PROPOSAL TO PROVIDE TECHNICAL ASSISTANCE FOR RULEMAKING AND REGULATORY ANALYSIS FOR REQUIREMENTS PRIMARILY INVOLVING ADMINISTRATIVE & PROCEDURAL MODIFICATIONS TO NRC LICENSED FACILITIES

Solicitation No. RS-RES-89-083

Clarifications to Technical Proposal

SC&A Inc.

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Submitted to:

U.S. Nuclear Regulatory Commission
Division of Contracts and Property Management
Contract Negotiation Br. 2; P-1042
Washington, D.C. 20555

Attn: Patricia Smith

Submitted by:

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INTRODUCTION

The clarifications to our original technical proposal are contained in the following pages. These clarifications answer the questions which were posed in discussions held on October 25th, and contained in the enclosure Ms. Smith's letter dated November 2, 1989. Our revised technical proposal is organized in accordance with the 9 questions that were posed. For easy in reference, the question is presented in **boldface**, and our response follows. Resumes of personnel added to the proposed project team to assure that the team possess the full range of experience and expertise needed to support this procurement are presented in Appendix A. Appendix B presents excerpts of two studies conducted by SC&A project members relating to non-power reactor licensees.

1. The RFP called for rulemaking support for requirements that might impact on any NRC licensee. The proposal, in its discussion and through its examples, focused almost exclusively on power reactor licensees.

The panel needs to know your capabilities and ability to provide support on non-power reactor rulemakings. Specifically, it is anticipated that tasks emanating from this contract may be heavily focused on NMSS rules. These are likely to concern:

- a. both high and low level waste facilities and activities;
- b. fuel processing plants;
- c. medical use licensees; and
- d. safeguards issues.

With this in mind, please discuss your proposed personnel qualifications to address requirements that may impact these types of facilities and activities. Specifically,

- (1) identify any personnel that has actual hands on experience working at these types of facilities;
- (2) demonstrate your knowledge of these facilities and their processes;
- (3) discuss any rulemaking and regulatory experience associated with these facilities and activities;
- (4) and knowledge of what is important to safety, what are the hazards, and what are the credible accident scenarios.

Response:

The proposed Project Manager, Dr. Sanford Cohen, began his professional career at General Atomics, where he was Chairman of the Criticality Safeguards Committee. In this role, he was responsible for licensing all of the special nuclear material, including research reactors and critical facilities, at this large research laboratory. In 1972, Dr. Cohen became a consultant to the AEC Office of Fuels and Materials (now the Fuel Cycle Safety Branch in NMSS), where over subsequent years he assisted the Office in the preparation of the Environmental Statement for the Exxon Mixed Oxide Facility, the Environmental Survey of the Uranium Fuel Cycle (WASH-1248), the Environmental Statement for the Nuclear Fuel Cycle West Valley Reprocessing Plant (since canceled), and the Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors (GESMO). In the later years of the 1970s, Dr. Cohen prepared for the NRC the accident sections of several uranium mill Environmental Statements (under sub-contract with Argonne National Laboratory) and for the Generic Environmental Statement on Uranium Milling. He also prepared for the Environmental Protection Agency a report which estimated the accident risks from all components of the nuclear fuel cycle.

After forming SC&A in 1981, Dr. Cohen performed studies for both the EPA and the NRC on the impacts of revised radiation protection standards (10 CFR Part 20 for the NRC). These involved evaluations of the impacts on several components of the nuclear fuel cycle, as well as byproduct material licensees, such as hospitals and nuclear medicine clinics. For the Department of Energy, Dr. Cohen developed a Program Management System and a Safety Plan for the high level waste repository (Office of Civilian Radioactive Waste Management). For the EPA, he evaluated for several byproduct material licensees (hospitals, in particular) the costs of compliance with proposed standards for radionuclides under the Clean Air Act.

The proposed Project Director, Mr. David Goldin has extensive experience supporting rulemakings and regulations affecting the NRC's non-power reactor licensees. For the NRC's Office of Inspection and Enforcement (I&E), under subcontract with Lawrence Livermore National Laboratory, Mr. Goldin assisted in the development of background information to support the revisions to the physical protection requirements for sites possessing low and moderate quantities of special nuclear material (10 CFR Part 73.67). His responsibilities in this work included evaluating the adequacy of existing protection systems and procedures at research and test reactors and performing an assessment of the radiological consequences of sabotage at these facilities. After the revised physical protection requirements were promulgated, Mr. Goldin assisted I&E by developing the Physical Protection Inspection Module used by I&E inspectors to evaluate compliance with the regulations at sites licensed to possess low and moderate quantities of special nuclear material.

Mr. Goldin has provided extensive support to the EPA's Office of Radiation Programs' rulemakings on NRC-licensed facilities under the Clean Air Act (40 CFR Part 61, subparts I, T, and W) and the Uranium Mill Tailings Radiation Control Act (40 CFR Part 192). This support has included the development of background information characterizing the processes, identifying existing effluent controls, quantifying emissions rates of radionuclides released to the air, calculating doses and risks to nearby individuals and regional populations from these emissions, and evaluating the costs and benefits of requiring additional effluent controls. Evaluations were made for the following classes of non-power reactor licensees: radiopharmaceutical manufacturers, medical users and nuclear pharmacies, both LWR and non-LWR fuel fabricators, manufacturers of sealed radiation sources and self-illuminating devices, test and research reactors, facilities using or producing source materials (including conventional uranium milling facilities), uranium conversion facilities, and waste shippers and low-level waste disposal facilities.

In addition to serving as SC&A's Task Manager for the development and preparation of the Background Information Documents supporting the EPA's recent radionuclides NESHAPS rulemaking Mr. Goldin also served as SC&A's Task Manager for the development of the implementation procedures and exemption criteria for NRC-licensed facilities subject to the rulemaking. As part of this work, he evaluated the processes at NRC material and fuel cycle licensees to develop release fractions of radioactive materials in process that become airborne and could be released to the environment. He also investigated the use and efficiency of effluent control systems at these types of facilities to develop effluent control adjustment factors. The release fractions and effluent control adjustment factors have been approved by the EPA for use by NRC licensed facilities in lieu of monitoring data for demonstrating compliance with the recently promulgated NESHAP dose standards.

[redacted]

As it is difficult to demonstrate in any limited number of pages our knowledge of non-power reactor licensees, what is important to safety at these facilities, and what the credible accident scenarios are, we have appended to this submission portions of two studies that were prepared by David Goldin and Sanford Cohen of SC&A. The first, prepared for the EPA, provides capsule discussions of the diverse activities at non-power reactor licensees. The second demonstrates our knowledge of what is important to safety and credible accident scenarios at fuel cycle facilities.

2. **With respect to the quantification of cost impacts**

a. Is it reasonable to conclude the JFA will be providing the cost quantification expertise?

