1983

Northwest Fresh Cherry Shipments: Domestic and Export		1979		1980		1981		1982		1983	
		%	tons	%	tons	%	tons	%	tons	%	tons
Domestic		85.4	49,185	84.0	36,538	78.8	30,512	85.6	40,503	86.1	63,124
Canada Export		6.4	3,653	5.7	2,471	7.7	2,999	6.7	3,159	8.5	6,247
Offshore Export		7.1	4,063	10.3	4,494	13.5	5,234	7.7	3,628	5.4	3,952
Northwest Cherry Distribution: Domestic ^(a)		Percent Arrivals									
Area		1979		1980		1981		1982		1983	
1. Northeast (ME, NH, VT, MA, RI, CT, NY)		9.98		9.35		9.17		8.19		9.42	
2. Metropolitan (New York City, Adj. NY & NJ)		15.63		15.28		13.29		16.38		12.86	
3. Mid Atlantic (PA, MD, DE, DC, VA, WV, NJ)		11.51		12.63		12.63		12.28		13.37	
4. Southeast (NC, SC, GA, FL, AL, MS, TN)		5.17		5.73		6.47		6.52		6.14	
5. North Central (OH, KY, MI, IN, IL, WI)		19.50		18.42		19.86		17.60		19.84	
6. Midwest (MN, IA, MO, KS, NE, ND, SD)		10.23		10.03		9.03		9.46		8.90	
7. Southwest (AK, LA, TX, OK)		3.66		4.44		4.95		4.51		4.26	
8. Rocky Mountain (MT, ID, WY, CO, NM, UT, AZ)		3.41		3.12		3.01		3.53		3.66	
9. West Coast (WA, OR, CA, NV, HI)		20.19		20.44		20.86		20.52		20.42	
10. Miscellaneous Unload Points		.72		.56		.73		1.01		1.13	
Northwest Cherry Distribution: Exports ^(b)											
Hong Kong	N/A ^(c)			15.32		8.09		9.16		7.99	
Japan	N/A			39.02		39.41		32.23		19.44	
Other Far East	N/A			.74		.51		2.05		1.94	
London	N/A			7.22		10.78		8.06		8.86	
Other Europe	N/A			.59		2.18		.63		.43	
Mexico - South America	N/A			1.62		2.57		1.27		.11	
Canada	N/A			35.49		36.46		46.60		61.23	

(a) Percent of domestic shipments arriving at domestic locations.

(b) Percent of export shipments arriving at selected importing countries. Includes Canada.

(c) Not available.

SOURCE: Washington Cherry Marketing Committee. (1983, 1982, 1981). "Fresh Cherry Shipments: Northwest and California." Seasonal Summary. Yakima, Washington.

TABLE 15. Production of Apples Grown in Washington and Oregon:
1979-1983, with Estimates for 1984

Apples	(million pounds)					
	1979	1980	1981	1982	1983	1984 ^(a)
Washington ^(b)						
Total Production	2,620	3,000	2,760	2,615	3,000	2,900
Total Utilized Production	2,620	3,000	2,760	2,615	3,000	NA ^(c)
Fresh	1,860	2,250	2,070	2,030	2,250	NA
Processed	759	755	690	585	750	NA
Oregon ^(d)						
Total Production	170	195	155	150	155	135
Total Utilized Production	170	195	155	150	155	NA
Fresh	115	139	119	121	120	NA
Processed	55	56	36	29	35	NA

(a) Estimates from USDA Statistical Reporting Service. 7/10/84. Crop Production Report.

(b) SOURCES: 1979-1981 Data: Washington Crop of Livestock Reporting Service. 1983. Washington Agricultural Statistics 1982-83. (December). 1982-1983 Data: Washington Crop of Livestock Reporting Service. 1984. Washington Agri-Facts. Released 7/20/84.

(c) Not available.

(d) Compiled from: USDA Statistical Reporting Service. (1984, 1983, 1982). Non-Citrus Fruits and Nuts Report. Washington, D.C.

Both domestic and export markets would have to be substantially expanded to maintain prices for fresh apples. O'Rourke (1984, p. i) summarizes the situation as follows:

"Even if the domestic market could absorb 50 million boxes (compared to the record domestic sales of 42 million boxes in 1983-84) there would still be over 30 million boxes available for export, to markets which to date have never absorbed more than 13 million boxes."^(a)

It may be inferred that any measure that could expand markets for fresh Washington state apples by the end of the decade would be timely and advantageous

(a) On the average, 43.36 pounds of raw product go into each 42 lb box.

TABLE 16. Exports of Washington State Apples: 1980-1984

	Millions of Pounds ^(a)			
	9/1/80- 8/31/81	9/81- 8/82	9/82- 8/83	9/83- 7/15/84
Total Exports ^(b)	496	377	403	360
<u>Exports to Selected Offshore Destinations</u>				
Taiwan	169	87	126	82
Saudi Arabia	87	74	65	78
Hong Kong	48	39	48	48
United Kingdom	16	N/A ^(c)	7	11
Singapore	16	17	19	20
Malaysia	N/A	13	21	22
Nordic Countries ^(d)	26	N/A	N/A	N/A
Central/South America ^(e)	N/A	65	48	17
United Arab Emirates	15	N/A	N/A	N/A

(a) Used conversion factor (derived by A. Desmond O. Rourke for period from 1979-83) of 43.36 lb raw product per 42 lb box.

(b) Canada not included.

(c) N/A = Not Available.

(d) Norway, Sweden and Finland.

(e) Mexico, Central and South America.

SOURCE: Washington State Apple Commission: Washington State Department of Agriculture, Inspection Certificate (first part of destination).

to growers. At the same time, it can be expected that growers will show financial restraint in any new capital investments if prices decline as expected.

Quarantines on Northwestern Cherries and Apples. A few buyers of Northwestern cherries and apples impose quarantine restrictions on the fruit. The quarantines prevent pests from accidentally spreading to uninfested areas via the importation of infested fruit. Quarantines cover only those pests not yet found in importing regions.

Fruit irradiation, at levels that the FDA soon may approve, can disinfest cherries and apples of some pests that are currently quarantined. These quarantine requirements presently are met by chemical treatments or by growing practices that prevent initial infestation of the fruit. The quarantining

TABLE 17. Washington Apple Orchard Trends and Projected Crop Size

	1978	1982	1979-83 (actual)	1986 (projected)(a)	1990 (projected)(a)	1994 (projected)(a)
Number of Farms	4,670	5,410				
Number of Acres	111,500	146,000				
Total Number of trees	15,500,000	23,100,000		24,700,000	24,700,000	24,700,000
Nonbearing	4,440,000	8,160,000		4,330,000	3,360,000	3,400,000
Bearing	11,100,000	14,900,000		20,300,000	21,300,000	21,300,000
Total Production (million lbs)	2,150	2,620	2,720	4,190	4,560	4,720
Processing	468	585	700.0	969.0	1,050.0	1,090.0
Fresh	1,680	2,030	2,090.0	3,220.0	3,510.0	3,630.0

(a) Assumes no additional acreage planted after 1984. 4% of bearing acreage replaced each year.
 Compiled From: Washington Crop and Livestock Reporting Service. 1983. Washington Agricultural Statistics 1982-83 (December); O'Rourke, A. Desmond. 1984. The Future Size of the Washington Apple Crop. Provisional IMPACT Center Working Paper No. 1, College of Agriculture and Home Economics, Washington State University, Pullman, Washington.

parties also assure compliance by onsite supervision of packing conditions. In addition, the fruit may be sampled before it is permitted into the pest-free region.

Quarantines affecting shipments of cherries and apples from the Northwest are summarized in Table 18. California, Japan and South Korea have restrictions designed to prevent the accidental introduction of the cherry fruit fly. The codling moth is also of concern in Japan and South Korea. The codling moth already infests areas of California so a quarantine there would not be useful. However, California has a quarantine on apple maggots.

Cherry growers who wish to ship cherries to California must be certified by their state's Department of Agriculture. Certification is awarded if the grower is located and maintains a California-approved pest control district. Precautionary measures are also taken during packing and shipping.

Only cherries are fumigated currently because results with fumigation of apples have not been satisfactory. Because cherries are not currently shipped from Northwestern growers to South Korea, the only Northwestern cherries to be fumigated are those designated for Japan. All cherries exported to Japan are fumigated.

Exports of Northwestern cherries to Japan began in 1978 and between 1,500 and 3,200 tons have been exported to the Japanese each year. The annual volume of these exports appears unlikely to increase to more than 5,000 tons within the next couple of years, and unlikely to exceed 10,000 tons even within 10 years.^(a)

Apples are not shipped to Japan at present. It is unclear how the successful irradiation of apples to control for pests would affect this market. It should be assumed, however, that pest control is only one barrier to shipment of Northwest apples to Japan.

Current Methods to Control Insects. Irradiation potentially could substitute for current quarantine control methods that rid cherries of fruit flies

(a) Telephone conversation with Ken Severn 8/16/84.

TABLE 18. Quarantines on Northwest Cherries and Apples and the Amount of Fruit Affected

	Fruit	Pest	Current Compliance Method	Volume Arrivals from Northwest (tons)															
Japan	Cherry	Cherry fruit flies Codling moth	Fumigation	Shipments since Northwest cherry exports to Japan began in 1978 have ranged from 1500 - 3200 tons <table> <tr> <td>1980</td><td>1981</td><td>1982</td><td>1983</td><td>1984</td></tr> <tr> <td>2718</td><td>3245</td><td>2191</td><td>1983</td><td>2040</td></tr> </table> Maximum Projections: 5000 tons, within a couple of years; 10,000 tons, within ten years.	1980	1981	1982	1983	1984	2718	3245	2191	1983	2040					
1980	1981	1982	1983	1984															
2718	3245	2191	1983	2040															
Japan	Apple	Apple codling moth	N/A 99.968% kill required. Fumigation adversely affects quality of product	None															
California	Cherry	Cherry fruit flies (<i>Rhagoletis indiffrens</i> and <i>Rhagoletis fausta</i>)	California-approved pest control districts	Volumes not known for California alone, but cannot exceed Northwest shipments to WA, OR, CA, NV, and HI destinations of: <table> <tr> <td colspan="5">(tons)</td></tr> <tr> <td>1979</td><td>1980</td><td>1981</td><td>1982</td><td>1983</td></tr> <tr> <td>9,930</td><td>7,468</td><td>6,365</td><td>8,311</td><td>12,890</td></tr> </table>	(tons)					1979	1980	1981	1982	1983	9,930	7,468	6,365	8,311	12,890
(tons)																			
1979	1980	1981	1982	1983															
9,930	7,468	6,365	8,311	12,890															
California	Apple	Apple maggot	Unknown. (Controlled atmosphere storage?)	Unknown															
Korea	Cherry	Codling moth Fruit fly	Not available	None															
Korea	Apple	Codling moth	Unknown	Unknown															

Led From: Washington Cherry Marketing Committee. (1983, 1982, 1981). "Fresh Cherry Shipments: Northwest and California." Seasonal Summary, Yakima, Washington; State of California Department of Food and Agriculture. 1984. California Plant Quarantine Manual. Quarantine Proclamation 8 and Quarantine Proclamation 20; Conversation with Dr. Art Burditt, 8/6/84. USDA Research Station, Yakima Washington; Conversation with Ken Sevorn, Washington State Fruit Commission, 8/16/84.

and other insects. In this section, alternative techniques for meeting quarantine restrictions are compared. Their costs, effects on crop quality and indirect economic impacts of fumigation, pest control areas and irradiation are discussed. The discussion is often preliminary due to lack of information about market factors, including 1) costs of irradiation on a commercial scale, including costs of regulatory compliance, 2) effects of irradiation on crop quality, 3) consumer reaction to food irradiation, and 4) potential advances in fumigation technology. Activities in preparing fumigated cherries for export to Japan are broken down so that their need or potential for elimination, were irradiation to be used instead, can be assessed. Overall, it seems that irradiation and fumigation could become substitutes for current quarantine control methods if consumers are willing to purchase irradiated foods.

Fumigation. Fumigation is a chemical treatment that kills fruit flies, apple maggots, and their larvae. These pests might also be eliminated by irradiation treatment. Cherries are fumigated at several Northwestern locations: in Oregon both The Dalles Cherry Growers and Diamond Central have fumigation plants, and in Washington, plants are located in Wenatchee, and Yakima. Only cherries to be exported to Japan are fumigated. Fumigation of apples is a quarantine treatment approved by the California Department of Agriculture, but no apple fumigation was identified in the Northwest. It is believed that no apples are fumigated commercially due to adverse effects on fruit quality.

Fumigation costs vary greatly per pound because the amount of cherries fumigated at once can vary significantly. Costs at one plant^(a) range from an estimated 2.5 to 5.3 cents per 20-pound box for fumigant gas and labor depending on the amount of cherries fumigated. Additional handling, for packing in a "sterilized" area instead of following usual packing procedures, probably adds another 2.5 to 5.0 cents per box to costs. The fumigation chamber at this plant can hold up to 10,000/20 lb boxes (200,000 lb) of cherries. Throughput was 48,000 lb in the 1984 season, no cherries in 1983, and 240,000 to 280,000 lb in 1982. In 1984 the growing season was short, and

(a) Because this information is business sensitive, the identity of the plant is withheld in this report.

in 1983 crop quality was poor due to rain so no cherries were fumigated for sale to quality-conscious Japanese markets. Variability in processing volumes may have been less at some of the other fumigation plants where throughputs tend to be higher. However, it is apparent that cherry throughput can vary significantly and may depend on factors beyond the control of packers.

Fumigation costs include costs of meeting requirements by the United States and Japanese governments to prevent reinfestation, as well as capitalization costs. One of the most significant costs incurred may be loss of plant capability to pack domestic fruit while Japanese fruit is being packed, because of plant operation in a quarantine situation. At one large plant, an estimated 33 to 50% plant capability/day may be lost for domestic fruit while Japanese cherries are packed. This difficulty is handled by cooperation among cherry packers so that excess fruit can be packed at plants not having fumigation capabilities, while fruit these other plants wish to ship to Japan are packed at the plant with fumigation capabilities.

A cost breakdown reveals that many of the costs of fumigation would also be incurred if quarantine requirements were met by irradiation. Costs of the fumigant and additional labor for loading and unloading the fumigation chamber are specific to fumigation, but other costs of quarantine requirements would be incurred regardless of the technology used:

1. sanitary cleanup (required by USDA Animal and Plant Health Inspection Service - Plant Protection and Quarantine (APHIS-PPQ); and the Japanese inspection service, Ministry of Agriculture, Forestry and Fisheries (MAFF)
2. USDA and MAFF inspection of sanitary cleanup
3. USDA and MAFF supervision of the packing process (representatives must be present)
4. USDA and MAFF inspection of the product

5. packaging materials needed to prevent reinfestation would not be needed for cherries going to other markets (includes heavy polyethylene liner, tape to seal the bags, and quarantine stickers that apparently cost \$0.05 per 20 lb. box of cherries)
6. labor for packaging
7. extra inspection equipment to run samples (random sampling of about 10% of processing volume)
8. typing of fumigation documents
9. loss of plant capability to pack domestic fruit while packing Japanese fruit.

Northwest cherry growers finance these costs themselves. They pay USDA and the Japanese government for the services and have received no subsidies for costs of the services to date.

The primary variable cost in fumigation is the amount of gas required. With methyl bromide (a common fumigant), four different temperature ranges are permitted. At lower temperatures, more gas is needed. At 43°F (the lowest temperature permitted), 4 lb of methyl bromide per 1,000 cu. ft of chamber space is used. At 72°F (the highest temperature permitted), 2 lb of methyl bromide per 1,000 cu. ft is used.

The effects of fumigation on the fruit quality have been questioned. Some people in the industry believe that effects of fumigation on the quality of cherries are not from the fumigant but from delays in cooling the fruit. Cherries that are not fumigated may be cooled almost immediately upon leaving the orchards. The cooling of cherries to be fumigated, however, is delayed while the cherries are shipped from the orchards to the fumigation plants, fumigated (for 2-4 hours), aerated (for a minimum of 2 hours), and put into boxes. This process may postpone cooling from 8-16 hours over normal handling. The cherries are not cooled earlier since fumigation must occur at controlled, generally warmer, temperatures in compliance with APHIS-PPQ standards.

Fruit Fly Control Areas. California has eradicated some pests still found in Northwestern states. The agricultural industry in California benefits from

that eradication because commodities originating in the state are exempt from some quarantine requirements that would otherwise add to producer costs. The prevention of re-entry of the fruit fly into the state is particularly emphasized through quarantine measures affecting cherry and apple growers in the Northwest. Washington, Oregon, Idaho, Montana and Utah are covered by California quarantines against cherry fruit fly. Apples and cherries are also under quarantine in California for the Mediterranean fruit fly.

Northwestern cherry growers currently comply with California's quarantine requirements by cooperating with conditions agreed upon by their individual states and by the California State Department of Agriculture. The conditions may include controlling cherry fruit flies with trapping and spraying programs approved by an official agricultural regulatory agency. In addition, certification must be obtained for each orchard and shipper, and truckers also must follow a protocol.

The precautionary measures and certification paperwork are necessary for admission of cherries from Northwestern states into California. If a truck is not from a certified shipper, its load is rejected at the border. In addition, a 40 lb sample of fruit is taken at the border. If one larvae is found, the shipper loses shipping privileges for five days. To obtain recertification, he must clean up his entire operation and reapply. This costly error is estimated by one border inspection employee to occur to about 3 truckloads each season. However, because the larvae may probably be a result of reinfestation from control failure in a preshipping stage, irradiated fruit could also experience the same occasional load rejection.

Cold Treatment of Apples. California quarantines against apple maggots affect apples in several counties of Washington and Oregon. Nineteen Oregon counties are under the quarantine; in Washington the counties affected are limited to Clark, Klickitat, Skamania and Spokane. Fumigation is approved by the California Department of Agriculture but is not believed to be used commercially on apples. Two cold treatments are also California approved.

The cold treatments may take 40 days, 90 days or longer. Apples qualify if they are stored for at least 40 days at temperatures at or below freezing. Alternatively, apples may be stored for 90 days at 3.3°C (38°F) or below, with

gas composition and humidity controlled according to specifications in the California Commodity Treatment Manual.

Data on apple shipments to California from the Northwest could not be found, so the extent to which apple shipments are affected is unknown.

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ASSESSMENT OF THE POTENTIAL DEMAND FOR GAMMA IRRADIATORS

The immediacy of demand for gamma irradiators and the level of use varies significantly among the candidate products. The following sections address the potential demand for gamma irradiators.

SIGNIFICANT INCREASES SEEN IN THE USE OF IRRADIATORS TO STERILIZE IRRADIATED MEDICAL SUPPLIES

Today, approximately 40% of all the sterilized disposable medical supplies such as surgical gloves, gowns, bandages, hypodermic needles, sutures, and scalpels (100 million ft³/yr) are sterilized by irradiation at a dose of 2,500 Krad (25 kGy). This is an eight-fold increase over the amount of supplies that was sterilized by irradiation only seven years ago. EPA restrictions placed on ethylene oxide (ETO), a fumigant used to sterilize medical supplies, are expected to increase the use of irradiation to 60 to 80% of the sterilized medical products by 1990 (Chin) and to 90% by the year 2000 (Savinski).

Medical supplies can be sterilized using irradiation from either gamma or electron beam sources. Electron beam irradiation is useful only on low-density items with thicknesses limited to a couple inches. Gamma irradiation, on the other hand, works effectively on packaged materials having thicknesses up to carton size. Thus, gamma irradiation is the preferred method of irradiation sterilization of the 100 million ft³ of medical supplies to be sterilized.

PORK IRRADIATION MAY NOT OCCUR FOR SOME TIME

Trichina-free pork is an objective that has not been reached in the U.S. An estimated 100,000 head of hogs out of 82,000,000 slaughtered annually are infected with trichina. Although several techniques are available for the control of trichina, such as heating, refrigeration, and irradiation, irradiation of pork at 1.6 to 1.9 cents per pound is one of the lowest cost methods of controlling trichina. The preferred approach would be to irradiate whole carcasses before the process of cutting and packaging begins.

Approximately 94% of all the hogs slaughtered in federally inspected plants are slaughtered in plants with throughputs of 100,000 hogs per year.

Assuming that 94% is a reasonable percent of hogs to be irradiated if a trichina-free pork program is to be established in the U.S., then approximately 77,000,000 hog carcasses need to be irradiated annually at a dose of 30 Krad (.3 kGy). Research has shown that at doses of 30 Krad (.3 kGy) trichina larvae die. Although some research on pork trichinosis has been done and the research findings given to the FDA, it appears that it will be some time before the FDA approves regulations allowing the irradiation of pork for public consumption.