Response:

The proposed project team will not be relying only on JFA's expertise in cost quantification. Rather, as indicated in Table 2-1 of our original proposal, the expertise and the responsibility for quantifying cost impacts is split between SC&A, SCIENTECH, and JFA, depending upon the type of costs. SC&A will have primary responsibility to develop and quantify costs impacts associated with requirements involving O&M, procedural, administrative, and analytical costs. SC&A and SCIENTECH will have joint responsibility for developing and quantifying cost impacts associated with requirements requiring physical modifications. And JFA will have the primary responsibility to develop and quantify socioeconomic costs and impacts. In addition JFA will have the primary responsibility for performing value impact assessments. In other words, JFA will be responsible for evaluating the economic impacts of these costs. In performing value/impact assessments, JFA will use the quantified cost impact and risk reduction (benefit) data developed by the appropriate member(s) of the project team.

b. **The proposal is silent on how it would treat socioeconomic impacts, O&M costs, and analytical costs. Who would be responsible for addressing these impacts. What experience do you posess relative to these issues? And what methodological tools and information do you have available to assess these impacts?**

Response:

The responsibility for addressing these impacts will be as discussed in 2a. Summaries of relevant experience and the methodologial tools and information available to assess these impacts are presented separately in the following paragraphs for each type of impact.

Socioeconomic Impacts

JFA posesses the required expertise to assess socioeconomic impacts. The following paragraphs summarize projects that they have performed involving quantification of socioeconomic impacts. This experience summary is followed by a discussion of the methodologies and information that we have available to evaluate socioeconomic impacts.

Jack Faucett Associates is a leader in the development of socioeconomic impacts of government or private industry projects. Current assignments for which we are conducting socioeconomic impact analysis include a study of Washington, D.C. bypass highway for Maryland and Virginia Departments of Transportation; the direct and indirect impacts of EPA rulemakings for emissions of radioactive materials at uranium mines, uranium mills, elemental phosphorus plants, phosphoric acid plants, and other facilities; the socioeconomic impact of U.S. Army Corps of Engineers flood control and share erosion projects in the Wyoming Valley and Lackawanna areas of Pennsylvania, the Chesapeake Bay Region, Walla Walla Washington, Vancouver Lake Washington and Washington, D.C.; and the economic impacts of OSHA regulations for worker protection from blood borne diseases and in high rise construction. We are also completing a study of the socioeconomic impacts of low water on the Ohio River during the drought of 1988.

Jack Faucett Associates has performed numerous studies of the economic and socioeconomic impacts of various public policies and regulatory activities. These include:

- Studies of the economic impacts of railroad abandonments (performed for the states of Maryland and Delaware and for USDOT);
- Assistance in the preparation of expert testimony regarding the impacts of railroad abandonment on affected shippers and communities (in support of the Unites States Railway Association's defense against a multi-billion dollar suit instituted by the estates of the major bankrupt Northeastern railroads);
- An analysis of the economic impacts on affected states of the elimination of grandfather-clause truck weight limits (performed as part of U.S. Department of Transportation's Truck Size and Weight Study);
- An assessment of the likely effects of the Tennessee-Tombigbee Waterway on the location of economic activities within the affected region and on additions to the economic base of individual subareas of this region (for the Appalachian Regional Commission (ARC));
- An evaluation of analyses of the economic benefits of the Cross-Florida Barge Canal (for the Barge Canal Authority of Florida);
- An evaluation of the socio-economic impacts of natural hazards in the Appalachian Region and the formulation of appropriate policies and control measures for dealing with the hazards (For ARC);
- An evaluation of the economic and social impacts of the water requirements of prospective energy developments in the Appalachian Region (for ARC);
- An analysis of the national and regional direct, indirect and induced economic impacts of the development of Ocean Thermal Energy Conversion power plants, as well as the impacts of significantly affected industrial sectors (for the U.S. Department of Energy);
- An exploration of the direct and indirect employment-generating effects of synfuel plants (for ARC);

- An analysis of the effects on transport costs and socio-economic impacts of alternative locations for coal-liquefaction plants (for the U.S. Department of the Interior);
- Participation in a U.S. Department of Transportation conference addressing the impacts of unit coal trains on small communities;
- Assistance to Carbon County, Wyoming, in the development of plans for mitigating the adverse impacts on the County of major increases in coal production;
- Technical assistance to U.S. Department of Energy relating to the development and administration of the Energy Impact Assistance program established by Section 601 of the Powerplant and Industrial Fuel Use Act;
- An analysis of the regional and urban economic impacts of the Federal Aviation Administration's airport and airway development program;
- An analysis of the impacts of corporate average fuel economy standards on domestic automobile manufacturers on the national and regional economies (for U.S. Department of Transportation);
- Several analyses of the economic impacts of various EPA mobile-source (i.e., motor-vehicle) regulations on local, regional and national economies (for the U.S. Environmental Protection Agency);
- An analysis of the national economic impacts of petroleum shortages under alternative tax-rebate policies (for U.S. Department of Energy);
- Several analyses of the national and regional economic impacts of potential work stoppages or service curtailments affecting rail, truck or water-transport industries (for U.S. Department of Transportation).

The following paragraphs discuss methodologies and information sources available to evaluate socioeconomic impacts. Exhibit 1, is an example of the socioeconomic impact assessment JFA made of Ocean Thermal Energy Conversion (OTEC) power plants. This brief Exhibit will assist the evaluation panel understand how the methodologies and databases are used in performing the assessment.

Economic impacts generated by power plant operation (or other licensee) occur at he national, regional and industry levels. These impacts can be divided

Exhibit 1

8th Ocean Energy Conference
Washington, DC
June 1981

DOMESTIC SOCIAL AND ECONOMIC IMPACTS OF OTEC COMMERCIAL DEVELOPMENT

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ABSTRACT

The widescale domestic development and utilization of OTEC power plants would have a significant impact upon the economy of the United States. This paper describes the detailed economic impact analysis undertaken by Jack Faucett Associates, Inc., for the U.S. Department of Energy, to identify these economic impacts and to measure them at the national, regional, and industry levels. It focuses on the impacts generated under a likely OTEC development scenario, dividing them into direct, indirect, and induced effects. These impacts include employment and production effects, tax revenue effects, and the effect on the balance of payments.

INTRODUCTION

OTEC power plants can provide the United States with a renewable domestic source of energy. Further, their construction and utilizaton in the United States could increase the nation's economic activity. Consequently, it is important to understand the varieties and magnitudes of the economic impacts associated with OTEC development.

This paper describes the detailed economic impact analysis that Jack Faucett Associates and its subcontractors are conducting for the U.S. Department of Energy. The analysis is designed to identify these economic impacts and to quantify them at the national, regional, and industry levels. It focuses on the effects on the United States' economy of the domestic development and utilization of twenty-five and fifty 400 MWe OTEC power plants by the year 2000.

The methodology employed is characteristic of economic impact analysis (Figure 1). After conducting a literature review, the study team developed a likely future OTEC scenario. This included technological, siting, and materials requirements parameters. The technological parameters developed in this phase were then used to identify the industries affected by OTEC development. An economic profile was then constructed for each of these industries. These profiles established an industrial baseline from which subsequent economic impact analysis is being developed, including the measurement of direct, indirect, and induced impacts.