IRRADIATION: A COMPETITOR TO FUMIGATION OF NORTHWEST CHERRIES

Irradiation at dosages not exceeding 100 kilorads (1 kGy) could be used commercially as a substitute for techniques that currently control insects for quarantine purposes. The dosages to be approved probably would not eliminate micro-organisms or extend product shelf life. Also, even though irradiation is less expensive and a faster technique than those currently being used, it probably would not be used in areas not having disinfestation requirements. Thus, irradiation could be applied commercially as a substitute for control techniques currently used on produce directed to areas under quarantine. Because the only Northwestern cherries and apples affected by quarantine restrictions are those going to Japan, California, and possibly South Korea, the maximum volume of these fruits that the technology might affect equals the maximum potential demand in these three locations. This assessment applies only to the role of irradiation at the levels being considered for approval. The market impacts of fruit irradiation if higher dosages were approved could differ substantially.

If irradiation were applied to all fresh Northwestern cherries distributed to Washington, California, Oregon, Nevada, and Hawaii locations, between 6,365 and 12,890 tons of fruit would be affected each year based on shipments over the last five years (see Table 9). No projections of future demand for fresh Northwestern cherries by California buyers were located. These cherry shipments are not currently fumigated, however, they do originate from fruit fly control areas and may at some future date require disinfestation.

If irradiation were to entirely replace fumigation of Northwestern cherries, between 1,500 and 3,200 tons of fruit each year would be affected based

on shipments in the last five years (see Table 18). Maximum projections of future annual cherry purchases by the Japanese are 5,000 tons within a couple of years, and 10,000 tons within ten years.

Staff who have worked with the Japanese at Northwest Fruit Exporters indicate that this may not be the time to introduce a new technology for disinfesting cherries exported to Japan. The current export standards are increasingly acceptable. The staff believe that for several years to come, a change from fumigation to irradiation for disinfesting American cherries would be strongly resisted both by the Japanese and by exporters who do not want to impair their current success by changing an accepted practice.

The key to expanding Northwest exports of cherries to Japan seems to be improved fruit quality. The demand for high-quality cherries seems to be relatively insensitive to price, while poor quality fruit from America will not be sold in Japan at any price. The average wholesale cost of cherries directed to Japan in 1983 was \$16 per 20 lb box at U.S. warehouses, and \$32 per 20 lb box at Japanese wholesalers (with much of the increase attributable to the cost of air freight transport). These prices substantially exceed the average 1983 fresh market price of Washington cherries of \$7.74 per 20 lb box. Thus, the most crucial comparison for Japanese markets, excluding potential consumer and exporter resistance, is between the qualities of irradiated and fumigated cherries. Costs are a secondary factor.

The maximum demand of cherry irradiation at or below 100 kilorads (1 kGy) is summarized in Table 19. If fumigants are barred it is assumed that irradiation is the preferred method of disinfestation. These estimates also assume no consumer resistance to irradiated cherries and maximum projected Japanese cherry demand. Irradiation at levels that could improve keeping qualities of fresh cherries would probably open up markets that are not considered here.

UNCERTAIN DEMAND FOR IRRADIATED NORTHWEST APPLES

Exports of Washington state apples have ranged from approximately 355 to 405 millions of pounds in the past three seasons (see Table 15). None of the countries currently importing these apples has a quarantine on codling moths or

TABLE 19. Maximum Cherry Irradiation

	<u>Current Disinfestation Techniques</u>	<u>Maximum Annual Volume</u>
Exports (Japan)	Fumigation	10,000 tons within ten years
Interstate (WA, OR, CA, NV and HI)	Pest Control District	(Maximum in past 5 years) 13,000 tons
Total	Complete Substitution with Irradiation	23,000 tons (46,000,000 lb)

Sources: Interstate estimate is the maximum annual shipment since 1979 (Washington Cherry Marketing Committee 1983, 1982, 1981). Export estimate based on current market and prospects, as estimated with the aid of a model and experience by Ken Severn (Northwest Fruit Exports 1984).

other insects infesting Washington state apples. Consequently, little incentive is apparent to initiate irradiation of apples shipped to the existing export markets.

The impact that fruit irradiation would have on markets that currently do not import U.S. apples is unknown. For example, Japan currently restricts imports of U.S. apples. Japan quarantines against codling moths, which could be eliminated through irradiation. It should not be assumed, however, that limitations to pest control technologies are the only or most significant barrier to shipments of Northwest apples to Japan. As mentioned earlier, irradiation may be used as a substitute for current quarantine methods of controlling insect movement into California. The amount of apples shipped to California from the Northwest has not been determined. For purposes of this preliminary assessment it is assumed that a market for 240 million pounds of irradiated apples would be in place by the year 2000.

These preliminary observations pertain only to irradiation at dosages at or below 100 kilorads (1 kGy). The commercial impact of irradiation at levels extending shelf life and eliminating microorganisms would be more likely to open up new markets but is not assessed here.

ADDED COST FOR FOOD IRRADIATION

Because irradiation of pork, cherries, and apples will be done at the slaughter and warehouse level of production, the costs associated with irradiation of these food products will be added to wholesale market costs. The wholesale market value for pork was taken at \$50 per hundred weight (cwt) live weight. Carcass weight is assumed to be 70% of live weight. Thus, hog carcasses were valued at \$71.00 per cwt. The 1983 packing-house-door market values for fresh cherries in Washington was \$774.00 per ton and for apples \$276.00 per ton.

The potential uses of irradiators on apples and cherries have several uncertainties. Even the most quantifiable market factor, average price, is unpredictable and has varied for fresh apples by as much as 59% and for fresh cherries by as much as 60% (nominal terms) over the past five years. Average prices of Washington state apples and cherries are shown in Table 20.

The percent increase in wholesale cost of irradiated food products is estimated in Table 21.

TABLE 20. Average Prices of Washington Apples and Cherries^(a)
(nominal dollars)

Season	Cherries (\$/ton)		Apples (\$/ton)	
	Fresh	Processing	Fresh	Processing
1983	774.00	\$377.00	\$276.00	\$95.00
1982	885.00	404.00	208.00	126.00
1981	1,134.00	430.00	268.00	70.00
1980	715.00	319.00	194.00	77.00
1979	N/A	N/A	310.00	114.00

(a) Packing-house-door equivalent.

Source: Compiled from the following Washington Crop and Livestock Reporting Service publications (1983, 1984): 1983. Washington Agricultural Statistics 1982-83. (December). 1984. Washington Agri-Facts.

Released 1/18/84.

TABLE 21. Added Cost for Irradiated Food

Product	Wholesale Value	Irradiation Costs ^(a)	% Cost Increase if Irradiated
Pork	\$71.00/cwt carcass	\$1.90/cwt carcass	2.7
Cherries	\$774.00/ton fresh	\$20.00/ton fresh	2.6
Apples	\$276.00/ton fresh	\$20.00/ton fresh	7.2

(a) Based on medium-sized irradiator facility.

SUMMARY

This analysis has taken a brief look at the potential market for irradiated products in four selected product areas: disposable medical supplies, pork, and Northwest cherries and apples. Table 22 shows the amount of product that may be irradiated and the dose required for either sterilization (disposable medical supplies), parasite control (pork) or disinfestation (cherries and apples). The market for sterilized disposable medical supplies is well established and is expected to expand rapidly during the remainder of the 1980s. Although pork is not currently irradiated commercially, the FDA is reviewing data on irradiation of trichina. For this analysis it is assumed that FOA rules will allow pork to be irradiated by the late 1980s. Current proposed rules by FDA will allow cherries and apples to be disinfested by irradiation. Presently from 3,000,000 to 6,000,000 pounds of cherries are fumigated and shipped to Japan. If fumigation of these cherries were barred then it is assumed that these cherries would be irradiated. The market for irradiated cherries could climb to 20,000,000 pounds within ten years. The market for irradiated apples is much less certain. If irradiation takes the place of present quarantine practices then the market for irradiated apples to California alone could be large. Although the amount of apples currently shipped to California from the Northwest is not known, it is assumed that 240,000,000 pounds of irradiated apples would be shipped out of the Northwest by the year 2000. This level of shipment of irradiated apples plus the 20,000,000 pounds of cherries would allow a medium sized irradiator (800,000 pound per day) to operate some 330 days a year.

TABLE 22. Potential for Irradiation of Selected Products

Product	Production	Amount Irradiated			Required Radiation Dose
		1983	1988	2000	
Medical Supplies	100,000,000 ft ³	40,000,000 ft ³	80,000,000 ft ³	90,000,000 ft ³	25 Krad
Pork	82,000,000 head	-0-	-0-	77,000,000 head	25 Krad
Northwest Cherries	268,000,000 lb	-0-	-0-	20,000,000 lb	40 Krad
Apples	3,150,000,000 lb			240,000,000 lb	

The prospective quantities of irradiated products identified in Table 22 for the year 2000 have been converted into potential demand for cesium-137 in Table 23. The conversions are based on the source requirements and product throughputs specified in the designs of Section 2.0. For instance, an apple plant irradiating 800,000 lb/day (or 233.6×10^6 lb/yr at an 80% capacity factor) would require an initial source loading of 1,080,000 Ci of Cs-137, with replenishment of 117,000 Ci every fifth year. Both the initial and periodic potential cesium demand is given in Table 23 for medical supplies, pork and Northwest cherries and apples. Actual cesium demand will vary depending on the market for irradiated products and the actual plant efficiency (lb product/Ci) for each of the products.

TABLE 23. Potential Demand for Cesium-137

Product	Initial Demand		Replacement Demand (every 5 years)	
	Mega Curies	No. of WESF Capsules	Mega Curies	No. of WESF Capsules
Medical Supplies	469	15,600	51	1,690
Pork	204	6,800	22	737
Northwest Cherries and Apples	1.2	40	.13	4

Note: Initial demand refers to the quantity of curies required to initially "charge" the irradiation source rack. The periodic demand would occur every fifth year on average.

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ACRONYMS AND SYMBOLS USED

CFR	Code of Federal Regulations
Ci	Curie
CWt	Hundred Weight
EDB	ethylene dibromide
EPA	Environmental Protection Agency
ETO	ethylene oxide
FAO	United Nations Food and Agriculture Organization
FDA	Food and Drug Administration
Gy	Gray
IAEA	International Atomic Energy Agency
K	Kilo (1,000)
Mega	Mega (1,000,000)
MeV	Million Electron Volts
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration
ppm	parts per million
rad	absorbed radiation dose
U.S.C.	United States Code
WHO	World Health Organization

APPENDIX A

DETAILS OF IRRADIATOR DESIGNS

Preliminary designs have been made for commercial-size irradiation facilities to disinfest apples and pork and to sterilize medical equipment using cobalt-60 and cesium-137 as radiation sources. Three process rates were used for apples and two were used for pork and medical supplies. The major process design bases are given below along with case identification. Design data are given in Tables B.1, B.2, and B.3.

PROCESS DESIGN BASES

<u>Material Processed:</u>	Apples	<u>Case I</u>	
Purpose:		Coddling moth control	
Radiation dose, krad:		Min.	40
		Max.	100
Throughput (initial), lb/day (lb/h):			
	Case I.A.	82,000	(3,417)
	Case I.B.	800,000	(33,300)
	Case I.C.	2,500,000	(104,000)
Box size (approximate), in.		12 x 12 x 20	
Weight per box, lb		40	
Package density, g/cm ³		0.3	

Case identifications are further broken down from the above in this case and the others for use in the tables. This identifies the radiation source. For instance, Case I.A.1 refers to the use of cobalt-60; Case I.A.2, to cesium-137.

The lowest throughput of 82,000 lb/day is based on the assumption that irradiated apples could be sold in the Orient in the same quantities as sweet cherries, which are currently fumigated before shipping. The other two rates are based on the 1983 Washington apple crop of 2 million tons. If it is assumed that one-fifth of this could be processed in an irradiator, 2.2 million lb would be processed daily. A design capacity of 2.5 million lb/day would be

TABLE A.1. Preliminary Design Data for Apple Irradiators - Case 1

Minimum dose: 40 krad Maximum dose: 100 krad
 Package size (approximate): 12 x 12 x 20 in.
 Package density: 0.3 g/cm³
 Irradiator geometry: continuous motion, single direction, multipass

	Throughput, lb/day (lb/h)					
	80,000 (3,417)		800,000 (33,300)		2,500,000 (104,000)	
	Case I.A.1 Co-60	Case I.A.2 Cs-137	Case I.B.1 Co-60	Case I.B.2 Cs-137	Case I.C.1 Co-60	Case I.C.2 Cs-137
Irradiator capacity, Mrad-lb/h(a)		137		1,333		4,170
Activity required, Ci, (net)	49,000	212,000	205,000	1,080,000	736,000	3,450,000
Activity required, Ci, (gross)	53,000	400,000	220,000	1,800,000	792,000	5,750,000
Co-60 to Cs-137 ratio, Ci/Ci (net)		4.3		5.3		4.7
Number of WESF Cs-137 capsules required	--	8	--	36	--	115
Dose uniformity ratio, D_{max}/D_{min}	1.7	1.7	1.3	1.4	1.8	1.8
Source utilization efficiency, %	24	25	55	48	48	47
Number of source plaque sets (2nd parallel to 1st)	1	1	1	2	2	2
SES source plaque dimensions, in. (L x H)	120 x 40	120 x 40	240 x 70	240 x 70	240 x 70	240 x 70
Design source plaque dimensions, in. (L x H)	20 x 40	20 x 40	20 x 70	20 x 70	20 x 70	80 x 70
Air gap between target and source, in.	6	6	3	3	3	3
Radiation exposure array area dimensions, ft (W x L)	5 x 10	5 x 10	0.5 x 20	9 x 20	8 x 20	8 x 20
Product carrier, number of packages high	3	3	5	5	5 (2 deep)	5 (2 deep)
Product carrier, height, in.	36	36	60	60	60	60
Number of passes of carrier by source plaques	4	4	6	6	3	3
Product carrier residence time per pass, h	0.18	0.18	0.066	0.066	0.042	0.042
Irradiation chamber dimensions, ft	9 x 20	9 x 20	11.5 x 30	14 x 30	13 x 30	13 x 30
Concrete shield thickness (walls and roof)	5	3.8	5	4	6	4.5
Concrete shield volume - building, yd ³	431	280	575	515	786	490
Total irradiator dimensions, ft	25 x 40	22.5 x 36.3	27.5 x 50	28 x 47	36.5 x 52	35.5 x 49.5
Conveyor length, ft	190	187	317	320	256	250
Number of product carriers	114	113	190	192	154	150
Source pool dimensions, ft (W x L x Depth)	6 x 11 x 18	6 x 11 x 16.8	6 x 16 x 18	6 x 16 x 18	6 x 16 x 19.3	6 x 19 x 17
Concrete for pool, yd ³ (net)	25	18.6	33	33	35	36
Pool water volume, gal	8,100	7,500	11,800	11,800	12,800	13,200
Stainless steel lining for pool, ft ²	678	635	890	890	945	964
Source heat generation, Btu/h	2,800	7,260	12,000	32,700	42,000	104,000
Ventilation air, scfm at 60°F	80	210	400	950	1,200	3,000

(a) Irradiator capacity (Q) is determined from the product mass flow rate (w) and the minimum dose (D_{min}), i.e., $Q = w \times D_{min}$. It is given in units of power, e.g., Mrad-lb/h as above.

TABLE A.2. Preliminary Design Data for Pork Irradiators - Case II

Minimum dose: 25 krad Maximum dose: 100 krad
 Package size (approximate): 9 x 36 x 60 in.
 Package density: 1.0 g/cm³
 Irradiator geometry: continuous motion, single direction, multipass

	Throughput, hog carcasses/day (lb/h)			
	20,000 (14,000)		4,000 (28,300)	
	Case II.A.1 Co-60	Case II.A.2 Cs-137	Case II.B.1 Co-60	Case II.B.2 Cs-137
Irradiator capacity, Mrad-lb/h		354		708
Activity required, Ci, (net)	317,000	1,550,000	634,000	3,100,000
Activity required, Ci, (gross)	341,000	2,600,000	682,000	5,200,000
Co-60 to Cs-137 ratio, Ci/Ci (net)		4.9		4.9
Number of WESF Cs-137 capsules required	--	52	--	104
Dose uniformity ratio, D _{max} /D _{min}	1.8	1.9	1.8	1.9
Source utilization efficiency, %	9.5	8.9	9.5	8.9
Number of source plaque sets (2nd parallel to 1st)	1	2	2	2
SES source plaque dimensions, in. (L x H)	240 x 70	240 x 70	240 x 70	240 x 70
Design Source plaque dimensions, in. (L x H)	36 x 70	36 x 70	36 x 70	72 x 70
Air gap between target and source, in.	6	6	6	6
Radiation exposure array area dimensions, ft (W x L)	5 x 20	8 x 20	8 x 20	8 x 20
Product carrier, number of packages high (hooks used for hog carcasses)	1	1	1	1
Product carrier, height, in.	60	60	60	60
Number of passes of carrier by source plaques	4	6	6	6
Product carrier residence time per pass, h	0.068	0.068	0.034	0.034
Irradiation chamber dimensions, ft	10.5 x 30	13.5 x 30	13.5 x 30	13.5 x 30
Concrete shield thickness (walls and roof)	5.8	4.5	6	4.5
Concrete shield volume - building, yd ³	665	540	766	540
Total irradiator dimensions, ft	28 x 52.3	28.5 x 48.5	31.5 x 53	28.5 x 48.5
Conveyor length, ft	280	316	330	316
Number of product carriers	--	--	--	--
Source pool dimensions, ft (W x L x Depth)	6 x 16.5 x 19	6 x 16.5 x 17	6 x 16.5 x 19	6 x 18 x 17
Concrete for pool, yd ³ (net)	28	25	28	26
Pool water volume, gal	13,000	11,300	13,000	12,300
Stainless steel lining for pool, ft ²	954	864	954	924
Source heat generation, Btu/h	18,000	47,200	36,000	94,400
Ventilation air, scfm at 60°F	500	1,400	1,000	2,700

TABLE A.3. Preliminary Design Data for Medical Supplies Irradiators - Case III

Minimum dose: 2.5 Mrad
 Package size (nominal): 18 x 18 x 18 in.
 Package density: 0.2 g/cm³
 Irradiator geometry: continuous motion, single direction, multipass

	Throughput, lb/day (lb/h)			
	18,000 (750)		54,000 (2,250)	
	Case III.A.1 Co-60	Case III.A.2 Cs-137	Case III.B.1 Co-60	Case III.B.2 Cs-137
Irradiator capacity, Mrad-lb/h		1,880		5,625
Activity required, Ci, (net)	627,000	2,720,000	1,680,000	6,600,000
Activity required, Ci, (gross)	674,000	4,530,000	1,810,000	11,000,000
Co-60 to Cs-137 ratio, Ci/Ci (net)		4.3		3.9
Number of WESF Cs-137 capsules required	--	92	--	220
Dose uniformity ratio, D_{max}/D_{min}	1.7	1.7	1.5	1.5
Source utilization efficiency, %	25	27	29	33
Number of source plaque sets (2nd parallel to 1st)	1	2	1	2
SES source plaque dimensions, in. (L x H)	240 x 60	240 x 60	240 x 80	240 x 80
Design source plaque dimensions, in. (L x H)	18 x 60	60 x 60	36 x 80	120 x 80
Air gap between target and source, in.	3	3	3	3
Radiation exposure array area dimensions, ft (W x L)	7 x 21	11 x 21	7 x 21	11 x 21
Product carrier, number of, packages high	3	3	4	4
Product carrier, height, in.	54	54	72	72
Number of passes of carrier by source plaques	4	6	4	4
Product carrier residence time per pass, h	2	2	0.9	0.9
Irradiation chamber dimensions, ft (L x W x H)*	12.5 x 33 x 7	16.5 x 33 x 7	12.5 x 33 x 8.5	16.5 x 33 x 8.5
Concrete shield thickness (walls and roof)	6	4.5	6.3	4.5
Concrete shield volume - building, yd ³	784	623	878	656
Total irradiator dimensions, ft	31.5 x 57	32.5 x 52.5	32 x 57.8	32.5 x 52.5
Conveyor length, ft	303	350	305	350
Number of product carriers	204	233	204	233
Source pool dimensions, ft (W x L x Depth)	6 x 16.3 x 19.5	6 x 18 x 17	6 x 17 x 19.8	6 x 20.5 x 17
Concrete for pool, yd ³	29	26	30	27
Pool water volume, gal	13,000	12,300	13,800	14,000
Stainless steel lining for pool, ft ²	967	924	1,011	1,024
Source heat generation, 8tu/h	36,000	83,500	96,000	200,000
Ventilation air, scfm at 60°F	1,000	2,400	2,800	5,800

* Chamber height is 7 ft in all cases except case III.B. where it is 8.5 ft to accommodate higher source plaque.

needed to meet this capacity if the facility operated 8,000 h each year. The third facility would have one-third of this capacity, or 800,000 lb/day.

Boxes for apples have dimensions of about 12.5 x 12.5 x 20.5 in. giving a package density of 0.346 g/cm³. This was rounded to the nearest tenth and the box dimensions reduced to 12 x 12 x 20 in. for use with tabulated specific dose rates (Galanter 1971 a, b).

<u>Material Processed:</u> Pork	<u>Case II</u>	
Purpose:	Trichina elimination	
Radiation dose, krad:	Min.	25
	Max.	100
Throughput (initial), hog carcasses/day (lb/h)		
	Case II.A.	2,000 (14,000)
	Case II.B.	4,000 (28,000)
Carcass weight, lb	170	
Package density, g/cm ³	1.0	

A hog carcass is irregular in shape but, for calculational purposes, it was assumed to be 36 in. wide, 60 in. high, and 9 in. thick. This is the same as that used by CH₂M Hill (1983). The processing rates are two of those used in this reference.

<u>Material Processed:</u> Medical supplies	<u>Case III</u>	
Purpose:	Sterilization	
Radiation dose, Mrad:	2.5	
Throughput (initial), lb/day (lb/h)		
	Case III.A.	18,000 (750) ^(a)
	Case III.B.	54,000 (2,250) ^(a)
Box size, in.	18 x 18 x 18	
Package density, g/cm ³	0.2	

(a) These rates are equivalent to 6 million and 18 million lb/yr, respectively, if sustained for 8,000 h/yr, or 5.25 million and 15.75 million if annual operating time were 7000 h.

The throughputs, box size, and package density are based on typical data given by Brown (1968) for medical supplies irradiators.

IRRADIATOR DESIGN PROCEDURE

The BNL-developed standard equivalent system (SES) design procedures used are those discussed in Section 2 and described in detail in the references (Rizzo 1968; Rizzo et al 1972).

IRRADIATOR GEOMETRY

The irradiator type used in these designs has a continuous motion, single-direction, multi-pass geometry. This means that product carriers move continuously in a horizontal direction for two or more passes by a radiation source plaque. This geometry is illustrated for a typical radiation exposure array in Figure B.1. In the illustration, a product carrier containing boxes stacked three high makes two passes on each side of a radiation source plaque. At the end of a pass on one side of a source plaque, a box is positioned so that the same side of the box (Side A in Figure B.1) faces the source plaque; on the second side of the source plaque, the opposite side of the box (Side B in Figure B.1) faces the plaque. This is done to give as even a radiation dose as possible to the target. The total number of passes of a product carrier and the number of parallel source plaques are listed in the tables along with other design data. For the larger facility designs, two parallel plaques are often used for cesium-137 as well as cobalt-60 in an effort to conform as much as possible to the design procedures.

The width of a radiation exposure array depends upon the number of passes around source plaques and package width. The length of the product array depends upon the length^(a) of the SES source plaque chosen to establish specific radiation dose rates. For the lowest throughput, apple case (Case I.A.), the SES source plaque used is 120 in. long; for other cases, a 240-in. long SES source plaque was used. In the SES (static equivalent system) calculational method, it is assumed that the source plaque moves rather than the product and generates an equivalent source plaque. This is described in detail in the BNL references. The array height is established by the box height and the number of boxes in a product carrier.

(a) Throughout this section, the length specifies the major horizontal dimension of a source plaque in its use position.

FIGURE A.1. Product Radiation Exposure Array and Conveyor Serpentine in Irradiator Labyrinth

Product carriers are used in both the apple and medical supply cases (Cases I and III). Individual packages are stacked three or more high in a product carrier rather than singly, and in Case I.C., two deep. This avoids both relatively high package velocities and longer product travel distances that would otherwise be required for a minimum radiation dose. An additional benefit of greater product height appears to be improved source utilization efficiency. In Case II, hog carcasses are placed on hooks rather than in product carriers.

RADIATION SOURCE PLAQUES

According to the SES method, the length of a source plaque should be the same as that of the target for a stop-dwell system, which would be the system if pneumatic actuators were used to move product carriers from position to position. The continuous system is a variant of this. Thus, whenever possible in this study, the product package length (or width for hog carcasses) was used to establish the effective source plaque length (horizontal). The source plaque height was determined from the total product carrier package height and a source overlap allowance. Source overlap is the distance a plaque extends either above or below the product. This overlap improves the dose uniformity, the $D_{\max}/D_{\min}$ ratio.

With cobalt-60 as the radiation source, the length of a box in a product carrier usually could be used to establish the length of the source plaque. This is due to the specific activity of cobalt-60 that can be used; normally, this is in the 70 to 100 Ci/g range. Distribution of source pencils or pins of this cobalt-60 specific activity in a source plaque generally allows sufficient open space in a plaque for future replenishment. These pencils are about 40 cm long and 1 cm in diameter. Cobalt-60 source pencils were assumed to have a self-adsorption of 7%, an average of a range given by CH₂M Hill (ca 1983).

With cesium-137 as the radiation source, the dimensions of a source plaque become a function of the number of WESF cesium-137 capsules required to provide the calculated activity needed and the capsule dimensions (2.625 in. outside diameter x 20.775 in. long). This led to selection of both use of parallel

source plaques and use of plaques having lengths a few times that of the target package. This goes beyond a general limit of the SES procedures which state that the length of the static equivalent source must be no less than 7 times the length of the real source. However, for these preliminary designs, it was felt that limit could be exceeded without substantial error.

The WESF capsules were assumed to have a gross activity of 50,000 Ci each and were 60% efficient (i.e., 40% self-adsorption). The average capsule activity of WESF capsules was calculated from data given by the U.S. DOE (1983). Libby (1977) established the source efficiencies of several cesium-137 capsule sizes and chemical compounds.

IRRADIATION CHAMBER AND CONVEYOR PASSAGE

The dimensions of the irradiation chamber are based on information given by Bradburne (1972). The area dimensions are set by the radiation exposure array dimensions, allowances for monorail supports and clearances, source plaque structure, product carrier maneuvering, facility maintenance needs, and delivery of source capsule casks to the source storage pool. The amount of the area allowances was minimized to avoid an undue impact on facility costs. The chamber height was generally set to allow a maintenance man to stand erect for his work. In the cases for treatment of medical supplies, this height was increased to accommodate the taller source plaques and conveyor supports.

The width of the conveyor passage was established from product carrier width. Clearance was provided between product carriers entering and leaving the irradiation chamber through the passage and between the carrier and the labyrinth walls. Greater widths were avoided for safety purposes to preclude easy irradiation chamber entry by personnel while the source plaque was in the operation position.

CONVEYOR SYSTEM

Bradburne (1972) states that there are several types and combinations of conveyor systems that are adaptable to handling the target material in package form. Among these are continuous monorail conveyors, using one driver, and pneumatic cylinder actuator systems. In the latter system, several actuators

are used, one to move product carriers into the irradiator labyrinth, another to transfer and move the carriers along a pass in the product radiation exposure array, another to transfer product carriers between passes, and so on. In this study, for simplicity, a continuous, chain-pulled, monorail system was selected.

The overall conveyor length depends upon the length and number of source passes in a radiation exposure array, the shielding amount which determines in part the conveyor entry/exit passage length, and allowances made for loading and unloading packages from product carriers. Packages can be loaded or unloaded manually or mechanically depending on the product throughput.

The number of product carriers required is set by the conveyor length and product carrier length. It is assumed that the conveyor line would be full of product carriers.

CONCRETE SHIELDING

The thickness of concrete shielding was determined from the activity of a radiation source and the personnel dose rate allowance at the outer surface of the irradiator labyrinth walls and roof. The dose rate used is 0.25 mR/h. The walls and the roof were assumed to be the same thickness. PNL-developed computer codes ISOSHL-D-II and SLAB were used for shield thickness calculations. The amount of concrete required in cubic yards was determined from shielding thickness and irradiator areas and heights. An allowance of 5 ft below ground level was made for walls and footings.

IRRADIATOR TOTAL AREA

The total irradiator area was determined from the irradiation chamber area, conveyor passages, concrete shielding thickness, and irradiator configurations. Figures B.2 and B.3 show a plan view and a cross-section view of the typical design configuration used in most cases. Figure B.4 shows a modified version used for Case I.C. in which boxes of apples are placed two deep in product carriers which are conveyed through the irradiator. In this case, a total of three passes was used to take the product by two parallel source plaques.

FIGURE A.3. Cross Section of Irradiation Chamber, Labyrinth, etc.

FIGURE A.4. Plan View of Apple Irradiator Using Two Parallel Cobalt-60 Source Plaques: Case I.C.1.

SOURCE PLAQUE STORAGE POOL

Water storage was chosen for the radiation source plaques rather than dry storage, a complex but satisfactory alternative. The pool width was set to allow temporary placement and unloading of a source transport cask. The length was established by the location and length of the source plaque or plaques. The depth was controlled by source activity, which determined the minimum water depth above the source, and transfers of source capsules from the transport cask. The minimum water depth was determined by the same computer codes used for concrete shielding. A freeboard allowance of 1.5 ft was added to the minimum water depth to fix the total pool depth.

It was assumed that the pool concrete walls were 1 ft thick and that they were lined with 0.25-in. thick stainless steel.

HANDLING OF HEAT GENERATED BY RADIATION SOURCES

Heat is generated by radiation sources when they are in either a use position or a stored position. Cooling is provided by air ventilation for the use position or by circulated water coolers for the stored position. The amount of heat to be removed is a function of the source activity.

MISCELLANEOUS EQUIPMENT

Miscellaneous equipment are such items as a sump pump, a deionizer, a water chemical treatment system, process control and personnel safety equipment, and a number of other items. A partial list of equipment that are needed and common to all of the irradiators is below:

- Process control devices and instrumentation
- Control panel
- "Fail-safe" electrical and mechanical interlocks for source plaques
- Radiation sensors
- Fire detection and extinguishing devices
- Power supply system
- Motor control equipment
- Lighting

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APPENDIX B

CAPITAL AND O&M COST DETAILS

The details of the capital and O&M cost estimates are presented in this Appendix. Costs are identified for each of the fourteen base cases at the component level. Each case is presented on three consecutive pages with the case name identified at the top of the first page of each group.

Please note that the cost of miscellaneous site facilities is equal to 1% of all the direct costs except for source and land costs. The cost of design and engineering, construction management and fees, contingency, miscellaneous supplies, tools, parts, and operating costs, and local taxes and insurance is equal to a percent of all direct costs, including miscellaneous site facilities, but again excluding source and land costs. The specific percentages that apply are 10% for design and engineering, 15% for construction management and fees, 25% for contingency, 2.5% for miscellaneous supplies, tools, parts, and operating costs, and 2% for local taxes and insurance.

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER I.A. 1 82,000 lbs. apples/day; Co-60

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	49,000	See Summary	See Summary
Source Rack	sq. ft.	5.56	600	3,336
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	431	290	124,990
Irradiator Earthwork	cu. yd.	185	7.5	1,388
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1,000	13	13,000
Land	acres	1.25	40,000	50,000
Site Prep.	acres	1.25	10,000	12,500
Surface Coverings				
gravel	acres	.625	6,000	3,750
pavement	acres	.188	35,000	6,580
concrete	acres	.125	85,000	10,625
Product Conveyor	ft.	190	70	13,300
	chain pull (lbs.)	594	5	2,970
Source Storage Pool				
concrete walls	cu. yd.	20	290	5,800
S.S. liner	sq. yd.	75	310	23,250
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	80	See Table 4	2,500
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	200	55	11,000
Equipment & Maintenance Shop	sq. ft.	800	35	28,000
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse	sq. ft.	7,000	35	245,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	2	15,000	30,000
Misc. Site Facilities	direct cost(1)		1%	7,400
Design & Engineering	direct cost(2)		10%	75,000
Construction Management and Fees	direct cost(2)		15%	112,000
Contingency	direct cost(2)		25%	187,000
Source Replacement	Ci	6,050	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrr	14,016	15	210,240
oper/maint/RM	plant size/ mhrr	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	1,752	20	35,040
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost(2)		2.5%	18,700
Local Taxes and Insurance	direct cost(2)		2%	15,000

SUMMARY

Initial Source Curies: 49,000 Ci Co-60	Source Rplc. Period: 1 year
Initial Source Fixed Cost: \$14,840	Source Rplc. Fraction: .12346
Initial Source Variable Cost: \$1.02/Ci	Source Rplc. Fixed Cost: \$9840
Land: \$50,000	Source Rplc. Variable Cost: \$1.02/Ci
Other Capital: \$1,120,000	Labor: \$350,400/year
Peak Capacity: 82,000 lb./day	Miscellaneous O&M: \$18,700/year

- (1) In Appendix B, the cost of miscellaneous site facilities is equal to 1% of all the direct costs except for source and land costs.
- (2) In Appendix B, the cost of design and engineering, construction management and fees, contingency, miscellaneous supplies, tools, parts, and operating costs, and local taxes and insurance is equal to a percent of all direct costs, including miscellaneous site facilities, but again excluding source and land costs. The specific percentages that apply are 10% for design and engineering, 15% for construction management and fees, 25% for contingency, 2.5% for miscellaneous supplies, tools, parts, and operating costs, and 2% for local taxes and insurance.

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER I.A. 2 82,000 lbs. apples/day; Cs-137

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	212,000	See Summary	See Summary
Source Rack	sq. ft.	5.56	600	3,336
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	280	290	81,200
Irradiator Earthwork	cu. yd.	151	7.5	1,133
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	816	13	10,608
Land	acres	1.25	40,000	50,000
Site Prep.	acres	1.25	10,000	12,500
Surface Coverings				
gravel	acres	.625	6,000	3,750
pavement	acres	.188	35,000	6,580
concrete	acres	.125	85,000	10,625
Product Conveyor	ft.	187	70	13,090
	chain pull (lbs.)	594	5	2,970
Source Storage Pool				
concrete walls	cu. yd.	19	290	5,510
S.S. liner	sq. yd.	71	310	22,010
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	210	See Table 4	5,816
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	200	55	11,000
Equipment & Maintenance Shop	sq. ft.	800	35	28,000
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse	sq. ft.	7,000	35	245,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	2	15,000	30,000
Misc. Site Facilities	direct cost		1%	6,950
Design & Engineering	direct cost		10%	70,000
Construction Management and Fees	direct cost		15%	105,000
Contingency	direct cost		25%	175,000
Source Re- placement	Ci	22,960	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	14,016	15	210,240
oper/maint/RM	plant size/ mhrs	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	1,752	20	35,040
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	17,500
Local Taxes and Insurance	direct cost		2%	14,000

SUMMARY

Initial Source: 212,000 Ci Cs-137	Source Rplc. Period: 5 years
Initial Source Fixed Cost: \$11,847	Source Rplc. Fraction: .10830
Initial Source Variable Cost: (1)	Source Rplc. Fixed Cost: \$6847
Land: \$50,000	Source Rplc. Variable Cost: (1)
Other Capital: \$1,053,000	Labor: \$350,400/year
Peak Capacity: 82,000 lb./day	Miscellaneous O&M: \$17,500/year

(1) The per Ci cost of Cs-137 was determined in the indifference analysis.

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER I.B.1

800,000 lbs. apples/day; Co-60

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	205,000	See Summary	See Summary
	Source Type	Cobalt		
Source Rack	sq. ft.	9.72	600	5,832
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	575	290	166,750
Irradiator Earthwork	cu. yd.	255	7.5	1,913
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1375	13	17,875
Land	acres	3.75	40,000	150,000
Site Prep.	acres	3.75	10,000	37,500
Surface Coverings				
gravel	acres	1.125	6,000	6,750
pavement	acres	.5625	35,000	19,688
concrete	acres	.375	85,000	31,875
Product Conveyor	ft.	317	70	22,190
	chain pull (lbs.)	1596	5	7,980
Source Storage Pool				
concrete walls	cu. yd.	33	290	9,570
S.S. liner	sq. yd.	99	310	30,690
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	400	See Table 4	10,456
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	400	55	22,000
Equipment & Maintenance Shop	sq. ft.	1800	35	63,000
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse	sq. ft.	66,000	35	2,310,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	4	15,000	60,000
Misc. Site Facilities	direct cost		1%	30,250
Design & Engineering	direct cost		10%	306,000
Construction Management and Fees	direct cost		15%	458,000
Contingency	direct cost		25%	763,000
Source Replacement	Ci	25,310	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	70,080	15	1,051,200
oper/maint/RM	plant size/ mhrs	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	7,008	20	140,160
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	76,400
Local Taxes and Insurance	direct cost		2%	61,100

SUMMARY

Initial Source: 205,000 Ci Co-60	Source Rplc. Period: 1 year
Initial Source Fixed Cost: \$14,840	Source Rplc. Fraction: .12346
Initial Source Variable Cost: \$0.99/Ci	Source Rplc. Fixed Cost: \$9840
Land: \$150,000	Source Rplc. Variable Cost: \$1.02/Ci
Other Capital: \$4,583,000	Labor: \$1,296,480/year
Peak Capacity: 800,000 lb./day	Miscellaneous O&M: \$76,400/year

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrr	7,008	20	140,160
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	76,500
Local Taxes and Insurance	direct cost		2%	61,200

SUMMARY

Initial Source: 1,080,000 Ci Cs-137	Source Rplc. Period: 5 years
Initial Source Fixed Cost: \$13,694	Source Rplc. Fraction: .10830
Initial Source Variable Cost: (1)	Source Rplc. Fixed Cost: \$6847
Land: \$150,000	Source Rplc. Variable Cost: (1)
Other Capital: \$4,591,000	Labor: \$1,296,480/year
Peak Capacity: 800,000 lb./day	Miscellaneous O&M: \$76,500/year

(1) The per Ci cost of Cs-137 was determined in the indifference analysis.

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER I.B. 2

800,000 lbs. apples/day; Cs-137

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	1,080,000	See Summary	See Summary
Source Rack	sq. ft.	23.72	800	14,232
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	523	290	151,670
Irradiator Earthwork	cu. yd.	244	7.5	1,830
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1316	13	17,108
Land	acres	3.75	40,000	150,000
Site Prep.	acres	3.75	10,000	37,500
Surface Coverings				
gravel	acres	1.125	6,000	6,750
pavement	acres	.5625	35,000	19,688
concrete	acres	.375	85,000	31,875
Product Conveyor	ft.	320	70	22,400
	chain pull (lbs.)	1596	5	7,980
Source Storage Pool				
concrete walls	cu. yd.	33	290	9,570
S.S. liner	sq. yd.	99	310	30,690
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	950	see Table 4.1.1	23,310
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	400	55	22,000
Equipment & Maintenance Shop	sq. ft.	1800	35	63,000
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse	sq. ft.	66,000	35	2,310,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	4	15,000	60,000
Misc. Site Facilities	direct cost		1%	30,300
Design & Engineering	direct cost		10%	306,000
Construction Management and Fees	direct cost		15%	459,000
Contingency	direct cost		25%	765,000
Source Replacement	Ci	116,964	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	70,080	15	1,051,200
oper/maint/RM	plant size/ mhrs	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrr	7,008	20	140,160
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	76,500
Local Taxes and Insurance	direct cost		2%	61,200

SUMMARY

Initial Source: 1,080,000 Ci Cs-137	Source Rplc. Period: 5 years
Initial Source Fixed Cost: \$13,694	Source Rplc. Fraction: .10830
Initial Source Variable Cost: (1)	Source Rplc. Fixed Cost: \$6847
Land: \$150,000	Source Rplc. Variable Cost: (1)
Other Capital: \$4,591,000	Labor: \$1,296,480/year
Peak Capacity: 800,000 lb./day	Miscellaneous O&M: \$76,500/year

(1) The per Ci cost of Cs-137 was determined in the indifference analysis.