First order output and employment effects are being estimated by consulting studies of materials and manpower requirements at each stage of commercialization. Subsequent output and employment impacts will be estimated at the national and industry levels by employing an existing econometric model. Regional impacts will also be estimated by using an existing model.

Each stage of this analysis is detailed below. Results are presented when they are available. Complete results will be available in the Fall of 1981.

LITERATURE REVIEW

In order to ensure that the study team was fully cognizant of the relevant OTEC technical and economic literature, an extensive literature review was conducted. JFA librarians performed a computer search of appropriate bibliographic data bases so as to locate government, academic and professional papers concerned with OTEC. Consequently, the study team became very familiar with the current state of OTEC development, and was able to apply this knowledge to the design of the OTEC scenario in the next stage of analysis. Furthermore, an extensive bibliography was assembled, with citations from the following bibliographic data bases:

- NTIS
- Smithsonian Scientific Information Exchange
- Energyline
- Congressional Information Service
- GPO
- Oceanic Abstracts

OTEC SCENARIO

The next step in the analysis was to develop a likely OTEC future scenario that would contain technological, offshore siting, and construction siting parameters. This scenario was constrained by DOE requirements that two-thirds of the OTEC facilities were to produce electricity for onshore power needs, and that one-third were to be involved in the production of energy intensive products. This breakdown was to be applied to both the twenty-five plant and fifty plant situation. Furthermore, a preliminary OTEC scenario suggested by DOE (Table 1) was considered while the complete scenario was developed.

Technology

The first issue to be resolved was to determine the most likely technology, open or closed cycle, to be employed in the majority of OTEC plants by the year 2000. Given the government's emphasis on closed cycle systems, plus uncertainties associated with the operation of open cycle systems, the study team concentrated on the closed cycle OTEC. This allowed the team to determine what materials and equipment would be required in the construction and operation of the plant. These included

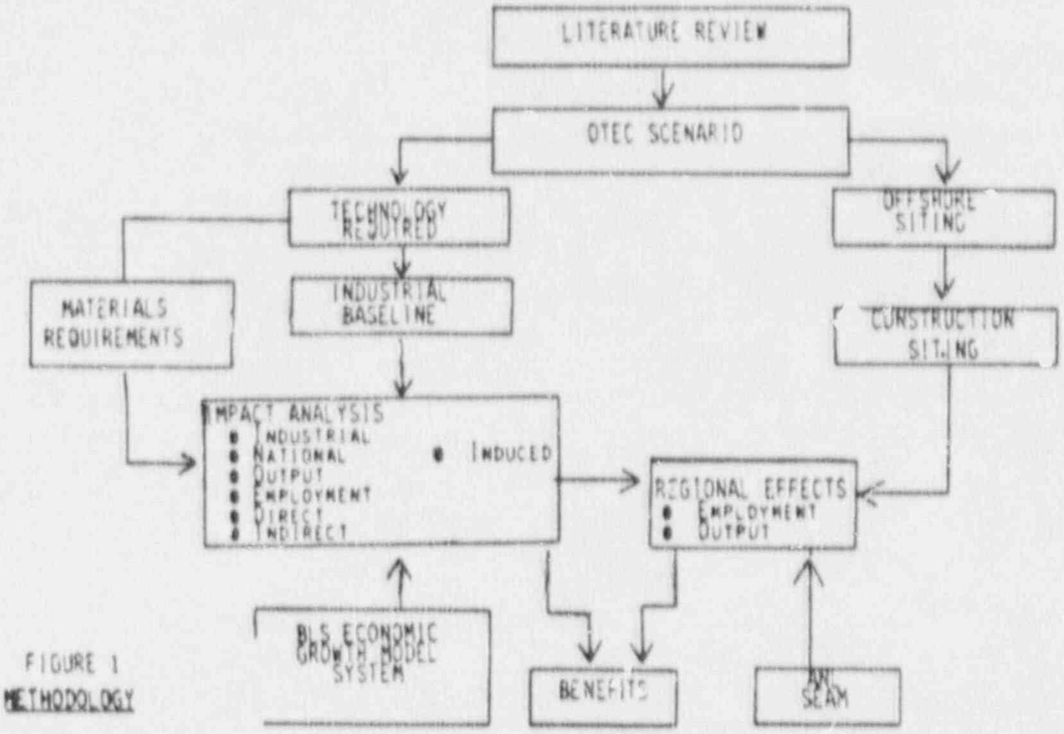


FIGURE 1
METHODOLOGY

steel, concrete, titanium, aluminum, warm and cold water pumps, and heat exchangers. A list of impacted industries was then generated. Finally, the team agreed with DOE's assessment that the most likely energy intensive products to be produced aboard an OTEC plantship would be aluminum and ammonia.

Offshore Siting

OTEC plants are usually designed for a nominal Δ T of 20°C for performance and economic reasons. This requires an ocean depth in excess of approximately three thousand feet. The depth must not be so great, however, that an electricity generating plant cannot be moored. The distance from shore will also have implications for the power cable in the electricity generating mode. Finally, for the OTEC concept to succeed as a commercial power plant system, a market for the power must exist.

Given the constraints cited above, OTEC power is not directly accessible to large portions of the United States. Other than the Virgin Islands and the islands of the Puerto Rico and Hawaii, the only area of the United States that could directly benefit from ocean thermal energy lies along the Gulf of Mexico. This region has both OTEC thermal resources available, and a substantial market growth in demand for electricity. These reasons, and the fact that this coastal area also has a rapidly expanding population as part of the Sun Belt, makes it the most likely U.S. region to consume OTEC generated electricity in large amounts.

The close proximity of Hawaii, Puerto Rico, and the Virgin Islands to a tropical ocean energy source make these U.S. islands potential consumers of OTEC electricity. However, the economies of these islands do not warrant large numbers of 400 MWe OTEC power plants, even if currently existing fossil fuel fired electricity is replaced.

The OTEC power produced offshore can also be used offshore in plantships producing energy intensive commodities. As noted earlier, the two commodities commonly cited in this mode are aluminum and ammonia. Several problems exist, however, in the producton of aluminum at sea. Consequently, the combination of a coastal based aluminum plant with a moored OTEC generating electricity seems more feasible. Ammonia, on the other hand, appears to be better suited to production at sea, where needed raw materials can be obtained from the air and water, and the final product can be easily transported. Furthermore, a strong market for ammonia exists in the United States, particularly for use in fertilizers. Consequently, the South Atlantic off the northeast coast of Brazil may be a good location for grazing OTEC's producing ammonia.

Construction Siting

A shipyard considered for OTEC construction must have both the necessary capabilities and facilities, and be reasonably close to the intended OTEC operating sites in the Atlantic, the Pacific, or the Gulf of Mexico. While there are twenty-eight major shipyards in the United States that have building or graving dock facilities in excess of 475 feet in length, eighteen shipyards are not suitable for OTEC construction. Of those yards, two are closed and four are on the Great Lakes. The remaining twelve were eliminated for a variety of factors, including lack of a suitable access channel to deep water, lack of engineering or skilled labor force, or lack of financial capabilities to undertake a project of this size. The ten shipyards deemed suitable are also forecast to be well below capacity in the 1980's, given current orders. Each also has the graving docks, personnel and support shops required in the construction of an OTEC facility. Furthermore, unemployment data has been developed for each yard's location so as to ascertain those yards that could benefit the most from OTEC construction.