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER I.C. 1 2,500,000 lbs. apples/day; Co-60

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	736,000	See Summary	See Summary
Source Rack	sq. ft.	19.44	600	11,664
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	786	290	227,940
Irradiator Earthwork	cu. yd.	351	7.5	2,636
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1898	13	24,674
Land	acres	8.5	40,000	340,000
Site Prep.	acres	8.5	10,000	85,000
Surface Coverings				
gravel	acres	1.275	6,000	7,650
pavement	acres	1.275	35,000	44,625
concrete	acres	.85	85,000	72,250
Product Conveyor	ft.	256	70	17,920
	chain pull (lbs.)	2555	5	12,777
Source Storage Pool				
concrete walls	cu. yd.	35	290	10,150
S.S. liner	sq. yd.	105	310	32,550
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	1200	See Table 4	29,017
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	200	55	11,000
Lunchroom	sq. ft.	650	55	35,750
Equipment & Maintenance Shop	sq. ft.	2600	35	91,000
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse	sq. ft.	208,000	35	7,280,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	12	15,000	180,000
Misc. Site Facilities	direct cost		1%	83,700
Design & Engineering	direct cost		10%	846,000
Construction Management and Fees	direct cost		15%	1,268,000
Contingency	direct cost		25%	1,114,000
Source Re- placement	Ci	90,867	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	210,240	15	3,153,600
oper/maint/RM	plant size/ mhrs	14,016	15	210,240

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	14,016	20	280,320
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	211,400
Local Taxes and Insurance	direct cost		2%	169,100

SUMMARY

Initial Source: 736,000 Ci Co-60	Source Rplc. Period: 1 year
Initial Source Fixed Cost: \$29,360	Source Rplc. Fraction: .12346
Initial Source Variable Cost: \$0.97/Ci	Source Rplc. Fixed Cost: \$14,840
Land: \$340,000	Source Rplc. Variable Cost: \$1.02/Ci
Other Capital: \$12,684,000	Labor: \$3,644,160/year
Peak Capacity: 2,500,000 lb./day	Miscellaneous O&M: \$211,400/year

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER		I.C. 2 2,500,000 lbs. apples/day; Cs-137		
COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	3,450,000	See Summary	See Summary
Source Rack	sq. ft.	94.90	600	56,940
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	490	290	142,100
Irradiator Earthwork	cu. yd.	268	7.5	2,010
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1449	13	18,837
Land	acres	8.5	40,000	340,000
Site Prep.	acres	8.5	10,000	85,000
Surface Coverings				
gravel	acres	1.275	6,000	7,650
pavement	acres	1.275	35,000	44,625
concrete	acres	.85	85,000	72,250
Product Conveyor	ft.	250	70	17,500
	chain pull (lbs.)	2496	5	12,480
Source Storage Pool				
concrete walls	cu. yd.	36	290	10,440
S.S. liner	sq. yd.	107	310	33,170
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	3000	See Table 4	69,100
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	200	55	11,000
Lunchroom	sq. ft.	650	55	35,750
Equipment & Maintenance Shop	sq. ft.	2600	35	91,000
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse	sq. ft.	208,000	35	7,280,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	12	15,000	180,000
Misc. Site Facilities	direct cost		1%	83,400
Design & Engineering	direct cost		10%	842,000
Construction Management and Fees	direct cost		15%	1,263,000
Contingency	direct cost		25%	2,105,000
Source Replacement	Ci	373,635	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	210,240	15	3,153,600
oper/maint/RM	plant size/ mhrs	14,016	15	210,240

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	14,016	20	280,320
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	210,500
Local Taxes and Insurance	direct cost		2%	168,400

SUMMARY

Initial Source: 3,450,000 Ci Cs-137	Source Rplc. Period: 5 years
Initial Source Fixed Cost: \$19,235	Source Rplc. Fraction: .10830
Initial Source Variable Cost: (1)	Source Rplc. Fixed Cost: \$11,847
Land: \$340,000	Source Rplc. Variable Cost: (1)
Other Capital: \$12,628,000	Labor: \$3,644,160/year
Peak Capacity: \$2,500,000 lb./day	Miscellaneous O&M: \$210,500/year

(1) The per Ci cost of Cs-137 was determined in the indifference analysis.

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER II.A. 1 2,000 Hogs/day; Co-60 (340,000 lb/day)

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	317,000	See Summary	See Summary
Source Rack	sq. ft.	17.5	600	10,500
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	665	290	192,850
Irradiator Earthwork	cu. yd.	271	7.5	2,033
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1463	13	19,019
Land	acres	1.75	40,000	70,000
Site Prep.	acres	1.75	10,000	17,500
Surface Coverings				
gravel	acres	.70	6,000	4,200
pavement	acres	.175	35,000	6,125
concrete	acres	.175	85,000	14,875
Product Conveyor	ft.	280	70	19,600
	chain pull (lbs.)	686	5	3,430
Source Storage Pool				
concrete walls	cu. yd.	35.3	290	10,237
S.S. liner	sq. yd.	106	310	32,860
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	500	See Table 4	12,840
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	300	55	16,500
Equipment & Maintenance Shop	sq. ft.	1300	35	45,500
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse w/ Conveyor	sq. ft.	27,000	100	2,700,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts		15,000	
Misc. Site Facilities	direct cost		1%	33,100
Design & Engineering	direct cost		10%	334,000
Construction Management and Fees	direct cost		15%	501,000
Contingency	direct cost		25%	836,000
Source Re- placement	Ci	39,137	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	42,048	15	630,720
oper/maint/RM	plant size/ mhrs	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	7,008	20	140,160
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	83,600
Local Taxes and Insurance	direct cost		2%	66,900

SUMMARY

Initial Source: 317,000 Ci Co-60	Source Rplc. Period: 1 year
Initial Source Fixed Cost: \$16,200	Source Rplc. Fraction: .12346
Initial Source Variable Cost: \$.99/Ci	Source Rplc. Fixed Cost: \$13,100
Land: \$70,000	Source Rplc. Variable Cost: \$1.02/Ci
Other Capital: \$5,013,0000	Labor: \$876,000/year
Peak Capacity: 340,000 lb. (2000 hogs)/day	Miscellaneous O&M: \$83,600/year

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER II.A. 2 2,000 hogs/day; Cs-137 (340,000 lb/day)

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	1,550,000	See Summary	See Summary
Source Rack	sq. ft.	35	600	21,000
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	540	290	156,600
Irradiator Earthwork	cu. yd.	256	7.5	1,920
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1382	13	17,966
Land	acres	1.75	40,000	70,000
Site Prep.	acres	1.75	10,000	17,500
Surface Coverings				
gravel	acres	.70	6,000	4,200
pavement	acres	.175	35,000	6,125
concrete	acres	.175	85,000	14,875
Product Conveyor	ft.	316	70	22,120
	chain pull (lbs.)	769	5	3,845
Source Storage Pool				
concrete walls	cu. yd.	32	290	9,280
S.S. liner	sq. yd.	96	310	29,760
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	1400	See Table 4	33,545
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	300	55	16,500
Equipment & Maintenance Shop	sq. ft.	1300	35	45,500
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse	sq. ft.	27,000	100	2,700,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts		15,000	
Misc. Site Facilities	direct cost		1%	33,000
Design & Engineering	direct cost		10%	333,000
Construction Management and Fees	direct cost		15%	500,000
Contingency	direct cost		25%	834,000
Source Replacement	Ci	167,865	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	42,048	15	630,720
oper/maint/RM	plant size/ mhrs	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	7,008	20	140,160
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	83,400
Local Taxes and Insurance	direct cost		2%	66,700

SUMMARY

Initial Source: 1,550,000 Ci Cs-137	Source Rplc. Period: 5 years
Initial Source Fixed Cost: \$19,570	Source Rplc. Fraction: .10830
Initial Source Variable Cost: (1)	Source Rplc. Fixed Cost: \$14,785
Land: \$70,000	Source Rplc. Variable Cost: (1)
Other Capital: \$5,002,000	Labor: \$876,000/year
Peak Capacity: 2,000 Hogs (340,000 lb.)/day	Miscellaneous O&M: \$83,400/year

(1) The per Ci cost of Cs-137 was determined in the indifference analysis.

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER		II.B. 1	4,000 Hogs/day; Co-60 (680,000 lb/day)		
COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST	
Source	Ci	634,000	See Summary	See Summary	
Source Rack	sq. ft.	35	600	21,000	
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000	
Concrete Irradiator	cu. yd.	766	290	222,140	
Irradiator Earthwork	cu. yd.	309	7.5	2,318	
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1670	13	21,710	
Land	acres	2.5	40,000	100,000	
Site Prep.	acres	2.5	10,000	25,000	
Surface Coverings					
gravel	acres	.75	8,000	4,500	
pavement	acres	.25	35,000	8,750	
concrete	acres	.25	85,000	21,250	
Product Conveyor	ft.	330	70	23,100	
	chain pull (lbs.)	802	5	4,010	
Source Storage Pool					
concrete walls	cu. yd.	35.3	290	10,237	
S.S. liner	sq. yd.	106	310	32,860	
water treatment	fixed	1	10,000	10,000	
Bldg. Ventilation	SCFM	1000	See Table 4	24,456	
Instrumentation & Control	fixed	1	100,000	100,000	

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	400	55	22,000
Equipment & Maintenance Shop	sq. ft.	1700	35	59,900
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse w/ Conveyor	sq. ft.	54,000	100	5,400,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts		15,000	
Misc. Site Facilities	direct cost		1%	61,000
Design & Engineering	direct cost		10%	616,000
Construction Management and Fees	direct cost		15%	925,000
Contingency	direct cost		25%	1,541,000
Source Re- placement	Ci	78,274	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	70,080	15	1,051,200
oper/maint/RM	plant size/ mhrs	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	7,008	20	140,160
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	154,100
Local Taxes and Insurance	direct cost		2%	123,300

SUMMARY

Initial Source: 634,000 Ci Co-60	Source Rplc. Period: 1 year
Initial Source Fixed Cost: \$19,339	Source Rplc. Fraction: .12346
Initial Source Variable Cost: \$.97/Ci	Source Rplc. Fixed Cost: \$13,113
Land: \$100,000	Source Rplc. Variable Cost: \$1.02/Ci
Other Capital: \$9,247,0000	Labor: \$1,296,480/year
Peak Capacity: 680,000 (4000 Hogs)/day	Miscellaneous O&M: \$154,100/year

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER II.B. 2 4,000 Hogs/day; Cs-137 (680,000 lb/day)

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	3,100,000	See Summary	See Summary
Source Rack	sq. ft.	70	600	42,000
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	540	290	156,600
Irradiator Earthwork	cu. yd.	256	7.5	1,920
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1382	13	17,966
Land	acres	2.5	40,000	100,000
Site Prep.	acres	2.5	10,000	25,000
Surface Coverings				
gravel	acres	.75	6,000	4,500
pavement	acres	.25	35,000	8,750
concrete	acres	.25	85,000	21,250
Product Conveyor	ft.	316	70	22,120
	chain pull (lbs.)	769	5	3,845
Source Storage Pool				
concrete walls	cu. yd.	34.2	290	9,918
S.S. liner	sq. yd.	103	310	31,930
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	2700	See Table 4	62,500
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	400	55	22,000
Equipment & Maintenance Shop	sq. ft.	1700	35	59,500
Health Physics Lab	sq. ft.	300	75	22,500
Refrigerated Warehouse w/ Conveyor	sq. ft.	54,000	100	5,400,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts		15,000	
Misc. Site Facilities	direct cost		1%	60,900
Design & Engineering	direct cost		10%	615,000
Construction Management and Fees	direct cost		15%	923,000
Contingency	direct cost		25%	1,538,000
Source Replacement	Ci	335,730	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhms	70,080	15	1,051,200
oper/maint/RM	plant size/ mhms	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	7,008	20	140,160
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	153,800
Local Taxes and Insurance	direct cost		2%	123,000

SUMMARY

Initial Source: 3,100,000 Ci Cs-137	Source Rplc. Period: 5 years
Initial Source Fixed Cost: \$29,140	Source Rplc. Fraction: .10830
Initial Source Variable Cost: (1)	Source Rplc. Fixed Cost: \$14,785
Land: \$100,000	Source Rplc. Variable Cost: (1)
Other Capital: \$9,228,000	Labor: \$1,296,480
Peak Capacity: 680,000 (2000 Hogs)/day	Miscellaneous O&M: \$153,800/year
(1) The per Ci cost of Cs-137 was determined in the indifference analysis.	

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER III.A 1 18,000 lb Medical Supplies/day; Co-60

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	627,000	See Summary	See Summary
Source Rack	sq. ft.	15	600	9,000
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	784	290	227,360
Irradiator Earthwork	cu. yd.	333	7.5	2,498
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1796	13	23,348
Land	acres	1	40,000	40,000
Site Prep.	acres	1	10,000	10,000
Surface Coverings				
gravel	acres	.5	6,000	3,000
pavement	acres	.2	35,000	7,000
concrete	acres	.15	85,000	12,750
Product Conveyor	ft.	306	70	21,420
	chain pull (lbs.)	1124	5	5,620
Source Storage Pool				
concrete walls	cu. yd.	35.8	290	10,382
S.S. liner	sq. yd.	107	310	33,170
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	1000	see Table 4	24,456
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	200	55	11,000
Equipment & Maintenance Shop	sq. ft.	800	35	28,000
Health Physics Lab	sq. ft.	300	75	22,500
Warehouse	sq. ft.	2,880	25	72,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	2	15,000	30,000
Misc. Site Facilities	direct cost		1%	7,320
Design & Engineering	direct cost		10%	73,900
Construction Management and Fees	direct cost		15%	111,000
Contingency	direct cost		25%	185,000
Source Replacement	Ci	77,409	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	14,016	15	210,240
oper/maint/RM	plant size/ mhrs		15	

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	1,752	20	35,040
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	18,500
Local Taxes and Insurance	direct cost		2%	14,800

SUMMARY

Initial Source: 627,000 Ci Co-60	Source Rplc. Period: 1 year
Initial Source Fixed Cost: \$19,339	Source Rplc. Fraction: .12346
Initial Source Variable Cost: \$.97/Ci	Source Rplc. Fixed Cost: \$13,113
Land: \$40,000	Source Rplc. Variable Cost: \$1.02/Ci
Other Capital: \$1,109,000	Labor: \$245,280
Peak Capacity: 18,000 lb./day	Miscellaneous O&M: \$18,500/year

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER III.A 2 18,000 lb Medical Supplies/day; Cs-137

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	2,720,000	See Summary	See Summary
Source Rack	sq. ft.	50	600	30,000
Source Rack Hoist	capacity (lbs.)	4,000		4,000
Concrete Irradiator	cu. yd.	623	290	180,670
Irradiator Earthwork	cu. yd.	316	7.5	2,370
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1706	13	22,178
Land	acres	1	40,000	40,000
Site Prep.	acres	1	10,000	10,000
Surface Coverings				
gravel	acres	.5	6,000	3,000
pavement	acres	.2	35,000	7,000
concrete	acres	.15	85,000	12,750
Product Conveyor	ft.	350	70	24,500
	chain pull (lbs.)	1241	5	6,205
Source Storage Pool				
concrete walls	cu. yd.	34.2	290	9,918
S.S. liner	sq. yd.	103	310	31,930
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	2400	see Table 4	55,872
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	200	55	11,000
Equipment & Maintenance Shop	sq. ft.	800	35	28,000
Health Physics Lab	sq. ft.	300	75	22,500
Warehouse	sq. ft.	2,880	25	72,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	2	15,000	30,000
Misc. Site Facilities	direct cost		1%	7,380
Design & Engineering	direct cost		10%	74,600
Construction Management and Fees	direct cost		15%	112,000
Contingency	direct cost		25%	186,000
Source Re- placement	Ci	294,576	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	14,016	15	210,240
oper/maint/RM	plant size/ mhrs		15	

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	1,752	20	35,040
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	18,600
Local Taxes and Insurance	direct cost		2%	14,900

SUMMARY

Initial Source: 2,720,000 Ci Cs-137	Source Rplc. Period: 5 years
Initial Source Fixed Cost: \$29,140	Source Rplc. Fraction: .10830
Initial Source Variable Cost: (1)	Source Rplc. Fixed Cost: \$14,785
Land: \$40,000	Source Rplc. Variable Cost: (1)
Other Capital: \$1,119,000	Labor: \$245,280/year
Peak Capacity: 18,000 lb./day	Miscellaneous O&M: \$18,600/year

(1) The per Ci cost of Cs-137 was determined in the indifference analysis.

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER III.B 1 54,000 lb Medical Supplies/day; Co-60

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	1,680,000	See Summary	See Summary
	Source Type	Cobalt		
Source Rack	sq. ft.	40	600	24,000
Source Rack Hoist	capacity (lbs.)	4,000	fixed	4,000
Concrete Irradiator	cu. yd.	878	290	254,620
Irradiator Earthwork	cu. yd.	342	7.5	2,565
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1848	13	24,024
Land	acres	1.25	40,000	50,000
Site Prep.	acres	1.25	10,000	12,500
Surface Coverings				
gravel	acres	.6	6,000	3,600
pavement	acres	.25	35,000	8,750
concrete	acres	.10	85,000	8,500
Product Conveyor	ft.	305	70	21,350
	chain pull (lbs.)	1436	5	7,180
Source Storage Pool				
concrete walls	cu. yd.	37.4	290	10,846
S.S. liner	sq. yd.	112	310	34,720
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	2800	see Table 4	64,700
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	200	55	11,000
Equipment & Maintenance Shop	sq. ft.	800	35	28,000
Health Physics Lab	sq. ft.	300	75	22,500
Warehouse	sq. ft.	8,640	25	216,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	2	15,000	30,000
Misc. Site Facilities	direct cost		1%	9,600
Design & Engineering	direct cost		10%	97,300
Construction Management and Fees	direct cost		15%	146,000
Contingency	direct cost		25%	243,000
Source Replacement	Ci	207,412	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrs	14,016	15	210,240
oper/maint/RM	plant size/ mhrs	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	1,752	20	35,040
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	24,300
Local Taxes and Insurance	direct cost		2%	19,400

SUMMARY

Initial Source: 1,680,000 Ci Co-60	Source Rplc. Period: 1 year
Initial Source Fixed Cost: \$38,017	Source Rplc. Fraction: .12346
Initial Source Variable Cost: \$.95/Ci	Source Rplc. Fixed Cost: \$13,113
Land: \$50,000	Source Rplc. Variable Cost: \$.99/Ci
Other Capital: \$1,459,000	Labor: \$350,400/year
Peak Capacity: 54,000 lb./day	Miscellaneous O&M: \$24,300/year

IRRADIATION FACILITY COST ESTIMATING COMPONENTS

CASE NAME AND NUMBER III.B 2 54,000 lb Medical Supplies/day; Cs-137

COMPONENT	CONTROLLING VARIABLE(S)	QUANTITY	UNIT COST	COMPONENT COST
Source	Ci	6,600,000	See Summary	See Summary
Source Rack	sq. ft.	133 1/3	600	80,000
Source Rack Hoist	capacity (lbs.)	6,000	fixed	6,000
Concrete Irradiator	cu. yd.	656	290	190,240
Irradiator Earthwork	cu. yd.	316	7.5	2,370
Irradiator Electrical, Lighting & Fire Protection Systems	sq. ft.	1706	13	22,178
Land	acres	1.25	40,000	50,000
Site Prep.	acres	1.25	10,000	12,500
Surface Coverings				
gravel	acres	.6	6,000	3,600
pavement	acres	.25	35,000	8,750
concrete	acres	.10	85,000	8,500
Product Conveyor	ft.	350	70	24,500
	chain pull (lbs.)	1643	5	8,215
Source Storage Pool				
concrete walls	cu. yd.	35.6	290	10,324
S.S. liner	sq. yd.	114	310	35,340
water treatment	fixed	1	10,000	10,000
Bldg. Ventilation	SCFM	5800	see Table 4	129,970
Instrumentation & Control	fixed	1	100,000	100,000

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

Utility Room	sq. ft.	200	45	9,000
Control Room	sq. ft.	150	45	6,750
Office	sq. ft.	150	55	8,250
Restroom	sq. ft.	100	55	5,500
Lunchroom	sq. ft.	200	55	11,000
Equipment & Maintenance Shop	sq. ft.	800	35	28,000
Health Physics Lab	sq. ft.	300	75	22,500
Warehouse	sq. ft.	8,640	25	216,000
Emergency Generator	fixed	1	5,000	5,000
Truck Scales	fixed	1	30,000	30,000
Forklifts	plant size/ # lifts	2	15,000	30,000
Misc. Site Facilities	direct cost		1%	10,240
Design & Engineering	direct cost		10%	103,000
Construction Management and Fees	direct cost		15%	155,000
Contingency	direct cost		25%	259,000
Source Re- placement	Ci	714,780	See Summary	See Summary
Labor				
loader/unloader	plant size/ mhrrs	14,016	15	210,240
oper/maint/RM	plant size/ mhrrs	7,008	15	105,120

IRRADIATION FACILITY COST ESTIMATING COMPONENTS
(Continued)

supervisor	plant size/ mhrs	1,752	20	35,040
Misc. Supplies, Tools, Parts, & Operating Costs	direct cost		2.5%	25,900
Local Taxes and Insurance	direct cost		2%	20,700

SUMMARY

Initial Source: 6,600,000 Ci Cs-137	Source Rplc. Period: 5 years
Initial Source Fixed Cost: \$53,065	Source Rplc. Fraction: .10830
Initial Source Variable Cost: (1)	Source Rplc. Fixed Cost: \$14,785
Land: \$50,000	Source Rplc. Variable Cost: (1)
Other Capital: \$1,552,000	Labor: \$350,400/year
Peak Capacity: 54,000 lb./day	Miscellaneous O&M: \$25,900/year

(1) The per Ci cost of Cs-137 was determined in the indifference analysis.

APPENDIX C

BASE CASE FINANCIAL ANALYSIS DETAILS

The details of the levelized cost analysis are presented in this Appendix for each of the base cases analyzed. These fourteen cash flow analyses correspond to the fourteen sets of capital and O&M cost estimates presented in Appendix B. The alphanumeric symbol printed at the top of each page (I.A.1, I.A.2, etc.) identifies the product, plant capacity, and isotope for each case.

Please note that the column headed "Rad Source Cost" represents "cost" in the Co-60 cases and "equivalent value" in the Cs-137 cases. This equivalent value, when divided by the needed curies, determines the indifference value for Cs-137.

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE 1.A.1
COMMERCIAL FINANCING

DATA		RESULTS			
CAPITAL COST	\$1,120,000	ESC. RATE	0.04	NOMINAL \$	REAL \$
RAD SOURCE COST	\$44,820	ESC. RATE	0.1	NPV COSTS	\$4,467,324
SUPPLIES COST	\$18,700	ESC. RATE	0.04	ANNUALIZED COST	\$844,400
LABOR COST	\$341,640	ESC. RATE	0.07	LEVELIZED COST	\$0.035
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.025
LAND COST	\$50,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL FRAC.	0.12346	DEBT COST	0.12		
RAD REPL FIXED	\$9,840	EQUITY COST	0.10		
RAD REPL VAR	\$1.02	DEBT RATIO	0.3		
TOTAL CURRIES	49000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	82000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$50,000	\$1,120,000	\$44,820	\$18,700	\$0	\$0	\$0	\$1,203,520
1	\$0	\$0	\$17,210	\$19,822	\$365,553	\$0	\$0	\$402,585
2	\$0	\$0	\$18,523	\$21,011	\$391,144	\$0	\$0	\$430,678
3	\$0	\$0	\$19,933	\$22,172	\$418,324	\$0	\$0	\$460,728
4	\$0	\$0	\$21,457	\$23,408	\$447,820	\$0	\$0	\$492,886
5	\$0	\$0	\$23,106	\$25,025	\$479,160	\$0	\$0	\$527,290
6	\$0	\$0	\$24,890	\$26,524	\$512,710	\$0	\$0	\$564,124
7	\$0	\$0	\$26,820	\$28,118	\$548,599	\$0	\$0	\$603,537
8	\$0	\$0	\$28,911	\$29,805	\$587,001	\$0	\$0	\$645,717
9	\$0	\$0	\$31,174	\$31,593	\$628,091	\$0	\$0	\$690,859
10	\$0	\$0	\$33,627	\$33,489	\$672,058	\$0	\$0	\$739,173
11	\$0	\$0	\$36,285	\$35,498	\$719,102	\$0	\$0	\$790,884
12	\$0	\$0	\$39,144	\$37,628	\$769,439	\$0	\$0	\$844,233
13	\$0	\$0	\$42,290	\$39,884	\$823,299	\$0	\$0	\$905,476
14	\$0	\$0	\$45,680	\$42,279	\$880,930	\$0	\$0	\$968,889
15	(\$119,828)	\$0	\$0	\$0	\$942,594	\$0	(\$0)	\$942,594
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
20	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
21	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
22	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
23	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
24	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

DATA

RESULTS

CAPITAL COST	\$1,053,000	ESC. RATE	0.06	NOMINAL \$		REAL \$	
RAD SOURCE COST	\$249,287	ESC. RATE	0.06	NPV COSTS	\$4,664,421		
SUPPLIES COST	\$17,500	ESC. RATE	0.06	ANNUALIZED COST	\$844,315	ANNUALIZED COST	\$591,217
LABOR COST	\$341,440	ESC. RATE	0.07	LEVELIZED COST	\$0.035	LEVELIZED COST	\$0.025
CONV ENERGY CST	\$0	ESC. RATE	0.08				
LAND COST	\$50,000	INFLATION	0.06				
FACILITY LIFE	15	TAX RATE	0.5				
RAD REPL PERIOD	5	ITC	0.1				
RAD REPL. FRAC.	0.10030	DEBT COST	0.12				
RAD REPL FIXED	\$6,847	EQUITY COST	0.18				
RAD REPL VAR	\$1.12	DEBT RATIO	0.3				
TOTAL CURRIES	212000	OTHER TAXES	0.02				
DEPR. LIFE	5	SALVAGE VALUE	\$0				
PEAK CAPACITY	12000	CAPACITY FACTOR	0.8				
CONST. TIME	1						

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$50,000	\$1,053,000	\$249,287	\$17,500	\$0	\$0	\$0	\$1,319,787
1	\$0	\$0	\$0	\$18,550	\$345,555	\$0	\$0	\$364,105
2	\$0	\$0	\$0	\$19,463	\$391,144	\$0	\$0	\$410,607
3	\$0	\$0	\$0	\$20,443	\$418,524	\$0	\$0	\$439,366
4	\$0	\$0	\$0	\$22,093	\$447,820	\$0	\$0	\$469,914
5	\$0	\$0	\$43,575	\$23,419	\$479,168	\$0	\$0	\$546,162
6	\$0	\$0	\$0	\$24,824	\$512,710	\$0	\$0	\$537,534
7	\$0	\$0	\$0	\$26,314	\$548,599	\$0	\$0	\$574,913
8	\$0	\$0	\$0	\$27,892	\$587,001	\$0	\$0	\$614,893
9	\$0	\$0	\$0	\$29,564	\$628,091	\$0	\$0	\$657,457
10	\$0	\$0	\$58,313	\$31,340	\$672,058	\$0	\$0	\$761,711
11	\$0	\$0	\$0	\$33,229	\$719,102	\$0	\$0	\$752,322
12	\$0	\$0	\$0	\$35,213	\$769,439	\$0	\$0	\$804,652
13	\$0	\$0	\$0	\$37,326	\$823,299	\$0	\$0	\$860,626
14	\$0	\$0	\$0	\$39,566	\$880,930	\$0	\$0	\$920,496
15	(\$119,828)	\$0	\$0	\$0	\$942,594	\$0	(\$0)	\$942,594
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE I.B.1
COMMERCIAL FINANCING

DATA		RESULTS			
CAPITAL COST	\$4,583,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$217,790	ESC. RATE	0.06	NPV COSTS	\$17,778,499
SUPPLIES COST	\$76,400	ESC. RATE	0.06	ANNUALIZED COST	\$3,212,485
LABOR COST	\$1,294,400	ESC. RATE	0.07	LEVELIZED COST	\$0.014
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.010
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL. FRAC.	0.12346	DEBT COST	0.12		
RAD REPL FIXED	\$9,440	EQUITY COST	0.18		
RAD REPL VAR	\$1.02	DEBT RATIO	0.3		
TOTAL CURRIES	205000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,583,000	\$217,790	\$76,400	\$0	\$0	\$0	\$4,877,190
1	\$0	\$0	\$37,795	\$80,984	\$1,387,234	\$0	\$0	\$1,506,012
2	\$0	\$0	\$40,063	\$85,843	\$1,404,340	\$0	\$0	\$1,610,245
3	\$0	\$0	\$42,466	\$90,994	\$1,588,244	\$0	\$0	\$1,721,704
4	\$0	\$0	\$45,814	\$96,453	\$1,699,421	\$0	\$0	\$1,840,888
5	\$0	\$0	\$47,715	\$102,240	\$1,818,380	\$0	\$0	\$1,968,334
6	\$0	\$0	\$50,578	\$108,375	\$1,945,667	\$0	\$0	\$2,104,620
7	\$0	\$0	\$53,613	\$114,877	\$2,081,864	\$0	\$0	\$2,250,354
8	\$0	\$0	\$56,829	\$121,770	\$2,227,594	\$0	\$0	\$2,406,193
9	\$0	\$0	\$60,239	\$129,874	\$2,383,526	\$0	\$0	\$2,572,641
10	\$0	\$0	\$63,854	\$136,821	\$2,550,372	\$0	\$0	\$2,751,047
11	\$0	\$0	\$67,685	\$145,038	\$2,728,898	\$0	\$0	\$2,941,613
12	\$0	\$0	\$71,746	\$153,732	\$2,919,921	\$0	\$0	\$3,145,399
13	\$0	\$0	\$76,051	\$162,956	\$3,124,316	\$0	\$0	\$3,363,322
14	\$0	\$0	\$80,614	\$172,733	\$3,343,018	\$0	\$0	\$3,596,365
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE I.B.7
COMMERCIAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$4,591,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$434,894	ESC. RATE	0.06	NPV COSTS	\$17,769,587
MISC. O&M	\$76,500	ESC. RATE	0.06	ANNUALIZED COST	\$3,210,540
LABOR COST	\$1,294,480	ESC. RATE	0.07	LEVELIZED COST	\$0.014
CONV ENERGY CST	\$0	ESC. RATE	0.00	LEVELIZED COST	\$0.018
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	5	ITC	0.1		
RAD REPL FRAC.	0.10830	DEBT COST	0.12		
RAD REPL FIXED	\$6,847	EQUITY COST	0.18		
RAD REPL VAR	\$0.39	DEBT RATIO	0.3		
TOTAL CURIES	1080000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,591,000	\$434,894	\$76,500	\$0	\$0	\$0	\$5,102,394
1	\$0	\$0	\$0	\$81,890	\$1,387,234	\$0	\$0	\$1,468,124
2	\$0	\$0	\$0	\$85,955	\$1,484,340	\$0	\$0	\$1,570,295
3	\$0	\$0	\$0	\$91,113	\$1,588,244	\$0	\$0	\$1,679,356
4	\$0	\$0	\$0	\$96,579	\$1,699,421	\$0	\$0	\$1,796,000
5	\$0	\$0	\$70,207	\$102,374	\$1,818,380	\$0	\$0	\$1,990,962
6	\$0	\$0	\$0	\$108,517	\$1,945,667	\$0	\$0	\$2,054,184
7	\$0	\$0	\$0	\$115,028	\$2,081,864	\$0	\$0	\$2,196,891
8	\$0	\$0	\$0	\$121,929	\$2,227,594	\$0	\$0	\$2,349,523
9	\$0	\$0	\$0	\$129,145	\$2,383,526	\$0	\$0	\$2,512,771
10	\$0	\$0	\$93,953	\$137,000	\$2,550,372	\$0	\$0	\$2,781,325
11	\$0	\$0	\$0	\$145,120	\$2,728,898	\$0	\$0	\$2,874,118
12	\$0	\$0	\$0	\$153,933	\$2,919,921	\$0	\$0	\$3,073,854
13	\$0	\$0	\$0	\$163,169	\$3,124,314	\$0	\$0	\$3,287,483
14	\$0	\$0	\$0	\$172,959	\$3,343,018	\$0	\$0	\$3,515,977
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE I.C.1
COMMERCIAL FINANCING

DATA			RESULTS			
CAPITAL COST	\$12,684,000	ESC. RATE	0.06	NOMINAL \$	REAL \$	
RAD SOURCE COST	\$743,280	ESC. RATE	0.06	NPV COSTS	\$49,878,966	
MISC O&M	\$211,400	ESC. RATE	0.06	ANNUALIZED COST	\$9,003,588	ANNUALIZED COST \$6,304,609
LABOR COST	\$3,444,160	ESC. RATE	0.07	LEVELIZED COST	\$0.012	LEVELIZED COST \$0.009
CONV ENERGY CST	\$0	ESC. RATE	0.08			
LAND COST	\$340,000	INFLATION	0.06			
FACILITY LIFE	15	TAX RATE	0.5			
RAD REPL PERIOD	1	ITC	0.1			
RAD REPL. FRAC.	0.12346	DEBT COST	0.12			
RAD REPL FIXED	\$14,840	EQUITY COST	0.18			
RAD REPL VAR	\$1.02	DEBT RATIO	0.3			
TOTAL CURVES	736000	OTHER TAXES	0.02			
DEPR. LIFE	5	SALVAGE VALUE	\$0			
PEAK CAPACITY	2500000	CAPACITY FACTOR	0.8			
CONST. TIME	1					

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$340,000	\$12,684,000	\$743,280	\$211,400	\$0	\$0	\$0	\$13,638,680
1	\$0	\$0	\$113,975	\$224,084	\$3,499,251	\$0	\$0	\$4,237,311
2	\$0	\$0	\$120,814	\$237,529	\$4,172,199	\$0	\$0	\$4,530,542
3	\$0	\$0	\$128,063	\$251,781	\$4,464,253	\$0	\$0	\$4,844,096
4	\$0	\$0	\$135,746	\$266,888	\$4,776,750	\$0	\$0	\$5,179,384
5	\$0	\$0	\$143,891	\$282,901	\$5,111,123	\$0	\$0	\$5,537,915
6	\$0	\$0	\$152,525	\$299,875	\$5,468,902	\$0	\$0	\$5,921,301
7	\$0	\$0	\$161,676	\$317,867	\$5,851,725	\$0	\$0	\$6,331,268
8	\$0	\$0	\$171,377	\$336,939	\$6,261,345	\$0	\$0	\$6,769,662
9	\$0	\$0	\$181,659	\$357,156	\$6,699,640	\$0	\$0	\$7,238,455
10	\$0	\$0	\$192,559	\$378,585	\$7,168,614	\$0	\$0	\$7,739,758
11	\$0	\$0	\$204,112	\$401,300	\$7,670,417	\$0	\$0	\$8,275,830
12	\$0	\$0	\$216,359	\$425,378	\$8,207,347	\$0	\$0	\$8,849,084
13	\$0	\$0	\$229,341	\$450,901	\$8,781,861	\$0	\$0	\$9,462,103
14	\$0	\$0	\$243,101	\$477,955	\$9,396,591	\$0	\$0	\$10,117,647
15	(\$814,830)	\$0	\$0	\$0	\$10,054,352	\$0	(\$0)	\$10,054,352
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE I.C.2
COMMERCIAL FINANCING

DATA			RESULTS			
OTHER CAPITAL	\$12,628,000	ESC. RATE	0.06	NOMINAL \$		REAL \$
RAD SOURCE COST	\$1,468,235	ESC. RATE	0.06	NPV COSTS	\$49,843,207	
MISC. O&M	\$210,500	ESC. RATE	0.06	ANNUALIZED COST	\$8,996,354	ANNUALIZED COST \$6,299,543
LABOR COST	\$3,644,160	ESC. RATE	0.07	LEVELIZED COST	\$0.012	LEVELIZED COST \$0.009
COMV ENERGY CST	\$0	ESC. RATE	0.08			
LAND COST	\$340,000	INFLATION	0.06			
FACILITY LIFE	15	TAX RATE	0.5			
RAD REPL PERIOD	5	ITC	0.1			
RAD REPL. FRAC.	0.10830	DEBT COST	0.12			
RAD REPL FIXED	\$11,847	EQUITY COST	0.10			
RAD REPL VAR	\$0.42	DEBT RATIO	0.3			
TOTAL CURIES	3450000	OTHER TAXES	0.02			
DEPR. LIFE	5	SALVAGE VALUE	\$0			
PEAK CAPACITY	2500000	CAPACITY FACTOR	0.8			
CONST. TIME	1					

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$340,000	\$12,628,000	\$1,468,235	\$210,500	\$0	\$0	\$0	\$14,306,735
1	\$0	\$0	\$0	\$223,130	\$3,899,251	\$0	\$0	\$4,122,381
2	\$0	\$0	\$0	\$236,518	\$4,172,199	\$0	\$0	\$4,408,717
3	\$0	\$0	\$0	\$250,709	\$4,464,253	\$0	\$0	\$4,714,962
4	\$0	\$0	\$0	\$265,751	\$4,776,750	\$0	\$0	\$5,042,502
5	\$0	\$0	\$225,857	\$281,694	\$5,111,123	\$0	\$0	\$5,618,677
6	\$0	\$0	\$0	\$298,598	\$5,468,902	\$0	\$0	\$5,767,500
7	\$0	\$0	\$0	\$316,514	\$5,851,725	\$0	\$0	\$6,168,239
8	\$0	\$0	\$0	\$335,505	\$6,261,345	\$0	\$0	\$6,596,850
9	\$0	\$0	\$0	\$355,635	\$6,699,640	\$0	\$0	\$7,055,275
10	\$0	\$0	\$382,248	\$376,973	\$7,168,614	\$0	\$0	\$7,847,834
11	\$0	\$0	\$0	\$399,592	\$7,670,417	\$0	\$0	\$8,078,009
12	\$0	\$0	\$0	\$423,567	\$8,207,347	\$0	\$0	\$8,630,914
13	\$0	\$0	\$0	\$448,981	\$8,781,861	\$0	\$0	\$9,238,842
14	\$0	\$0	\$0	\$475,970	\$9,396,591	\$0	\$0	\$9,872,511
15	(\$814,830)	\$0	\$0	\$0	\$10,054,352	\$0	(\$0)	\$10,054,352
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION

13-Sep-84

CASE II.A.1

COMMERCIAL FINANCING

DATA		RESULTS			
CAPITAL COST	\$5,013,000	ESC. RATE	0.04	NOMINAL \$	REAL \$
RAD SOURCE COST	\$330,030	ESC. RATE	0.04	NPV COSTS	\$14,424,702
MISC O&M	\$83,400	ESC. RATE	0.04	ANNUALIZED COST	\$2,711,332
LABOR COST	\$874,000	ESC. RATE	0.07	LEVELIZED COST	\$0.027
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.019
LAND COST	\$70,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL. FRAC.	0.12344	DEBT COST	0.12		
RAD REPL FIXED	\$13,100	EQUITY COST	0.18		
RAD REPL VAR	\$1.02	DEBT RATIO	0.3		
TOTAL CURES	317800	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	340000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$70,000	\$5,013,000	\$330,030	\$83,400	\$0	\$0	\$0	\$5,426,630
1	\$0	\$0	\$54,201	\$88,416	\$937,320	\$0	\$0	\$1,082,137
2	\$0	\$0	\$59,573	\$93,933	\$1,002,932	\$0	\$0	\$1,156,438
3	\$0	\$0	\$63,147	\$99,349	\$1,073,138	\$0	\$0	\$1,235,854
4	\$0	\$0	\$66,936	\$105,543	\$1,148,257	\$0	\$0	\$1,320,736
5	\$0	\$0	\$70,952	\$111,874	\$1,228,635	\$0	\$0	\$1,411,463
6	\$0	\$0	\$75,209	\$118,388	\$1,314,640	\$0	\$0	\$1,508,437
7	\$0	\$0	\$79,722	\$125,703	\$1,406,665	\$0	\$0	\$1,612,090
8	\$0	\$0	\$84,505	\$133,246	\$1,505,131	\$0	\$0	\$1,722,882
9	\$0	\$0	\$89,575	\$141,240	\$1,610,490	\$0	\$0	\$1,841,304
10	\$0	\$0	\$94,950	\$149,715	\$1,723,225	\$0	\$0	\$1,967,889
11	\$0	\$0	\$100,647	\$158,698	\$1,843,850	\$0	\$0	\$2,103,195
12	\$0	\$0	\$106,686	\$168,220	\$1,972,920	\$0	\$0	\$2,247,825
13	\$0	\$0	\$113,087	\$178,313	\$2,111,024	\$0	\$0	\$2,402,424
14	\$0	\$0	\$119,872	\$189,012	\$2,258,796	\$0	\$0	\$2,567,680
15	(\$167,759)	\$0	\$0	\$0	\$2,416,912	\$0	(\$0)	\$2,416,912
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE II.A.2
COMMERCIAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$5,002,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$670,370	ESC. RATE	0.06	NPV COSTS	\$16,613,389
MISC. O&M	\$83,400	ESC. RATE	0.06	ANNUALIZED COST	\$2,708,580
LABOR COST	\$874,000	ESC. RATE	0.07	LEVELIZED COST	\$0.027
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.019
LAND COST	\$70,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	5	ITC	0.1		
RAD REPL. FRAC.	0.10830	DEBT COST	0.12		
RAD REPL FIXED	\$14,785	EQUITY COST	0.18		
RAD REPL VAR	\$0.42	DEBT RATIO	0.3		
TOTAL CURIES	1550000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	340000	CAPACITY FACTOR	0.6		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$70,000	\$5,002,000	\$670,370	\$83,400	\$0	\$0	\$0	\$5,755,970
1	\$0	\$0	\$0	\$88,404	\$937,320	\$0	\$0	\$1,025,724
2	\$0	\$0	\$0	\$93,708	\$1,002,932	\$0	\$0	\$1,096,641
3	\$0	\$0	\$0	\$99,331	\$1,073,138	\$0	\$0	\$1,172,468
4	\$0	\$0	\$0	\$105,291	\$1,148,257	\$0	\$0	\$1,253,548
5	\$0	\$0	\$114,195	\$111,608	\$1,228,635	\$0	\$0	\$1,454,378
6	\$0	\$0	\$0	\$118,304	\$1,314,640	\$0	\$0	\$1,432,944
7	\$0	\$0	\$0	\$125,403	\$1,406,665	\$0	\$0	\$1,532,067
8	\$0	\$0	\$0	\$132,927	\$1,505,131	\$0	\$0	\$1,638,058
9	\$0	\$0	\$0	\$140,903	\$1,610,490	\$0	\$0	\$1,751,393
10	\$0	\$0	\$152,730	\$149,357	\$1,723,225	\$0	\$0	\$2,025,320
11	\$0	\$0	\$0	\$158,318	\$1,843,850	\$0	\$0	\$2,002,168
12	\$0	\$0	\$0	\$167,817	\$1,972,920	\$0	\$0	\$2,140,737
13	\$0	\$0	\$0	\$177,886	\$2,111,024	\$0	\$0	\$2,288,910
14	\$0	\$0	\$0	\$188,559	\$2,258,796	\$0	\$0	\$2,447,355
15	(\$167,759)	\$0	\$0	\$0	\$2,416,912	\$0	(\$0)	\$2,416,912
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE II.B.1
COMMERCIAL FINANCING