Conclusion

Given the constraints and requirements identified in the offshore siting and construction siting analyses, Table 2 shows the matrix of shipyards, locations, and OTEC plant modes for the twenty-five plant scenario. As can be seen, the majority of OTEC's are involved in the production of electricity along the coast of the Gulf of Mexico.

TABLE I

OTEC SCENARIO

PRELIMINARY
OTEC SCENARIOS SUGGESTED BY DOE

		1	2	3	4	5
		ISLANDS			GULF	
		FLOATING		SHELF		
		SUBMERSIBLE	SURFACE		SUBMERSIBLE	FLOATING
TECHNOLOGY		CLOSED	CLOSED	1-CLOSED 2-OPEN	CLOSED	CLOSED
HULL		STEEL	STEEL		STEEL	STEEL
PIPE		FIBERGLASS	FIBERGLASS	FIBERGLASS	FIBERGLASS	FIBERGLASS
HEAT EXCHANGER		TITANIUM	TITANIUM	TITANIUM (CU/NI)	TITANIUM	TITANIUM
NO. OF UNITS	25	1	6	3	1	1
	50	2	12	6	2	2

		6	7	8	9	10
		INTERNATIONAL		PLANTSHIP		
		SURFACE	SHELF	NH_3	AL	H
TECHNOLOGY		CLOSED	1-CLOSED 1-OPEN	CLOSED	CLOSED	CLOSED
HULL		STEEL		CEMENT	CEMENT	CEMENT
PIPE		STEEL	CEMENT	FIBERGLASS	FIBERGLASS	FIBERGLASS
HEAT EXCHANGER		TITANIUM	TITANIUM (CU/NI)	AL	AL	AL
NO. OF UNITS	25	1	2	3	2	5
	50	2	4	6	4	10

INDUSTRIAL BASELINE

After the OTEC scenario was determined, economic profiles of the OTEC impacted industries were developed. These profiles detail an impacted industry's history, its financial and economic characteristics, its technological and production traits, and any resource constraints that might impede its operation. Some of the historical data collected includes output, value of shipments, number of firms, employment, prices, exports, and imports. This data establishes a baseline from which subsequent economic impact analysis is developed, including the measurement of direct, indirect, and induced impacts.

Profiles were developed for the following industries: steel, concrete, cement, titanium, aluminum, fiberglass reinforced plastic, underwater electrical cable, metal fabrication, offshore service, shipbuilding, and ammonia.

In the course of developing these profiles, several problems were identified. For example, the underwater electrical transmission cable industry is non-existent in the United States, and may be difficult to create. Secondly, there is a concrete aggregate and cement shortage on the Gulf coast that could impede the construction of OTEC hulls there. Thirdly, a fiberglass reinforced plastic cold water pipe of the size necessary for an OTEC plant has never been constructed. Fourthly, there is insufficient capacity in the titanium industry to support the construction of a large number of titanium heat exchangers, especially if potential defense demand for titanium is considered. Finally, the offshore service industry, which does not currently exist on the East coast of the United States, is projected to experience a severe manpower shortage that could adversely affect the deployment and operation of OTEC powerplants.

The primary regional impact is that on employment. This impact may be estimated by using Argonne National Laboratory's Social and Economic Assessment Model (SEAM). This model uses economic base theory to derive ratio employment multipliers. This theory holds that the growth of an area is dependent upon the growht of basic industries such as construction or manufacturing. The multiplier is simply a scalar that relates total area employment to employment in these basic industries. Thus, the total expected change in regional employment can be estimated by multiplying a given change in basic employment by the multiplier. This provides an estimate of the changes in secondary and induced employment when the change in base employment is subtracted. We anticipate applying such multipliers at the county level.

NATIONAL BENEFITS

The national benefits arising from domestic OTEC development may occur in several areas. Firstly, the stimulus could result in employment and production effects that would reduce unemployment and increase GNP. Secondly, a net energy study by Westinghouse indicates that a 50 MWe *OTEC* facility is a highly efficient facility in terms of energy inputs and outputs, with an output/input ratio of 9.37 for a steel hulled facility and 12.25 for a concrete hulled OTEC, per year (Table 5). Furthermore, OTEC power plants producing 10,000 MWe by the year 2000 would produce non-renewable fuel equivalent savings that would not be inconsequential. Finally, the balance of payments impacts of OTEC may be favorable, particularly if one considers the potential export of energy intensive products coupled with *reduced oil imports. However, the* change in net imports resulting from the increase in industry activity must be included if a complete balance of payments analysis is to be done.

TABLE 3

MATERIALS REQUIREMENTS

(400 MWE)

	Short tons
Concrete Hull	507,416
Steel Hull	107,872
Other Steel	24,696
Titanium	10,368
Turbine/Pump	7,296
MHE	4,800
Motor/Generator	6,360
Transformer	400
Switchgear	5,320
Stainless Steel	5,440
Wiring	520
Ammonia	9,248
Nitrogen	1,184

REFERENCES

Stenehjem, Erik J. and James E. Metzger, A Framework For Projecting Employment And Population Changes Accompanying Energy Development, Volume I. Argonne National Laboratory, ANL/AA-14, Vol. I. Argonne, Illinois, May 1980.

U.S. Department of Labor, Bureau of Labor Statistics, Methodology for Projections of Industry Employment to 1990. Bulletin 2036, Washington, D.C., February 1980.

TABLE 4

IMPACT ANALYSIS

A. DIRECT IMPACTS

OTEC MANNING -- DOUBLE CREW SCENARIO

● ELECTRICITY	90 TO 120 PER PLANT
● AMMONIA	140 TO 180 PER PLANT
● ALUMINUM	180 TO 220 PER PLANT
● 25 PLANTS	2830 TO 3880 TOTAL
● 50 PLANTS	5660 TO 7360 TOTAL

● MEETS CURRENT COAST GUARD REQUIREMENTS

TABLE 5

ENERGY CONTRIBUTIONS

WESTINGHOUSE NET ENERGY STUDY

	10^6 BTU
● INPUT ENERGY	
- Syeel Hull	143,863
- Concrete Hull	110,026

● OUTPUT ENERGY
- Gross 70.0 MWe
- Less 19.9 MWe
- Net 50.1 MWe
- Per Year (90%)
  395×10^6 kWh or 1,348,000

● OUTPUT/INPUT RATIO
  Steel Hull = 9.37
- Concrete Hull = 12.25

into direct, indirect and induced impacts. Direct impacts are those attributed to plant construction and operation. Indirect impacts occur as those industries involved in supporting the construction, maintenance, and operation activities purchase necessary inputs to production from other industries. Finally, induced impacts are evidenced as the expansion of output and employment from direct and indirect activities results in increased spending. The increased spending induces the production of more goods and services in the economy and is frequently termed the multiplier effect. Impact leakages occur when materials and services are supplied from firms outside the study area and have no further effect on the study area economy except for wholesaling and transportation activities (in some cases purchases from outside the study area will have a "feedback" effect on the study area when these outside firms in turn purchase inputs from firms in the study area, but this is generally minimal).