DATA		RESULTS			
CAPITAL COST	\$9,247,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$634,319	ISC. RATE	0.06	NPV COSTS	\$24,020,496
MISC O&M	\$154,100	ESC. RATE	0.06	ANNUALIZED COST	\$4,505,371
LABOR COST	\$1,296,400	ESC. RATE	0.07	LEVELIZED COST	\$0.023
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.014
LAND COST	\$100,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.3		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL. FRAC.	0.12346	DEBT COST	0.12		
RAD REPL FIXED	\$13,113	EQUITY COST	0.18		
RAD REPL VAR	\$1.02	DEBT RATIO	0.3		
TOTAL CURIES	434000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	400000	CAPACITY FACTOR	0.6		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$100,000	\$9,247,000	\$634,319	\$154,100	\$0	\$0	\$0	\$10,035,419
1	\$0	\$0	\$98,529	\$143,344	\$1,387,234	\$0	\$0	\$1,629,107
2	\$0	\$0	\$104,441	\$173,147	\$1,484,340	\$0	\$0	\$1,761,928
3	\$0	\$0	\$110,707	\$183,534	\$1,588,244	\$0	\$0	\$1,882,487
4	\$0	\$0	\$117,350	\$194,540	\$1,699,421	\$0	\$0	\$2,011,318
5	\$0	\$0	\$124,391	\$206,221	\$1,818,380	\$0	\$0	\$2,148,992
6	\$0	\$0	\$131,854	\$218,594	\$1,945,447	\$0	\$0	\$2,296,115
7	\$0	\$0	\$139,764	\$231,709	\$2,081,864	\$0	\$0	\$2,453,339
8	\$0	\$0	\$148,152	\$245,412	\$2,227,594	\$0	\$0	\$2,621,358
9	\$0	\$0	\$157,041	\$260,349	\$2,383,524	\$0	\$0	\$2,800,915
10	\$0	\$0	\$166,463	\$275,970	\$2,550,372	\$0	\$0	\$2,992,805
11	\$0	\$0	\$176,451	\$292,528	\$2,728,898	\$0	\$0	\$3,197,877
12	\$0	\$0	\$187,038	\$310,079	\$2,919,921	\$0	\$0	\$3,417,039
13	\$0	\$0	\$198,260	\$328,684	\$3,124,316	\$0	\$0	\$3,651,260
14	\$0	\$0	\$210,156	\$348,405	\$3,343,018	\$0	\$0	\$3,901,579
15	(\$239,456)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE II.8.2
COMMERCIAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$9,228,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$1,238,140	ESC. RATE	0.06	NPV COSTS	\$24,800,334
MISC. O&M	\$153,800	ESC. RATE	0.06	ANNUALIZED COST	\$4,581,282
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.023
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.016
LAND COST	\$100,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	5	ITC	0.1		
RAD REPL FRAC.	0.10030	DEBT COST	0.12		
RAD REPL FIXED	\$14,785	EQUITY COST	0.18		
RAD REPL VAR	\$0.39	DEBT RATIO	0.3		
TOTAL CURIES	3100000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	680000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$100,000	\$9,228,000	\$1,238,140	\$153,800	\$0	\$0	\$0	\$10,619,940
1	\$0	\$0	\$0	\$163,028	\$1,387,234	\$0	\$0	\$1,550,262
2	\$0	\$0	\$0	\$172,810	\$1,484,340	\$0	\$0	\$1,657,150
3	\$0	\$0	\$0	\$183,178	\$1,588,244	\$0	\$0	\$1,771,422
4	\$0	\$0	\$0	\$194,169	\$1,699,421	\$0	\$0	\$1,893,590
5	\$0	\$0	\$195,004	\$205,819	\$1,818,380	\$0	\$0	\$2,219,203
6	\$0	\$0	\$0	\$218,168	\$1,945,467	\$0	\$0	\$2,163,635
7	\$0	\$0	\$0	\$231,250	\$2,081,864	\$0	\$0	\$2,313,112
8	\$0	\$0	\$0	\$245,134	\$2,227,594	\$0	\$0	\$2,472,728
9	\$0	\$0	\$0	\$259,842	\$2,383,524	\$0	\$0	\$2,643,367
10	\$0	\$0	\$260,962	\$275,432	\$2,550,372	\$0	\$0	\$3,086,767
11	\$0	\$0	\$0	\$291,958	\$2,728,898	\$0	\$0	\$3,020,857
12	\$0	\$0	\$0	\$309,476	\$2,919,921	\$0	\$0	\$3,229,397
13	\$0	\$0	\$0	\$328,044	\$3,124,316	\$0	\$0	\$3,452,360
14	\$0	\$0	\$0	\$347,727	\$3,343,818	\$0	\$0	\$3,690,745
15	(\$239,656)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE III.A.1
COMMERCIAL FINANCING

DATA			RESULTS			
CAPITAL COST	\$1,109,000	ESC. RATE	0.06	NOMINAL \$	REAL \$	
RAD SOURCE COST	\$627,529	ESC. RATE	0.06	NPV COSTS	\$4,943,773	
MISC O&M	\$18,500	ESC. RATE	0.06	ANNUALIZED COST	\$944,236	ANNUALIZED COST \$661,185
LABOR COST	\$245,180	ESC. RATE	0.07	LEVELIZED COST	\$0.180	LEVELIZED COST \$0.126
COMV ENERGY CST	\$0	ESC. RATE	0.08			
LAND COST	\$40,000	INFLATION	0.06			
FACILITY LIFE	15	TAX RATE	0.5			
RAD REPL PERIOD	1	ITC	0.1			
RAD REPL. FRAC.	0.12346	DEBT COST	0.12			
RAD REPL FIXED	\$13,113	EQUITY COST	0.18			
RAD REPL VAR	\$1.02	DEBT RATIO	0.3			
TOTAL CURES	627000	OTHER TAXES	0.02			
DEPR. LIFE	5	SALVAGE VALUE	\$0			
PEAK CAPACITY	18000	CAPACITY FACTOR	0.4			
CONST. TIME	1					

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$40,000	\$1,109,000	\$627,529	\$18,500	\$0	\$0	\$0	\$1,755,029
1	\$0	\$0	\$97,595	\$19,610	\$262,450	\$0	\$0	\$379,654
2	\$0	\$0	\$103,451	\$20,787	\$280,821	\$0	\$0	\$405,058
3	\$0	\$0	\$189,658	\$22,834	\$308,479	\$0	\$0	\$432,170
4	\$0	\$0	\$116,237	\$23,356	\$321,512	\$0	\$0	\$461,105
5	\$0	\$0	\$123,211	\$24,757	\$344,018	\$0	\$0	\$491,986
6	\$0	\$0	\$130,606	\$26,243	\$368,899	\$0	\$0	\$524,946
7	\$0	\$0	\$138,440	\$27,817	\$393,866	\$0	\$0	\$560,123
8	\$0	\$0	\$146,747	\$29,486	\$421,437	\$0	\$0	\$597,669
9	\$0	\$0	\$155,551	\$31,255	\$450,937	\$0	\$0	\$637,744
10	\$0	\$0	\$164,884	\$33,131	\$482,583	\$0	\$0	\$680,518
11	\$0	\$0	\$174,778	\$35,119	\$516,278	\$0	\$0	\$726,174
12	\$0	\$0	\$185,264	\$37,226	\$552,418	\$0	\$0	\$774,907
13	\$0	\$0	\$196,380	\$39,459	\$591,087	\$0	\$0	\$826,926
14	\$0	\$0	\$208,163	\$41,827	\$632,463	\$0	\$0	\$882,452
15	(\$95,862)	\$0	\$0	\$0	\$676,735	\$0	(\$0)	\$676,735
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE III.A.2
COMMERCIAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$1,119,000	ESC. RATE	0.04	NOMINAL \$	REAL \$
RAD SOURCE COST	\$1,198,740	ESC. RATE	0.06	NPV COSTS	\$4,924,108
MISC. O&M	\$18,600	ESC. RATE	0.06	ANNUALIZED COST	\$940,423
LABOR COST	\$245,200	ESC. RATE	0.07	LEVELIZED COST	\$0.179
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.125
LAND COST	\$40,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAC REPL PERIOD	5	ITC	0.1		
RAC REPL FRAC.	0.10838	DEBT COST	0.12		
RAC REPL FIXED	\$14,785	EQUITY COST	0.18		
RAC REPL VAR	\$0.43	DEBT RATIO	0.3		
TOTAL CURIES	2720000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	18000	CAPACITY FACTOR	0.8		
CONST TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$40,000	\$1,119,000	\$1,198,740	\$18,600	\$0	\$0	\$0	\$2,336,340
1	\$0	\$0	\$0	\$19,716	\$262,450	\$0	\$0	\$282,166
2	\$0	\$0	\$0	\$20,899	\$280,821	\$0	\$0	\$301,720
3	\$0	\$0	\$0	\$22,153	\$300,479	\$0	\$0	\$322,631
4	\$0	\$0	\$0	\$23,482	\$321,512	\$0	\$0	\$344,994
5	\$0	\$0	\$189,296	\$24,891	\$344,018	\$0	\$0	\$558,204
6	\$0	\$0	\$0	\$26,384	\$368,099	\$0	\$0	\$394,484
7	\$0	\$0	\$0	\$27,968	\$393,866	\$0	\$0	\$421,834
8	\$0	\$0	\$0	\$29,646	\$421,437	\$0	\$0	\$451,082
9	\$0	\$0	\$0	\$31,424	\$450,937	\$0	\$0	\$482,361
10	\$0	\$0	\$253,320	\$33,310	\$482,503	\$0	\$0	\$769,133
11	\$0	\$0	\$0	\$35,308	\$514,278	\$0	\$0	\$551,586
12	\$0	\$0	\$0	\$37,427	\$552,418	\$0	\$0	\$589,844
13	\$0	\$0	\$0	\$39,672	\$591,087	\$0	\$0	\$630,759
14	\$0	\$0	\$0	\$42,053	\$632,463	\$0	\$0	\$674,516
15	(\$95,862)	\$0	\$0	\$0	\$676,735	\$0	(\$0)	\$676,735
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE III.B.1
COMMERCIAL FINANCING

DATA		RESULTS			
CAPITAL COST	\$1,459,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$1,634,017	ESC. RATE	0.06	NPV COSTS	\$8,369,931
MISC O&M	\$24,300	ESC. RATE	0.06	ANNUALIZED COST	\$1,428,094
LABOR COST	\$350,400	ESC. RATE	0.07	LEVELIZED COST	\$0.103
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.072
LAND COST	\$50,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL FRAC	0.12346	DEBT COST	0.12		
RAD REPL FIXED	\$13,113	EQUITY COST	0.18		
RAD REPL VAR	\$0.99	DEBT RATIO	0.3		
TOTAL CURES	1680000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	54000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$50,000	\$1,459,000	\$1,634,017	\$24,300	\$0	\$0	\$0	\$3,117,317
1	\$0	\$0	\$231,359	\$25,758	\$374,928	\$0	\$0	\$632,245
2	\$0	\$0	\$245,452	\$27,303	\$401,173	\$0	\$0	\$673,929
3	\$0	\$0	\$260,179	\$28,943	\$429,255	\$0	\$0	\$718,376
4	\$0	\$0	\$275,790	\$30,678	\$459,303	\$0	\$0	\$765,771
5	\$0	\$0	\$292,338	\$32,519	\$491,454	\$0	\$0	\$816,311
6	\$0	\$0	\$309,870	\$34,470	\$525,856	\$0	\$0	\$870,204
7	\$0	\$0	\$328,471	\$36,538	\$562,466	\$0	\$0	\$927,675
8	\$0	\$0	\$348,179	\$38,731	\$602,052	\$0	\$0	\$988,962
9	\$0	\$0	\$369,070	\$41,054	\$644,194	\$0	\$0	\$1,054,320
10	\$0	\$0	\$391,214	\$43,510	\$689,290	\$0	\$0	\$1,124,021
11	\$0	\$0	\$414,686	\$46,129	\$737,540	\$0	\$0	\$1,198,355
12	\$0	\$0	\$439,568	\$48,896	\$789,168	\$0	\$0	\$1,277,632
13	\$0	\$0	\$465,942	\$51,830	\$844,410	\$0	\$0	\$1,362,182
14	\$0	\$0	\$493,898	\$54,940	\$903,518	\$0	\$0	\$1,452,357
15	(\$119,828)	\$0	\$0	\$0	\$966,765	\$0	(\$0)	\$966,765
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
CASE III.B.2
COMMERCIAL FINANCING

DATA			RESULTS			
OTHER CAPITAL	\$1,552,000	ESC. RATE	0.06	NOMINAL \$	REAL \$	
RAD SOURCE COST	\$2,957,065	ESC. RATE	0.06	NPV COSTS	\$8,370,426	
MISC. O&M	\$25,900	ESC. RATE	0.06	ANNUALIZED COST	\$1,627,498	\$1,139,627
LABOR COST	\$350,400	ESC. RATE	0.07	LEVELIZED COST	\$0.103	\$0.072
CONV ENERGY CST	\$0	ESC. RATE	0.08			
LAND COST	\$50,000	INFLATION	0.06			
FACILITY LIFE	15	TAX RATE	0.5			
RAD REPL PERIOD	5	ITC	0.1			
RAD REPL. FRAC.	0.10830	DEBT COST	0.12			
RAD REPL FIXED	\$16,705	EQUITY COST	0.10			
RAD REPL VAR	\$0.44	DEBT RATIO	0.3			
TOTAL CURES	4600000	OTHER TAXES	0.02			
DEPR. LIFE	5	SALVAGE VALUE	\$0			
PEAK CAPACITY	54000	CAPACITY FACTOR	0.8			
CONST. TIME	1					

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$50,000	\$1,552,000	\$2,957,065	\$25,900	\$0	\$0	\$0	\$4,534,965
1	\$0	\$0	\$0	\$27,454	\$374,928	\$0	\$0	\$402,382
2	\$0	\$0	\$0	\$29,101	\$401,173	\$0	\$0	\$430,274
3	\$0	\$0	\$0	\$30,847	\$429,255	\$0	\$0	\$460,102
4	\$0	\$0	\$0	\$32,698	\$459,303	\$0	\$0	\$492,001
5	\$0	\$0	\$440,662	\$34,668	\$491,454	\$0	\$0	\$966,774
6	\$0	\$0	\$0	\$36,740	\$525,856	\$0	\$0	\$562,596
7	\$0	\$0	\$0	\$38,944	\$562,666	\$0	\$0	\$601,610
8	\$0	\$0	\$0	\$41,281	\$602,052	\$0	\$0	\$643,333
9	\$0	\$0	\$0	\$43,758	\$644,196	\$0	\$0	\$687,954
10	\$0	\$0	\$589,705	\$46,383	\$689,290	\$0	\$0	\$1,325,378
11	\$0	\$0	\$0	\$49,166	\$737,540	\$0	\$0	\$786,706
12	\$0	\$0	\$0	\$52,116	\$789,168	\$0	\$0	\$841,284
13	\$0	\$0	\$0	\$55,243	\$844,410	\$0	\$0	\$899,653
14	\$0	\$0	\$0	\$58,357	\$903,518	\$0	\$0	\$962,076
15	(\$119,828)	\$0	\$0	\$0	\$966,765	\$0	(\$0)	\$966,765
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

APPENDIX D

SENSITIVITY CASE FINANCIAL ANALYSIS DETAILS

The details of the levelized cost analysis are presented in this Appendix for each of the sensitivity cases analyzed. The variation analyzed is indicated at the top of each page.

Please note that the column headed "Rad Source Cost" represents "cost" in the Co-60 cases and "equivalent value" in the Cs-137 cases. This equivalent value, when divided by the needed curies, determines the indifference value for Cs-137.

FOOD IRRADIATION CALCULATION 13-Sep-84
 SENSITIVITY A1
 SALVAGE VALUE WITH COBALT

DATA		RESULTS			
CAPITAL COST	\$4,583,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$217,790	ESC. RATE	0.06	NPV COSTS	\$17,718,426
SUPPLIES COST	\$76,400	ESC. RATE	0.06	ANNUALIZED COST	\$3,199,669
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.014
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.010
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL FRAC.	0.12346	DEBT COST	0.12		
RAD REPL FIXED	\$9,840	EQUITY COST	0.10		
RAD REPL VAR	\$1.02	DEBT RATIO	0.3		
TOTAL CUBRIES	205000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$451,929		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	OMM COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,583,000	\$217,790	\$76,400	\$0	\$0	\$0	\$4,877,190
1	\$0	\$0	\$37,795	\$80,984	\$1,387,234	\$0	\$0	\$1,506,012
2	\$0	\$0	\$40,063	\$85,843	\$1,484,340	\$0	\$0	\$1,610,245
3	\$0	\$0	\$42,466	\$90,994	\$1,588,244	\$0	\$0	\$1,721,704
4	\$0	\$0	\$45,014	\$96,453	\$1,699,421	\$0	\$0	\$1,840,888
5	\$0	\$0	\$47,715	\$102,240	\$1,818,380	\$0	\$0	\$1,968,336
6	\$0	\$0	\$50,578	\$108,375	\$1,945,667	\$0	\$0	\$2,104,620
7	\$0	\$0	\$53,613	\$114,877	\$2,081,864	\$0	\$0	\$2,250,354
8	\$0	\$0	\$56,829	\$121,770	\$2,227,594	\$0	\$0	\$2,406,193
9	\$0	\$0	\$60,239	\$129,074	\$2,383,524	\$0	\$0	\$2,572,841
10	\$0	\$0	\$63,854	\$136,821	\$2,550,372	\$0	\$0	\$2,751,047
11	\$0	\$0	\$67,685	\$145,030	\$2,728,898	\$0	\$0	\$2,941,613
12	\$0	\$0	\$71,746	\$153,732	\$2,919,921	\$0	\$0	\$3,145,399
13	\$0	\$0	\$76,051	\$162,954	\$3,124,316	\$0	\$0	\$3,363,322
14	\$0	\$0	\$80,614	\$172,733	\$3,343,018	\$0	\$0	\$3,596,365
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$451,929)	\$3,125,101
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
 SENSITIVITY 12
 SALVAGE VALUE WITH CESIUM