The competitive models for indirect economic impact analysis are input- output models and econometric models. Input-output models have the structural detail necessary to yield estimates of the impact on industry output, employment and earnings in specific industry detail. Econometric models have the virtue of incorporating macroeconomic variables that measure indirect impacts on consumer spending, local government spending and possibly on population change. A combination of the two models will be ideal but each study would depend on the available models and data for the area or industry examined.

One system often applied for impact analysis is the RIMS II multiplier approach and data base at the Regional Economics Division of the Bureau of Economic Analysis in the U.S. Department of Commerce. The RIMs multipliers are derived in an input-output model framework. The national input-output coefficients are adjusted for each study area to reflect import leakages, i.e., they are reduced by estimates of the fraction of the input that is estimated to be imported from other areas. The adjusted matrix of input-output coefficients is then inverted so as to obtain coefficients that measure the direct and indirect impacts on industry output and earnings that are generated by specified direct expenditures for each industry. These coefficients are known as industrial multipliers or Type I multipliers. The calculations are made for individual counties in 500-plus industry detail encompassing the total economy.

The RIMs procedure also takes account of the further spending of the income flows that are generated by both the direct and indirect industry expenditures. This is accomplished by "closing" the model on personal consumption expenditures (PCE). An estimate is made of the savings rate out of the income generated plus a tax rate based on Federal and local tax data. This leaves a high fraction of the local income generated in each round of expenditures that is multiplied by the PCE spending vector to obtain a further round of expenditures. The "closing" of the model on PCE and the inversion of the resulting matrix captures all of the effects of these further rounds of expenditures. The resulting multiplier is known as the income multiplier or Type II multiplier.

The two types of multipliers that are yielded by the RIMS procedure encompass most of the indirect impacts on industry output, employment and earnings that result from the direct expenditures. They do not capture the effects of induced investment or changes in local government expenuitures. And, of course

they do not estimate any change in population. These impacts possibly could be measured in an econometric model, or on an ad hoc basis to capture these further effects.
Induced investment can be estimated based ont he size of the important impacts on specific local industries and the degree of capacity utilization in these industries in each study area. Capacity utilization will be estimated based on interviews with local industry officials and business analysts closely familiar with each study area.

The effect on local government expenditures will depend upon increased infrastructural and public service needs generated by the increased industrial activity, any increases in populations and increases in local income that leads to greater demand for public services. These effects can best be estimated by interviews with local officials and by analyzing what happened in specific local communities that have been significantly impacts by similar development. These effects will be quantified as a coefficient in each study area which will represent a percentage increase in local government expenditures for a specified percentage increase in local income flows, or some other variable that is conveniently obtained from the output of the model.

The effect on population will be estimated in conjunction with the estimation of the effect on local government expenditures as described above; this is convenient since any changes in population will have an effect on local government expenditures and thus their simultaneous estimation is appropriate. Immigration will depend upon the amount of new employment generated in industries requiring skills not in excess supply in the study area. We will estimate a coefficient(s) for each study area as a function of increased employment in selected industries based at least partly on what has occurred in communities that have already been impacted by similar development activities.

O&M Costs

The proposed SC&A project team has gained experience in analyzing nuclear O&M costs during studies performed for the U.S. Department of Energy's Energy Information Administration (EIA) and for the Edison Electric Institute (EEI). These studies have provided team members the opportunity to examine the costs incurred by operating utilities in meeting the requirements imposed by NRC regulations on a plant-specific basis. In addition, the team has gained an in-depth understanding of industry-wide data available on nuclear plant performance and operating costs -- knowledge that will be extremely helpful in assisting NRC on the proposed effort. Brief summaries of these studies are presented below.

EIA - Capital Additions Study. As part of EIA's continuing scrutiny of rising O&M costs for nuclear units, SC&A examined the so-called "capital additions" costs incurred in operating five nuclear units over a 10-year period in order to determine what portion of the cost increases were due to NRC regulatory actions. Due to the fact that utility accounting practices vary in their allocation of such costs to depreciable and expensable accounts, it was necessary to examine thousands of post-startup projects to ascertain which were true capital additions and which were in O&M accounts. The detailed cost information for these case studies was obtained during visits to the participating utilities and covered BWRs, PWRs, units of all four LWR vendors, single-unit and dual-unit plants, and units of various sizes and vintages. As part of the estimates of NRC regulatory impacts, the specific effects of post-TMI regulations were also determined.

EEI - Guide to Nuclear Operating Data. [redacted] in response to this question (resume included [redacted], is currently developing a document for the EEI Nuclear Operations Committee that will identify and characterize the various sources of data on the operations of all U.S. nuclear units. The document will serve as a "road map" for the location of information on O&M costs (by component), performance indicators, outages, and other parameters of interest to member company operating and maintenance organizations. The needs of the EEI members for specific types of operating data, their preferences for cost and performance parameter definitions, and the ways in which the data will be utilized are also being identified through written and telephone surveys.

EEI - Nuclear Operating Prudence Project. [redacted] is also completing a two-year study of industry experience with regulatory examinations of nuclear operating prudence. These examinations are generally within the context of rate case reviews and focus on a wide variety of issues related to the prudence of nuclear operations and the reasonableness of decisions that affected the operating costs incurred by the utilities. Information used to develop the case studies presented in the final report was obtained during [redacted] interviews with utility staff in the operations, rate, and legal areas. Many presentations on the results of the project have been given to utility groups at EEI committee meetings and workshops on the subject.

In performing these studies, SC&A has demonstrated its ability to work closely with utility companies to obtain and analyze information on operating costs and to identify those portions of operating costs that were incurred as a result of regulatory actions. As discussed further below, we feel that this experience will be of considerable importance to the proposed effort.

SC&A is aware of attempts that have been made to formalize the estimation of cost impacts resulting from various actions taken to comply with regulatory changes. We feel that these estimates are usually very approximate and, in fact, can often be misleading because of the difficulty involved in modelling the range of real utility situations. Only the utilities will incur these costs, and they are naturally the best sources of information on the level of costs most likely to be incurred. For this reason, coupled with our proven ability to work with utility companies in obtaining such information, we prefer to utilize our utility contacts to obtain specific input required for cost impact estimates.

The ongoing project to develop a guide to available information on nuclear operations also provides the SC&A team with in-depth knowledge of all sources of data on operating costs and unit performance for U.S. nuclear units. Government, utility industry, and commercial sources are included. In addition to gaining an awareness of specific data sources available, this work requires extensive interfacing with operations and maintenance managers of many nuclear utilities. The other projects described above, as well as the extensive experience of the SC&A team in gathering information from utilities over the past two decades, have also provided us with the opportunity to establish excellent relationships among the utilities. These contacts will facilitate the ad hoc acquisition of information needed to accurately estimate the effects of regulatory compliance on O&M costs for nuclear units of various types, ages, sizes, and operating histories. A list of our utility contacts was provided in Table 4-1 of our original proposal.