DATA		RESULTS			
OTHER CAPITAL	\$4,591,000	ESC. RATE	0.04	NOMINAL \$	REAL \$
RAD SOURCE COST	\$511,294	ESC. RATE	0.04	MPV COSTS	\$17,713,900
MISC O&M	\$74,500	ESC. RATE	0.04	ANNUALIZED COST	\$3,198,440
LABOR COST	\$1,294,480	ESC. RATE	0.07	LEVELIZED COST	\$0.014
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.016
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	5	ITC	0.1		
RAD REPL FRAC.	0.10838	DEBT COST	0.12		
RAD REPL FIXED	14,847	EQUITY COST	0.18		
RAD REPL VAR	\$0.47	DEBT RATIO	0.3		
TOTAL CURIES	1000000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$1,149,832		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,591,000	\$511,294	\$74,500	\$0	\$0	\$0	\$5,188,794
1	\$0	\$0	\$0	\$81,090	\$1,387,234	\$0	\$0	\$1,468,324
2	\$0	\$0	\$0	\$85,955	\$1,484,340	\$0	\$0	\$1,570,295
3	\$0	\$0	\$0	\$91,113	\$1,588,244	\$0	\$0	\$1,679,356
4	\$0	\$0	\$0	\$94,579	\$1,699,421	\$0	\$0	\$1,796,000
5	\$0	\$0	\$82,729	\$102,374	\$1,818,380	\$0	\$0	\$2,003,484
6	\$0	\$0	\$0	\$108,517	\$1,945,667	\$0	\$0	\$2,054,184
7	\$0	\$0	\$0	\$115,028	\$2,081,864	\$0	\$0	\$2,196,891
8	\$0	\$0	\$0	\$121,929	\$2,227,594	\$0	\$0	\$2,349,523
9	\$0	\$0	\$0	\$129,245	\$2,383,526	\$0	\$0	\$2,511,771
10	\$0	\$0	\$110,718	\$137,000	\$2,550,372	\$0	\$0	\$2,798,083
11	\$0	\$0	\$0	\$145,220	\$2,728,898	\$0	\$0	\$2,874,118
12	\$0	\$0	\$0	\$153,933	\$2,919,921	\$0	\$0	\$3,073,854
13	\$0	\$0	\$0	\$163,169	\$3,124,316	\$0	\$0	\$3,287,485
14	\$0	\$0	\$0	\$172,959	\$3,343,018	\$0	\$0	\$3,515,977
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$1,149,832)	\$2,427,198
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 13-Sep-84
 SENSITIVITY #1
 MUNICIPAL FINANCING ALTERNATIVE TO B1

DATA		RESULTS			
CAPITAL COST	\$4,583,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$217,798	ESC. RATE	0.06	NPV COSTS	\$21,841,992
SUPPLIES COST	\$74,400	ESC. RATE	0.06	ANNUALIZED COST	\$2,871,449
LABOR COST	\$1,294,480	ESC. RATE	0.07	LEVELIZED COST	\$0.012
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.008
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0		
RAD REPL PERIOD	1	ITC	0		
RAD REPL. FRAC.	0.12344	DEBT COST	0.1		
RAD REPL FIXED	\$9,440	EQUITY COST	0		
RAD REPL VAR	\$1.02	DEBT RATIO	1		
TOTAL CURRENIES	205000	OTHER TAXES	0		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,583,000	\$217,798	\$74,400	\$0	\$0	\$0	\$4,877,190
1	\$0	\$0	\$37,795	\$80,984	\$1,387,234	\$0	\$0	\$1,504,012
2	\$0	\$0	\$40,863	\$85,843	\$1,484,340	\$0	\$0	\$1,610,245
3	\$0	\$0	\$42,466	\$90,994	\$1,588,244	\$0	\$0	\$1,721,704
4	\$0	\$0	\$45,014	\$94,453	\$1,699,421	\$0	\$0	\$1,840,888
5	\$0	\$0	\$47,715	\$102,240	\$1,818,380	\$0	\$0	\$1,968,336
6	\$0	\$0	\$50,578	\$108,375	\$1,945,667	\$0	\$0	\$2,104,620
7	\$0	\$0	\$53,613	\$114,877	\$2,081,864	\$0	\$0	\$2,250,354
8	\$0	\$0	\$56,829	\$121,770	\$2,227,594	\$0	\$0	\$2,406,193
9	\$0	\$0	\$60,239	\$129,076	\$2,383,526	\$0	\$0	\$2,572,841
10	\$0	\$0	\$63,854	\$136,821	\$2,550,372	\$0	\$0	\$2,751,047
11	\$0	\$0	\$67,685	\$145,030	\$2,728,898	\$0	\$0	\$2,941,613
12	\$0	\$0	\$71,746	\$153,732	\$2,919,921	\$0	\$0	\$3,145,399
13	\$0	\$0	\$76,051	\$162,956	\$3,124,316	\$0	\$0	\$3,363,322
14	\$0	\$0	\$80,614	\$172,733	\$3,343,018	\$0	\$0	\$3,596,365
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY B2
 MUNICIPAL FINANCING- CASE 1B2

DATA		RESULTS			
OTHER CAPITAL	\$4,591,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$499,694	ESC. RATE	0.06	NPV COSTS	\$21,841,235
MISC. O&M	\$76,500	ESC. RATE	0.06	ANNUALIZED COST	\$2,871,550
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.012
CONV ENERGY COST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.008
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0		
RAD REPL PERIOD	5	ITC	0		
RAD REPL FRAC.	0.10830	DEBT COST	0.1		
RAD REPL FIXED	\$6,847	EQUITY COST	0		
RAD REPL VAR	\$0.45	DEBT RATIO	1		
TOTAL CURIES	1080000	OTHER TAXES	0		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,591,000	\$499,694	\$76,500	\$0	\$0	\$0	\$5,167,194
1	\$0	\$0	\$0	\$81,090	\$1,387,234	\$0	\$0	\$1,468,324
2	\$0	\$0	\$0	\$85,955	\$1,484,340	\$0	\$0	\$1,570,295
3	\$0	\$0	\$0	\$91,113	\$1,588,244	\$0	\$0	\$1,679,356
4	\$0	\$0	\$0	\$96,579	\$1,699,421	\$0	\$0	\$1,796,000
5	\$0	\$0	\$79,599	\$102,374	\$1,818,380	\$0	\$0	\$2,000,353
6	\$0	\$0	\$0	\$108,517	\$1,945,667	\$0	\$0	\$2,054,184
7	\$0	\$0	\$0	\$115,028	\$2,081,864	\$0	\$0	\$2,196,891
8	\$0	\$0	\$0	\$121,929	\$2,227,594	\$0	\$0	\$2,349,523
9	\$0	\$0	\$0	\$129,245	\$2,383,526	\$0	\$0	\$2,512,771
10	\$0	\$0	\$106,521	\$137,000	\$2,550,372	\$0	\$0	\$2,793,893
11	\$0	\$0	\$0	\$145,220	\$2,728,898	\$0	\$0	\$2,874,118
12	\$0	\$0	\$0	\$153,933	\$2,919,921	\$0	\$0	\$3,073,854
13	\$0	\$0	\$0	\$163,169	\$3,124,316	\$0	\$0	\$3,287,485
14	\$0	\$0	\$0	\$172,959	\$3,343,018	\$0	\$0	\$3,515,977
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
20	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
21	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY ANALYSIS C1- CASE IIA1 WITH MUNICIPAL FINANCING
 MUNICIPAL FINANCING

DATA			RESULTS		
CAPITAL COST	\$5,013,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$330,030	ESC. RATE	0.06	NPV COSTS	\$17,529,055
MISC O&M	\$89,600	ESC. RATE	0.06	ANNUALIZED COST	\$2,304,611
LABOR COST	\$876,000	ESC. RATE	0.07	LEVELIZED COST	\$0.023
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.016
LAND COST	\$70,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0		
RAD REPL PERIOD	1	ITC	0		
RAD REPL. FRAC.	0.12346	DEBT COST	0.1		
RAD REPL FIXED	\$13,100	EQUITY COST	0		
RAD REPL VAR	\$1.02	DEBT RATIO	1		
TOTAL CURIES	317000	OTHER TAXES	0		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	340000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$70,000	\$5,013,000	\$330,030	\$89,600	\$0	\$0	\$0	\$5,426,630
1	\$0	\$0	\$56,201	\$88,616	\$937,320	\$0	\$0	\$1,082,137
2	\$0	\$0	\$59,579	\$93,933	\$1,002,932	\$0	\$0	\$1,156,438
3	\$0	\$0	\$63,147	\$99,569	\$1,073,138	\$0	\$0	\$1,235,854
4	\$0	\$0	\$66,936	\$105,543	\$1,148,257	\$0	\$0	\$1,320,736
5	\$0	\$0	\$70,952	\$111,876	\$1,228,635	\$0	\$0	\$1,411,463
6	\$0	\$0	\$75,209	\$118,588	\$1,314,640	\$0	\$0	\$1,508,437
7	\$0	\$0	\$79,722	\$125,703	\$1,406,665	\$0	\$0	\$1,612,090
8	\$0	\$0	\$84,505	\$133,246	\$1,505,131	\$0	\$0	\$1,722,882
9	\$0	\$0	\$89,575	\$141,240	\$1,610,490	\$0	\$0	\$1,841,306
10	\$0	\$0	\$94,950	\$149,715	\$1,723,225	\$0	\$0	\$1,967,889
11	\$0	\$0	\$100,647	\$158,698	\$1,843,850	\$0	\$0	\$2,103,195
12	\$0	\$0	\$106,686	\$168,220	\$1,972,920	\$0	\$0	\$2,247,825
13	\$0	\$0	\$113,087	\$178,313	\$2,111,024	\$0	\$0	\$2,402,424
14	\$0	\$0	\$119,872	\$189,012	\$2,258,796	\$0	\$0	\$2,567,680
15	(\$167,759)	\$0	\$0	\$0	\$2,416,912	\$0	(\$0)	\$2,416,912
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY ANALYSIS C2- CASE IIA2 WITH MUNICIPAL FINANCING
 MUNICIPAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$5,002,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$763,570	ESC. RATE	0.06	NPV COSTS	\$17,525,813
MISC. O&M	\$83,400	ESC. RATE	0.06	ANNUALIZED COST	\$2,304,185
LABOR COST	\$876,000	ESC. RATE	0.07	LEVELIZED COST	\$0.023
CONV ENERGY COST	\$0	ESC. RATE	0.08		
LAND COST	\$70,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0		
RAD REPL PERIOD	5	ITC	0		
RAD REPL FRAC.	0.10830	DEBT COST	0.1		
RAD REPL FIXED	\$14,785	EQUITY COST	0		
RAD REPL VAR	\$0.48	DEBT RATIO	1		
TOTAL CURIES	1550000	OTHER TAXES	0		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	340000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$70,000	\$5,002,000	\$763,570	\$83,400	\$0	\$0	\$0	\$5,848,970
1	\$0	\$0	\$0	\$88,404	\$937,320	\$0	\$0	\$1,025,724
2	\$0	\$0	\$0	\$93,708	\$1,002,932	\$0	\$0	\$1,096,641
3	\$0	\$0	\$0	\$99,331	\$1,073,138	\$0	\$0	\$1,172,468
4	\$0	\$0	\$0	\$105,291	\$1,148,257	\$0	\$0	\$1,253,548
5	\$0	\$0	\$127,613	\$111,608	\$1,228,635	\$0	\$0	\$1,467,857
6	\$0	\$0	\$0	\$118,304	\$1,314,640	\$0	\$0	\$1,432,944
7	\$0	\$0	\$0	\$125,403	\$1,406,665	\$0	\$0	\$1,532,067
8	\$0	\$0	\$0	\$132,927	\$1,505,131	\$0	\$0	\$1,638,058
9	\$0	\$0	\$0	\$140,903	\$1,610,490	\$0	\$0	\$1,751,393
10	\$0	\$0	\$170,776	\$149,357	\$1,723,225	\$0	\$0	\$2,043,357
11	\$0	\$0	\$0	\$158,318	\$1,843,850	\$0	\$0	\$2,002,168
12	\$0	\$0	\$0	\$167,817	\$1,972,920	\$0	\$0	\$2,140,737
13	\$0	\$0	\$0	\$177,886	\$2,111,024	\$0	\$0	\$2,288,910
14	\$0	\$0	\$0	\$188,559	\$2,258,796	\$0	\$0	\$2,447,355
15	(\$167,759)	\$0	\$0	\$0	\$2,416,912	\$0	(\$0)	\$2,416,912
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY ANALYSIS 01- MUNICIPAL FINANCING CASE IIIA1
 MUNICIPAL FINANCING

DATA	RESULTS			
CAPITAL COST	\$1,109,000	ESC. RATE	0.06	NOMINAL \$
RAD SOURCE COST	\$627,529	ESC. RATE	0.06	NPV COSTS \$5,927,845
MISC O&M	\$18,500	ESC. RATE	0.06	ANNUALIZED COST \$779,356
LABOR COST	\$245,280	ESC. RATE	0.07	LEVELIZED COST \$0.148
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST \$0.100
LAND COST	\$40,000	INFLATION	0.06	
FACILITY LIFE	15	TAX RATE	0	
RAD REPL PERIOD	1	ITC	0	
RAD REPL. FRAC.	0.12346	DEBT COST	0.1	
RAD REPL FIXED	\$13,113	EQUITY COST	0	
RAD REPL VAR	\$1.02	DEBT RATIO	1	
TOTAL CURIES	627000	OTHER TAXES	0	
DEPR. LIFE	5	SALVAGE VALUE	\$0	
PEAK CAPACITY	18000	CAPACITY FACTOR	0.8	
CONST. TIME	1			

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$40,000	\$1,109,000	\$627,529	\$18,500	\$0	\$0	\$0	\$1,755,029
1	\$0	\$0	\$97,595	\$19,610	\$262,450	\$0	\$0	\$379,654
2	\$0	\$0	\$103,451	\$20,787	\$280,821	\$0	\$0	\$405,058
3	\$0	\$0	\$109,658	\$22,034	\$300,479	\$0	\$0	\$432,170
4	\$0	\$0	\$116,237	\$23,356	\$321,512	\$0	\$0	\$461,105
5	\$0	\$0	\$123,211	\$24,757	\$344,018	\$0	\$0	\$491,986
6	\$0	\$0	\$130,604	\$26,248	\$368,099	\$0	\$0	\$524,946
7	\$0	\$0	\$138,440	\$27,817	\$393,866	\$0	\$0	\$560,123
8	\$0	\$0	\$146,747	\$29,486	\$421,437	\$0	\$0	\$597,669
9	\$0	\$0	\$155,551	\$31,255	\$450,937	\$0	\$0	\$637,744
10	\$0	\$0	\$164,884	\$33,131	\$482,503	\$0	\$0	\$680,518
11	\$0	\$0	\$174,778	\$35,119	\$516,278	\$0	\$0	\$726,174
12	\$0	\$0	\$185,264	\$37,226	\$552,418	\$0	\$0	\$774,907
13	\$0	\$0	\$196,380	\$39,459	\$591,087	\$0	\$0	\$826,926
14	\$0	\$0	\$208,163	\$41,827	\$632,463	\$0	\$0	\$882,452
15	(\$95,862)	\$0	\$0	\$0	\$676,735	\$0	(\$0)	\$676,735
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY ANALYSIS D2- CASE IIIA2 WITH MUNICIPAL FINANCING
 MUNICIPAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$1,119,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAO SOURCE COST	\$1,334,740	ESC. RATE	0.06	NPV COSTS	\$5,896,587
MISC. O&M	\$18,600	ESC. RATE	0.06	ANNUALIZED COST	\$775,247
LABOR COST	\$245,280	ESC. RATE	0.07	LEVELIZED COST	\$0.147
CONV ENERGY CST	\$0	ESC. RATE	0.08		
LAND COST	\$40,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0		
RAO REPL PERIOD	5	ITC	0		
RAO REPL FRAC.	0.10830	DEBT COST	0.1		
RAO REPL FIXED	\$14,785	EQUITY COST	0		
RAO REPL VAR	\$0.48	DEBT RATIO	1		
TOTAL CURIES	2720000	OTHER TAXES	0		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	18000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAO SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$40,000	\$1,119,000	\$1,334,740	\$18,600	\$0	\$0	\$0	\$2,472,340
1	\$0	\$0	\$0	\$19,716	\$262,450	\$0	\$0	\$282,166
2	\$0	\$0	\$0	\$20,899	\$280,821	\$0	\$0	\$301,720
3	\$0	\$0	\$0	\$22,153	\$300,479	\$0	\$0	\$322,631
4	\$0	\$0	\$0	\$23,482	\$321,512	\$0	\$0	\$344,994
5	\$0	\$0	\$209,006	\$24,891	\$344,018	\$0	\$0	\$577,915
6	\$0	\$0	\$0	\$26,384	\$368,099	\$0	\$0	\$394,484
7	\$0	\$0	\$0	\$27,968	\$393,866	\$0	\$0	\$421,834
8	\$0	\$0	\$0	\$29,646	\$421,437	\$0	\$0	\$451,082
9	\$0	\$0	\$0	\$31,424	\$450,937	\$0	\$0	\$482,362
10	\$0	\$0	\$279,697	\$33,310	\$482,503	\$0	\$0	\$795,510
11	\$0	\$0	\$0	\$35,308	\$516,278	\$0	\$0	\$551,586
12	\$0	\$0	\$0	\$37,427	\$552,418	\$0	\$0	\$589,844
13	\$0	\$0	\$0	\$39,672	\$591,087	\$0	\$0	\$630,759
14	\$0	\$0	\$0	\$42,053	\$632,463	\$0	\$0	\$674,516
15	(\$95,862)	\$0	\$0	\$0	\$676,735	\$0	(\$0)	\$676,735
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

SENSITIVITY E1

FOOD IRRADIATION CALCULATION 13-Sep-84
 SENSITIVITY E1
 30 YEAR LIFE- CASE 1B1

DATA		RESULTS			
CAPITAL COST	\$4,583,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$217,790	ESC. RATE	0.06	NPV COSTS	\$22,503,300
SUPPLIES COST	\$76,400	ESC. RATE	0.06	ANNUALIZED COST	\$3,550,761
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.015
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.009
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	30	TAX RATE	0.5		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL FRAC.	0.12346	DEBT COST	0.12		
RAD REPL FIXED	\$9,940	EQUITY COST	0.18		
RAD REPL VAR	\$1.02	DEBT RATIO	0.3		
TOTAL CURRIES	205000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,583,000	\$217,790	\$76,400	\$0	\$0	\$0	\$4,877,190
1	\$0	\$0	\$37,795	\$80,984	\$1,387,234	\$0	\$0	\$1,506,012
2	\$0	\$0	\$40,063	\$85,843	\$1,484,340	\$0	\$0	\$1,610,245
3	\$0	\$0	\$42,466	\$90,994	\$1,588,244	\$0	\$0	\$1,721,704
4	\$0	\$0	\$45,014	\$96,453	\$1,699,421	\$0	\$0	\$1,840,888
5	\$0	\$0	\$47,715	\$102,240	\$1,818,380	\$0	\$0	\$1,968,336
6	\$0	\$0	\$50,578	\$108,375	\$1,945,667	\$0	\$0	\$2,104,620
7	\$0	\$0	\$53,613	\$114,877	\$2,081,864	\$0	\$0	\$2,250,354
8	\$0	\$0	\$56,829	\$121,770	\$2,227,594	\$0	\$0	\$2,406,193
9	\$0	\$0	\$60,239	\$129,076	\$2,383,526	\$0	\$0	\$2,572,841
10	\$0	\$0	\$63,854	\$136,821	\$2,550,372	\$0	\$0	\$2,751,047
11	\$0	\$0	\$67,685	\$145,030	\$2,728,898	\$0	\$0	\$2,941,613
12	\$0	\$0	\$71,746	\$153,732	\$2,919,921	\$0	\$0	\$3,145,399
13	\$0	\$0	\$76,051	\$162,956	\$3,124,316	\$0	\$0	\$3,363,322
14	\$0	\$0	\$80,614	\$172,733	\$3,343,018	\$0	\$0	\$3,596,365
15	\$0	\$0	\$95,443	\$183,097	\$3,577,029	\$0	\$0	\$3,855,569
16	\$0	\$0	\$99,682	\$194,083	\$3,827,421	\$0	\$0	\$4,121,186
17	\$0	\$0	\$104,312	\$205,728	\$4,095,341	\$0	\$0	\$4,405,380
18	\$0	\$0	\$109,377	\$218,072	\$4,382,015	\$0	\$0	\$4,709,463
19	\$0	\$0	\$114,864	\$231,156	\$4,688,756	\$0	\$0	\$5,034,775
20	\$0	\$0	\$120,750	\$245,025	\$5,016,969	\$0	\$0	\$5,382,743
21	\$0	\$0	\$127,142	\$259,727	\$5,368,156	\$0	\$0	\$5,755,025
22	\$0	\$0	\$134,469	\$275,310	\$5,743,927	\$0	\$0	\$6,153,706
23	\$0	\$0	\$142,617	\$291,829	\$6,146,002	\$0	\$0	\$6,580,448
24	\$0	\$0	\$151,258	\$309,339	\$6,576,222	\$0	\$0	\$7,036,819
25	\$0	\$0	\$160,334	\$327,899	\$7,036,558	\$0	\$0	\$7,524,791
26	\$0	\$0	\$170,049	\$347,573	\$7,529,117	\$0	\$0	\$8,046,739
27	\$0	\$0	\$180,353	\$368,427	\$8,056,155	\$0	\$0	\$8,604,935
28	\$0	\$0	\$191,281	\$390,533	\$8,620,086	\$0	\$0	\$9,201,900
29	\$0	\$0	\$202,871	\$413,965	\$9,223,492	\$0	\$0	\$9,840,328