Analytical Costs

SC&A also posesses the requisite expertise to develop analytical costs. The following paragraphs summarize relevant projects that have been performed involving quantification of analytical costs. This experience summary is followed by a discussion of the methodologies and information that we have available to develop and evaluate analytical costs.

SC&A has had extensive experience in estimating analytical costs attributable to NRC actions. For example, in the ANL/SC&A report to the NRC ("A Handbook of Cost Estimating," NUREG/CR-3971), SC&A developed several "functional responses" to NRC actions, including:

F.R. #14: Perform conceptual design, including unresolved safety question determination, resource estimate, and preliminary schedule;

F.R. #16: Perform detailed design and/or design review, including specifications for outside procurement;

F.R. #17: Perform safety/risk/reliability analysis; and

F.R. #23: Develop software

The analytical costs in complying with the proposed revisions to 10 CFR Part 20 contributed substantially to the total cost estimate, which was prepared by SC&A under contract with the NRC and used by the NRC in its regulatory impact assessment. As discussed in our original proposal, these estimates were prepared for ten categories of NRC licensees, including power reactors, fuel cycle facilities, and materials licensees. The largest analytical costs were estimated for power reactor operators, who would need substantial software modifications to comply with the new dose estimating prescription contained in ICRP 27/30. Fuel fabrication facilities were also expected to incur substantial costs in upgrading their software to accommodate the new dose estimating system.

Also, as discussed in the response to Part d of Question 2, SC&A evaluated for the DOE Energy Information Administration the role of NRC regulation in the escalation of construction costs at nuclear power plants. A-E scope changes were reviewed in detail for an early and a later vintage plant, to determine the causative factors for the cost growth. Each A-E scope change, which represented a modification to the original design of the plant, was reviewed and the costs were broken down and attributed to NRC regulations or plant betterments. Many of the scope changes corresponded to A-E analytical efforts. In fact, the costs of pipe stress analysis constituted a significant fraction of the cost escalation for the later vintage plant.

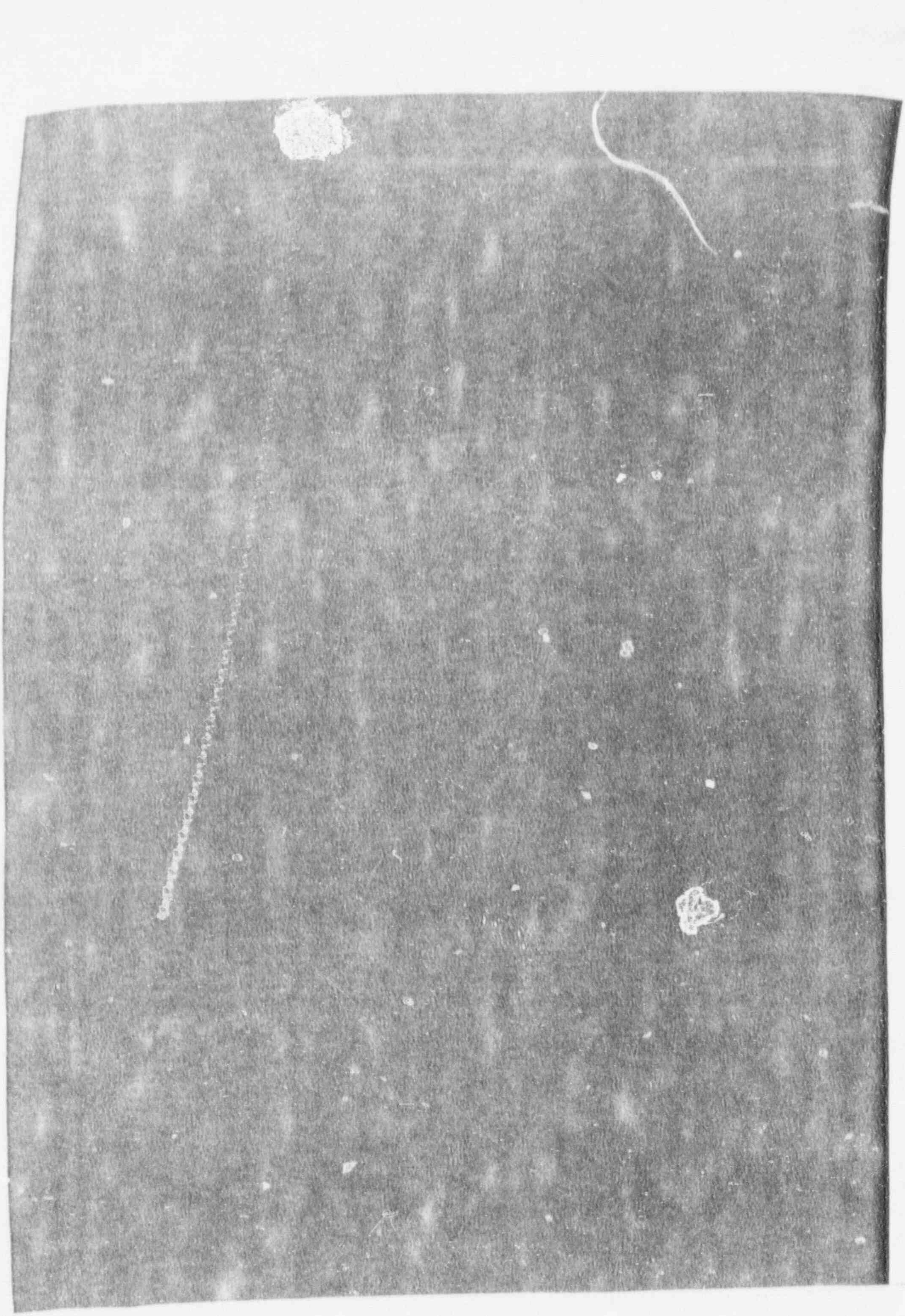
Information availability is discussed in Chapter 4 of our original proposal. We made the point in that Chapter that the generic cost estimating methodology developed by Science and Engineering Associates with the assistance of SC&A would be of little help in evaluating the costs of procedural and administrative changes at nuclear facilities. The same comment applies to the estimation of analytical costs. In fact, there are no abstracts given in NUREG/CR-4627 for estimating analytical costs. Even if there were, we would recommend a case-specific analysis, as suggested in the abstracts pertaining to procedural and administrative costs.

Our experience suggests that accurate estimates of the costs of analytical efforts at nuclear facilities can only be obtained through carefully-considered discussions with utility personnel.

c. **Replacement energy costs were discussed only in the most general terms. Who would be responsible for addressing these impacts. What experience do you posess relative to this issue? And what methodological tools and information do you have available to assess these impacts?**

Response:

[redacted]



d. **When it comes to making physical modifications at nuclear power reactors, has anyone had hands on experience in costing this? Who will make the determination on what kind of QA requirements and security constraints will be in place? Or the level of congestion or adequacy of lay down areas associated with the work? Or whether the equipment and materials need to be seismic or safety grade?**

Response:

Both the SC&A and SCIENTECH project teams have personnel with experience in costing physical modifications at nuclear power plants. Examples of past projects are cited below. These examples are followed by a discussion of the personnel who would be assigned to determine whether or not a specific modification involves special QA or security requirements, whether or not the location involves heavy congestion and/or inadequate laydown areas, and whether or not the equipment and/or materials need to be seismic or safety grade.

As background material for the preparation of the Handbook for Cost Estimating (NUREG/CR-3971), SC&A in 1983 conducted two cost estimates using the proposed methodology for the Handbook, one on the installation of accident monitoring instrumentation at a nuclear power plant and one on the development of an emergency preparedness capability. The former estimate is an example of SC&A's hands-on experience in developing cost estimates for physical modifications. Three utilities were visited in the process of obtaining input data for the cost estimates. The breakdown of costs for the installation of the complete systems, taken from SC&A's report to Argonne National Laboratory (NRC's prime contractor), is reproduced in Exhibit 2.

For the DOE Energy Information Administration, SC&A in 1986 evaluated the role of NRC regulation in the escalation of construction costs at nuclear power plants. Two plants of different vintages were selected as case studies. These two plants had the same utility management, the same NSSS vendor, the same A-E/constructor, and were originally intended to be twins. They were separated in time by approximately seven years, and each plant incurred a cost growth of nearly 300 percent. The A-E scope changes were reviewed in detail for each plant to determine the causative factors for the cost growth. Each A-E scope change, which represented a modification to the original design of the plant, was reviewed and the costs were broken down and attributed to NRC regulations or plant betterments. The costs and causative factors were tabulated by SC&A personnel in close coordination with utility staff. A copy of one page of the extensive tabulation of costs for several hundred scope changes is reproduced in Exhibit 3.

In 1985, SC&A assisted Science & Engineering Associates in developing the cost estimates for the proposed modifications to 10 CFR Part 50, Appendix J, the containment leak testing requirements. Initially, we reviewed all of the material in the Public Document Room for reports from utilities to the NRC summarizing containment leak tests, reports from the utilities to the NRC summarizing test procedures and results for specific types of valves, requests by utilities for exemptions from certain testing requirements of Appendix J, and internal NRC documents and memoranda relating to the proposed revision of Appendix J. We then conducted surveys of four utilities to determine the costs of type A containment tests, including equipment, labor, and contractor technical support.

Exhibit 2

TABLE III

Magnitude of the Costs for Accident Monitoring Instrumentation

	Utility #1	Utility #2			Utility #3	
	2 unit op. CE PWR	3 unit op. BWR	2 unit op. W PWR[1]	2 unit W PWR (const.)[2]	2 unit op. BWR	1 unit op. W PWR
Noble Gas Monitor	$1500K	N/A	N/A	$533K	N/A	N/A
Iodine-Part. Sampling	Not required	N/A	N/A	3065K	N/A	N/A
Both of Above	--	--	$513K	--	--	--
Contain. High Range Monitor	425K	$350K	493K	840K	N/A	N/A
All 3 of Above	--	--	--	--	$5300K	$700K
Containment Pressure	370K	200K	407K	120K	175K	102K
Containment Water Level	302K	350K	Not required	N/A	2200K	217K
Containment Hydrogen	1300K	1000K	Not required	N/A	7500K[3]	260K

Notes:

[1] Does not include materials cost, estimated to comprise approx. 30% of the total

[2] Budgeted, not actual costs

[3] Includes replacement of other monitors in containment in addition to hydrogen monitor

EXHIBIT 5

ST. LUCIE UNIT 2
SCOPE CHANGES RESULTING FROM
PLANT BETTERMENTS

SCOPE CHANGE	DESCRIPTION OF CHANGE	PLANT SYSTEM	A/E $ ONLY	A/E COST	CONST COST	TOTAL FRONTFIT	BACKFIT A/E COST	BACKFIT CONST	TOTAL BACKFIT	GRAND TOTAL
1.000	Implement CX charging pump bypass to fix thermal transient problem.	RCP		62,800	132,300	195,100	0	0	0	195,100
55.000	Modify valves to improve access for type C LLRTs	CONT		54,800	50,000	104,800	0	84,000	84,000	188,800
108.000	Additional eng. & design for rad. monitoring system.	INST	Y	181,200	0	181,200	0	0	0	181,200
571.000	Replace chlorine system with a hypochlorite system.	F		174,800	0	174,800	0	0	0	174,800
567.000	Perform Intake Cooling Water System Piping Study/SL1 biofouling problem.	ICW	Y	163,200	0	163,200	0	0	0	163,200
98.000	Replace portable pump in fuel transfer canal with permanent pump	FHB		28,900	0	28,900	0	132,000	132,000	160,900
16.000	Redesign to Rx Head cable tray to facilitate refueling	RCS		59,600	97,000	156,600	0	0	0	156,600
236.000	Intertie U2 turbine lube oil line with U1	T-G		14,100	69,000	83,100	0	72,200	72,200	155,300
584.000	Modify charging system to eliminate vibration problems.	RCS		150,700	0	150,700	0	0	0	150,700
95.000	Third intake pipeline	ICW	Y	148,600	0	148,600	0	0	0	148,600
198.100	Design intermediate filter cask and associated remote handling equipment	WMS		37,200	90,000	127,200	0	0	0	127,200
521.000	Redesign layout of personnel facilities in the RAB/FPAL request.	RAB		118,300	0	118,300	0	0	0	118,300
525.000	Review pipe rupture design criteria to minimize number of restraints.	ALL	Y	115,300	0	115,300	0	0	0	115,300
41.000	Design permanent ILRT test equipment	CONT	Y	105,800	0	105,800	0	0	0	105,800
530.000	Redesign A/C system for SL2 control room.	HVAC		102,300	0	102,300	0	0	0	102,300
188.000	Replace gland steam condenser	PS		30,800	0	30,800	0	55,000	55,000	85,800
81.000	Evaluate problems with condensate storage tanks.	CST		19,300	61,000	80,300	0	0	0	80,300
576.000	Redesign RAB HVAC system to improve operability and maintainability of plant.	HVAC		78,100	0	78,100	0	0	0	78,100
20.000	Provide specs. for misc. lifting equip in various bldgs.	ALL		27,500	50,000	77,500	0	0	0	77,500
92.000	Phase 1 Waste Management System	WMS	Y	75,900	0	75,900	0	0	0	75,900
147.000	Provide leak detection system in condenser	CWS		52,600	18,000	70,600	0	0	0	70,600
12.000	Replacement of liquid level gauges.	INST		12,500	56,000	68,500	0	0	0	68,500
565.000	Redesign charging system piping to alleviate thermal transient problem.	RCS	Y	68,500	0	68,500	0	0	0	68,500
28.000	Provide additional 120V and 480V receptacles.	ELEC	Y	68,100	0	68,100	0	0	0	68,100
519.200	Prepare bid specs for AC-DC panels.	ELEC	Y	65,800	0	65,800	0	0	0	65,800
578.000	Provide hydraulic lift for the RCB maintenance hatch.	RCB		65,400	0	65,400	0	0	0	65,400
97.000	Provide a block valve to close on high water level in the refueling water tank	FHB		12,800	0	12,800	0	52,000	52,000	64,800
513.000	Reclassify ductwork to Seismic I to save $.	HVAC	Y	63,100	0	63,100	0	0	0	63,100
285.000	Paving of the drumming area	RWST		6,300	0	6,300	0	55,000	55,000	61,300
307.000	Modify relief valve on the primary water to volume control tank line	RCS		27,600	0	27,600	0	33,000	33,000	60,600
125.120	Perform redesign of radiochemistry laboratory	PS	Y	57,600	0	57,600	0	0	0	57,600

Also in 1985, SC&A assisted Science & Engineering Associates in developing the cost estimates for the management of low-level radioactive waste (LLW) by conducting a comprehensive review of the literature on LLW and recommending an initial approach to the development of costs. SC&A also conducted three utility case studies on utility experience and cost performance in managing LLW. Finally, based on contacts with nearly a dozen waste generators and handlers, SC&A developed a methodology for estimating the volumes of waste generated in the course of performing plant modifications. A summary description of the method is reproduced here in Exhibit 4.