SENSITIVITY E1

30	(4861,524)	\$0	\$0	\$0	\$9,869,136	\$0	(\$0)	\$9,869,136
31	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
32	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
33	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
34	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

SENSITIVITY E2- CESIUM CASE IB2 WITH 30 YEAR LIFE

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY ANALYSIS E2
 CESIUM PLANT IB2 WITH 30 YEAR LIFE

DATA		RESULTS			
OTHER CAPITAL	\$4,591,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$445,694	ESC. RATE	0.06	NPV COSTS	\$22,491,734
MISC. O&M	\$76,500	ESC. RATE	0.06	ANNUALIZED COST	\$3,548,502
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.015
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$2,134,950
LAND COST	\$150,000	INFLATION	0.06		\$0.009
FACILITY LIFE	30	TAX RATE	0.5		
RAD REPL PERIOD	5	ITC	0.1		
RAD REPL FRAC.	0.10830	DEBT COST	0.12		
RAD REPL FIXED	\$6,847	EQUITY COST	0.18		
RAD REPL VAR	\$0.40	DEBT RATIO	0.3		
TOTAL CURIES	1080000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,591,000	\$445,694	\$76,500	\$0	\$0	\$0	\$5,113,194
1	\$0	\$0	\$0	\$81,090	\$1,387,234	\$0	\$0	\$1,468,324
2	\$0	\$0	\$0	\$85,955	\$1,484,340	\$0	\$0	\$1,570,295
3	\$0	\$0	\$0	\$91,113	\$1,588,244	\$0	\$0	\$1,679,356
4	\$0	\$0	\$0	\$96,579	\$1,699,421	\$0	\$0	\$1,796,000
5	\$0	\$0	\$71,773	\$102,374	\$1,818,380	\$0	\$0	\$1,992,527
6	\$0	\$0	\$0	\$108,517	\$1,945,667	\$0	\$0	\$2,054,184
7	\$0	\$0	\$0	\$115,028	\$2,081,864	\$0	\$0	\$2,196,891
8	\$0	\$0	\$0	\$121,929	\$2,227,594	\$0	\$0	\$2,349,523
9	\$0	\$0	\$0	\$129,245	\$2,383,526	\$0	\$0	\$2,512,771
10	\$0	\$0	\$96,048	\$137,000	\$2,550,372	\$0	\$0	\$2,783,420
11	\$0	\$0	\$0	\$145,220	\$2,728,898	\$0	\$0	\$2,874,118
12	\$0	\$0	\$0	\$153,933	\$2,919,921	\$0	\$0	\$3,073,854
13	\$0	\$0	\$0	\$163,169	\$3,124,316	\$0	\$0	\$3,287,485
14	\$0	\$0	\$0	\$172,959	\$3,343,018	\$0	\$0	\$3,515,977
15	\$0	\$0	\$401,649	\$183,337	\$3,577,029	\$0	\$0	\$4,162,015
16	\$0	\$0	\$0	\$194,337	\$3,827,421	\$0	\$0	\$4,021,758
17	\$0	\$0	\$0	\$205,997	\$4,095,341	\$0	\$0	\$4,301,338
18	\$0	\$0	\$0	\$218,357	\$4,382,015	\$0	\$0	\$4,600,372
19	\$0	\$0	\$0	\$231,458	\$4,688,756	\$0	\$0	\$4,920,214
20	\$0	\$0	\$429,845	\$245,346	\$5,016,969	\$0	\$0	\$5,692,160
21	\$0	\$0	\$0	\$260,067	\$5,368,156	\$0	\$0	\$5,628,223
22	\$0	\$0	\$0	\$275,671	\$5,743,927	\$0	\$0	\$6,019,598
23	\$0	\$0	\$0	\$292,211	\$6,146,002	\$0	\$0	\$6,438,213
24	\$0	\$0	\$0	\$309,744	\$6,576,222	\$0	\$0	\$6,885,966
25	\$0	\$0	\$433,021	\$328,328	\$7,036,558	\$0	\$0	\$7,797,907
26	\$0	\$0	\$0	\$348,028	\$7,529,117	\$0	\$0	\$7,877,145
27	\$0	\$0	\$0	\$368,909	\$8,056,155	\$0	\$0	\$8,425,065
28	\$0	\$0	\$0	\$391,044	\$8,620,086	\$0	\$0	\$9,011,130
29	\$0	\$0	\$0	\$414,507	\$9,223,492	\$0	\$0	\$9,637,999

SENSITIVITY E2- CESIUM CASE IB2 WITH 30 YEAR LIFE

30	(\$861,524)	\$0	\$0	\$0	\$9,869,136	\$0	(\$0)	\$9,869,136
31	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
32	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
33	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
34	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
35	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY F1- CASE IB1 WITH COBALT PRICE DOUBLED
 COMMERCIAL FINANCING

DATA		RESULTS			
CAPITAL COST	\$4,583,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$420,740	ESC. RATE	0.06	NPV COSTS	\$18,195,214
SUPPLIES COST	\$76,400	ESC. RATE	0.06	ANNUALIZED COST	\$3,301,390
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.014
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.010
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL FRAC.	0.12346	DEBT COST	0.12		
RAD REPL FIXED	\$9,840	EQUITY COST	0.18		
RAD REPL VAR	\$2.04	DEBT RATIO	0.3		
TOTAL CURRIES	205000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	OGM COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,583,000	\$420,740	\$76,400	\$0	\$0	\$0	\$5,080,140
1	\$0	\$0	\$65,159	\$80,984	\$1,387,234	\$0	\$0	\$1,533,977
2	\$0	\$0	\$69,069	\$85,843	\$1,484,340	\$0	\$0	\$1,639,252
3	\$0	\$0	\$73,213	\$90,994	\$1,588,244	\$0	\$0	\$1,752,450
4	\$0	\$0	\$77,606	\$96,453	\$1,699,421	\$0	\$0	\$1,873,480
5	\$0	\$0	\$82,262	\$102,240	\$1,818,380	\$0	\$0	\$2,002,883
6	\$0	\$0	\$87,198	\$108,375	\$1,945,667	\$0	\$0	\$2,141,239
7	\$0	\$0	\$92,430	\$114,877	\$2,081,864	\$0	\$0	\$2,289,171
8	\$0	\$0	\$97,975	\$121,770	\$2,227,594	\$0	\$0	\$2,447,339
9	\$0	\$0	\$103,854	\$129,076	\$2,383,526	\$0	\$0	\$2,616,456
10	\$0	\$0	\$110,085	\$136,821	\$2,550,372	\$0	\$0	\$2,797,278
11	\$0	\$0	\$116,690	\$145,030	\$2,728,898	\$0	\$0	\$2,990,619
12	\$0	\$0	\$123,692	\$153,732	\$2,919,921	\$0	\$0	\$3,197,345
13	\$0	\$0	\$131,113	\$162,956	\$3,124,316	\$0	\$0	\$3,418,385
14	\$0	\$0	\$138,980	\$172,733	\$3,343,018	\$0	\$0	\$3,654,731
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY F2-CASE 1B2 WITH COMPARATIVE COBALT PRICE DOUBLED
 COMMERCIAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$4,591,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$812,894	ESC. RATE	0.06	NPV COSTS	\$18,194,641
MISC. O&M	\$76,500	ESC. RATE	0.06	ANNUALIZED COST	\$3,301,224
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.014
CONV ENERGY CST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.010
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	5	ITC	0.1		
RAD REPL. FRAC.	0.10830	DEBT COST	0.12		
RAD REPL FIXED	\$6,847	EQUITY COST	0.18		
RAD REPL VAR	\$0.74	DEBT RATIO	0.3		
TOTAL CUBES	1080000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	D&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,591,000	\$812,894	\$76,500	\$0	\$0	\$0	\$5,480,394
1	\$0	\$0	\$0	\$81,090	\$1,387,234	\$0	\$0	\$1,468,324
2	\$0	\$0	\$0	\$85,955	\$1,484,340	\$0	\$0	\$1,570,295
3	\$0	\$0	\$0	\$91,113	\$1,588,244	\$0	\$0	\$1,679,356
4	\$0	\$0	\$0	\$96,579	\$1,699,421	\$0	\$0	\$1,796,000
5	\$0	\$0	\$124,991	\$102,374	\$1,818,380	\$0	\$0	\$2,045,745
6	\$0	\$0	\$0	\$108,517	\$1,945,667	\$0	\$0	\$2,054,184
7	\$0	\$0	\$0	\$115,028	\$2,081,864	\$0	\$0	\$2,196,891
8	\$0	\$0	\$0	\$121,929	\$2,227,594	\$0	\$0	\$2,349,523
9	\$0	\$0	\$0	\$129,245	\$2,383,526	\$0	\$0	\$2,512,771
10	\$0	\$0	\$167,266	\$137,000	\$2,550,372	\$0	\$0	\$2,854,638
11	\$0	\$0	\$0	\$145,220	\$2,728,898	\$0	\$0	\$2,874,118
12	\$0	\$0	\$0	\$153,933	\$2,919,921	\$0	\$0	\$3,073,854
13	\$0	\$0	\$0	\$163,169	\$3,124,316	\$0	\$0	\$3,287,485
14	\$0	\$0	\$0	\$172,959	\$3,343,018	\$0	\$0	\$3,515,977
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY G1-COBALT PRICES ESCALATING AT 10%
 COMMERCIAL FINANCING

DATA			RESULTS			
CAPITAL COST	\$4,583,000	ESC. RATE	0.06	NOMINAL \$	REAL \$	
RAD SOURCE COST	\$217,790	ESC. RATE	0.1	NPV COSTS	\$17,837,426	
SUPPLIES COST	\$76,400	ESC. RATE	0.06	ANNUALIZED COST	\$3,225,057	ANNUALIZED COST \$2,258,291
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.014	LEVELIZED COST \$0.010
CONV ENERGY CST	\$0	ESC. RATE	0.08			
LAND COST	\$150,000	INFLATION	0.06			
FACILITY LIFE	15	TAX RATE	0.5			
RAD REPL PERIOD	1	ITC	0.1			
RAD REPL. FRAC.	0.12346	DEBT COST	0.12			
RAD REPL FIXED	\$9,840	EQUITY COST	0.18			
RAD REPL VAR	\$1.02	DEBT RATIO	0.3			
TOTAL CURRIES	205000	OTHER TAXES	0.02			
DEPR. LIFE	5	SALVAGE VALUE	\$0			
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8			
CONST. TIME	1					

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,583,000	\$217,790	\$76,400	\$0	\$0	\$0	\$4,877,190
1	\$0	\$0	\$38,827	\$80,984	\$1,387,234	\$0	\$0	\$1,507,045
2	\$0	\$0	\$42,293	\$85,843	\$1,484,340	\$0	\$0	\$1,612,476
3	\$0	\$0	\$46,080	\$90,994	\$1,588,244	\$0	\$0	\$1,725,317
4	\$0	\$0	\$50,219	\$96,453	\$1,699,421	\$0	\$0	\$1,846,093
5	\$0	\$0	\$54,744	\$102,240	\$1,818,380	\$0	\$0	\$1,975,365
6	\$0	\$0	\$59,692	\$108,375	\$1,945,667	\$0	\$0	\$2,113,734
7	\$0	\$0	\$65,103	\$114,877	\$2,081,864	\$0	\$0	\$2,261,844
8	\$0	\$0	\$71,021	\$121,770	\$2,227,594	\$0	\$0	\$2,420,385
9	\$0	\$0	\$77,496	\$129,076	\$2,383,526	\$0	\$0	\$2,590,098
10	\$0	\$0	\$84,581	\$136,821	\$2,550,372	\$0	\$0	\$2,771,774
11	\$0	\$0	\$92,334	\$145,030	\$2,728,898	\$0	\$0	\$2,966,262
12	\$0	\$0	\$100,820	\$153,732	\$2,919,921	\$0	\$0	\$3,174,473
13	\$0	\$0	\$110,110	\$162,956	\$3,124,316	\$0	\$0	\$3,397,382
14	\$0	\$0	\$120,282	\$172,733	\$3,343,018	\$0	\$0	\$3,636,033
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 17-Sep-84
 SENSITIVITY G2-CESIUM ANALYSIS WHEN COBALT ESCALATES AT 10%
 COMMERCIAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$4,591,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$488,894	ESC. RATE	0.06	NPV COSTS	\$17,830,309
MISC. O&M	\$76,500	ESC. RATE	0.06	ANNUALIZED COST	\$3,223,495
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.014
CONV ENERGY COST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.010
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	5	ITC	0.1		
RAD REPL FRAC	0.10830	DEBT COST	0.12		
RAD REPL FIXED	\$6,847	EQUITY COST	0.18		
RAD REPL VAR	\$0.44	DEBT RATIO	0.3		
TOTAL CURIES	1080000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,591,000	\$488,894	\$76,500	\$0	\$0	\$0	\$5,156,394
1	\$0	\$0	\$0	\$81,090	\$1,387,234	\$0	\$0	\$1,468,324
2	\$0	\$0	\$0	\$85,955	\$1,484,340	\$0	\$0	\$1,570,295
3	\$0	\$0	\$0	\$91,113	\$1,588,244	\$0	\$0	\$1,679,356
4	\$0	\$0	\$0	\$96,579	\$1,699,421	\$0	\$0	\$1,796,000
5	\$0	\$0	\$78,033	\$102,374	\$1,818,380	\$0	\$0	\$1,998,788
6	\$0	\$0	\$0	\$108,517	\$1,945,667	\$0	\$0	\$2,054,184
7	\$0	\$0	\$0	\$115,028	\$2,081,864	\$0	\$0	\$2,196,891
8	\$0	\$0	\$0	\$121,929	\$2,227,594	\$0	\$0	\$2,349,523
9	\$0	\$0	\$0	\$129,245	\$2,383,526	\$0	\$0	\$2,512,771
10	\$0	\$0	\$104,426	\$137,000	\$2,550,372	\$0	\$0	\$2,791,799
11	\$0	\$0	\$0	\$145,220	\$2,728,898	\$0	\$0	\$2,874,118
12	\$0	\$0	\$0	\$153,933	\$2,919,921	\$0	\$0	\$3,073,854
13	\$0	\$0	\$0	\$163,169	\$3,124,316	\$0	\$0	\$3,287,485
14	\$0	\$0	\$0	\$172,959	\$3,343,018	\$0	\$0	\$3,515,977
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 02-Oct-84
 SENSITIVITY H1- CASE I.B.1 WITH HISTORICAL FINANCING RATES
 COMMERCIAL FINANCING

DATA		RESULTS			
CAPITAL COST	\$4,583,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$217,790	ESC. RATE	0.06	NPV COSTS	\$21,791,167
SUPPLIES COST	\$76,400	ESC. RATE	0.06	ANNUALIZED COST	\$3,046,248
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.013
CONV ENERGY COST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.009
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	1	ITC	0.1		
RAD REPL FRAC.	0.12346	DEBT COST	0.077		
RAD REPL FIXED	\$9,840	EQUITY COST	0.127		
RAD REPL VAR	\$1.02	DEBT RATIO	0.3		
TOTAL CURRIES	205000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST. TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,583,000	\$217,790	\$76,400	\$0	\$0	\$0	\$4,877,190
1	\$0	\$0	\$37,795	\$80,984	\$1,387,234	\$0	\$0	\$1,506,012
2	\$0	\$0	\$40,063	\$85,843	\$1,484,340	\$0	\$0	\$1,610,245
3	\$0	\$0	\$42,466	\$90,994	\$1,588,244	\$0	\$0	\$1,721,704
4	\$0	\$0	\$45,014	\$96,453	\$1,699,421	\$0	\$0	\$1,840,888
5	\$0	\$0	\$47,715	\$102,240	\$1,818,380	\$0	\$0	\$1,968,336
6	\$0	\$0	\$50,578	\$108,375	\$1,945,667	\$0	\$0	\$2,104,620
7	\$0	\$0	\$53,613	\$114,877	\$2,081,864	\$0	\$0	\$2,250,354
8	\$0	\$0	\$56,829	\$121,770	\$2,227,594	\$0	\$0	\$2,406,193
9	\$0	\$0	\$60,239	\$129,076	\$2,383,526	\$0	\$0	\$2,572,841
10	\$0	\$0	\$63,854	\$136,821	\$2,550,372	\$0	\$0	\$2,731,047
11	\$0	\$0	\$67,685	\$145,030	\$2,728,898	\$0	\$0	\$2,941,613
12	\$0	\$0	\$71,746	\$153,732	\$2,919,921	\$0	\$0	\$3,145,399
13	\$0	\$0	\$76,051	\$162,956	\$3,124,316	\$0	\$0	\$3,363,322
14	\$0	\$0	\$80,614	\$172,733	\$3,343,018	\$0	\$0	\$3,596,365
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
19	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0

FOOD IRRADIATION CALCULATION 02-Oct-84
 SENSITIVITY M2- CASE 1.B.2 WITH HISTORICAL FINANCING RATES
 COMMERCIAL FINANCING

DATA		RESULTS			
OTHER CAPITAL	\$4,591,000	ESC. RATE	0.06	NOMINAL \$	REAL \$
RAD SOURCE COST	\$499,694	ESC. RATE	0.06	NPV COSTS	\$21,791,215
MISC. O&M	\$76,500	ESC. RATE	0.06	ANNUALIZED COST	\$3,046,219
LABOR COST	\$1,296,480	ESC. RATE	0.07	LEVELIZED COST	\$0.013
CONV ENERGY COST	\$0	ESC. RATE	0.08	LEVELIZED COST	\$0.009
LAND COST	\$150,000	INFLATION	0.06		
FACILITY LIFE	15	TAX RATE	0.5		
RAD REPL PERIOD	5	ITC	0.1		
RAD REPL FRAC.	0.10830	DEBT COST	0.077		
RAD REPL FIXED	\$6,847	EQUITY COST	0.127		
RAD REPL VAR	\$0.45	DEBT RATIO	0.3		
TOTAL CURIES	1080000	OTHER TAXES	0.02		
DEPR. LIFE	5	SALVAGE VALUE	\$0		
PEAK CAPACITY	800000	CAPACITY FACTOR	0.8		
CONST TIME	1				

CASH FLOWS

YEAR	LAND COST	CAPITAL COST	RAD SOURCE COST	SUPPLIES COST	O&M COST	ENERGY COST	SALVAGE POTENTIAL	TOTAL PRE-TAX EXPENDITURES
0	\$150,000	\$4,591,000	\$499,694	\$76,500	\$0	\$0	\$0	\$5,167,194
1	\$0	\$0	\$0	\$81,090	\$1,387,234	\$0	\$0	\$1,468,324
2	\$0	\$0	\$0	\$85,955	\$1,484,340	\$0	\$0	\$1,570,295
3	\$0	\$0	\$0	\$91,113	\$1,588,244	\$0	\$0	\$1,679,356
4	\$0	\$0	\$0	\$96,579	\$1,699,421	\$0	\$0	\$1,796,000
5	\$0	\$0	\$79,599	\$102,374	\$1,818,380	\$0	\$0	\$2,000,353
6	\$0	\$0	\$0	\$108,517	\$1,945,667	\$0	\$0	\$2,054,184
7	\$0	\$0	\$0	\$115,028	\$2,081,864	\$0	\$0	\$2,196,891
8	\$0	\$0	\$0	\$121,929	\$2,227,594	\$0	\$0	\$2,349,523
9	\$0	\$0	\$0	\$129,245	\$2,383,526	\$0	\$0	\$2,512,771
10	\$0	\$0	\$106,521	\$137,000	\$2,550,372	\$0	\$0	\$2,793,893
11	\$0	\$0	\$0	\$145,220	\$2,728,898	\$0	\$0	\$2,874,118
12	\$0	\$0	\$0	\$153,933	\$2,919,921	\$0	\$0	\$3,073,854
13	\$0	\$0	\$0	\$163,169	\$3,124,316	\$0	\$0	\$3,287,485
14	\$0	\$0	\$0	\$172,959	\$3,343,018	\$0	\$0	\$3,515,977
15	(\$359,484)	\$0	\$0	\$0	\$3,577,029	\$0	(\$0)	\$3,577,029
16	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
17	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
18	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
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