SC&A assisted Science & Engineering Associates with the generic cost validation study in 1987 by obtaining plant cost data from several utilities. Spent fuel pool rerack cost data were obtained from Duke Power Company, as-built cost data were obtained from Florida Power & Light Company, as-built cost data were obtained from Washington Public Power Supply System, as-built cost data were obtained from South Carolina Electric & Gas Company, unit rate data were obtained from Arkansas Power & Light Company, and baseline cost data were obtained from Public Service Electric & Gas Company. These data were supplied to SEA for the analysis of the comparison between actual plant data and the generic cost estimating methodology. Finally, SC&A met with the Nuclear Utility Backfit and Reform Group and solicited the cooperation of this group in obtaining additional plant data.

SC&A would also like to call to the attention of the source evaluation panel its extensive experience in occupational radiation exposure assessment and dosimetry. A frequent application of this expertise is the ALARA assessment. An ALARA assessment is a cost estimate without the labor rates. In other words, an ALARA analysis consists of breaking a job down into its component parts, estimating the skill levels and man-hours for each part, and the dose rates in the areas where the work is done. Substituting direct and indirect costs for the dose rates converts the ALARA analysis into a cost estimate. Also, since an ALARA analaysis is only necessary for an operating plant, it is only performed for the case of physical modifications to an operating plant.

SC&A developed an ALARA analysis methodology for the Atomic Industrial Forum (AIF/NESP-039), which was eventually converted into software for the PC by SC&A under the sponsorship of the Nuclear Utility and Management Resources Council (NUMARC/NESP-0001). One of SC&A's proposed personnel under this solicitation, Bruce Mann, served as the ALARA engineer for several BWR recirculation piping replacements, and most recently was the ALARA coordinator at Philadelphia Electric's Peach Bottom station.

An example of the application of the ALARA analysis to NRC's cost estimating work is provided in Exhibit 5. One of earliest task assignments under the original SEA team contract with the NRC was to estimate the costs and radiation exposures for nuclear power plant startup and shutdown. SC&A developed the occupational radiation exposure information from ALARA analysis information provided by the utilities. However, the work breakdown structure and the estimated man-hours for each subtask, which were also obtained from the ALARA assessment, also comprised the basis for the cost estimate. Hourly labor rates and indirect rates were applied by SEA and its other subcontractor to the data illustrated in the Exhibit to estimate the costs.

Exhibit 4

SUMMARY APPROACH TO WASTE VOLUME ESTIMATING

Waste Stream	Components	Approach	Quantitative Guidance
Non-Compactible DAW (P- or B-NCTRASH)	Piping, conduit, insulation, valves, pumps, cable trays, concrete, dirt, etc.	1. Estimate physical volume of plant components.	Use geometry.
		2. Estimate packing fraction in waste containers.	Range of 0.2 to 0.75 in ~100 ft^3 boxes.
		3. Might be able to decontaminate and recycle at a lower cost.	Overall, estimated cost of recycle ~80-85% cost of disposal.
Compactible DAW (P- or B-COTRASH)	Largely paper and plastic.	Estimate based on correlation between volume of compactible DAW and man-rem, man-hours, or volume of non-compactible DAW.	Correlation based on 1981 data for volumes of compactible and non-compactible wastes: At PWRs: $\frac{\text{Vol.Comp.DAW}}{\text{Vol.Non-Comp.DAW}} \approx 0.9$ At BWRs: $\frac{\text{Vol.Comp.DAW}}{\text{Vol.Non-Comp.DAW}} \approx 2.1$
Ion Exchange Resin (P- or B-IXRESIN)	From cleanup of primary system, fuel pool water, or plant drain water.	Depletion of resin is a function of concentration of dissolved solids in liquid steam	For ~ 2 μmho conductivity: ~1.5 ft^3 of waste / 10^5 gal. For ~ 150 μmho conductivity: ~1.5 ft^3 of waste / 10^3-10^4 gal.
	From cleanup of decontamination solution.	Depletion of resin is a function of volume and condition of system being decontaminated, and the decon solution used.	For LOMI decon solution: ~0.1 ft^3 of waste / gal. of decon soln.
Filters	From decontamination of personnel respirators.	Use actual data.	$<10^{-3}$ ft^3 of waste / respirator deconned (~½ comp. & ~½ non-comp.)
	From laundering protective clothing.	Use actual data.	~2X10^{-3} ft^3 of waste / dressout (all compactible)

Exhibit 5

PWR REFUELING MAN-HOURS

	A	B(1)	B(2)	B(3)	C	D1	D2(1)	D2(2)	D2(3)	D2(4)	D3(1)	D3(2)	D4	D5	D6(1)	D6(2)	D6(3)
Job Preparation	32	—	—	—	1	—	—	—	—	—	36	—	—	—	—	—	—
Disassemble Rx Vessel	129	6	268	212	82	—	—	—	—	—	—	—	—	—	—	—	—
Reassemble Rx Vessel	117	335	386	247	164	—	—	—	—	—	481	—	212	—	—	—	—
Subtotal - Disassemble & Reassemble Rx Vess.	246	341	654	459	246	—	—	—	—	—	—	—	—	—	—	—	—
Remove Studs	86	317	583	295	190	—	—	—	—	—	—	—	—	—	—	—	—
Tension Studs	191	468	424	617	265	—	—	—	—	—	382	—	454	—	—	—	—
Subtotal - Remove & Tension Studs	277	785	1007	912	455	—	—	—	—	—	—	—	—	—	—	—	—
Cavity Preparations & Internals Removal	57	636	732	276	84	—	—	—	—	—	—	—	—	—	—	—	—
Head Preparations & Internals Replacement	85	621	328	288	9	—	—	—	—	—	376	—	324	—	—	—	—
Subtotal - Cavity Preps & Internals Removal & Head Preps & Internals Replace.	142	1257	1060	564	93	—	—	—	—	—	—	—	—	—	—	—	—
Subtotal - Rx Disass.	272	959	1583	783	356	—	2749	2537	4180	3200	2560	—	1632	—	—	—	—
Subtotal - Rx Assembly	393	1424	1138	1152	438	—	992	890	1349	699	1239	—	990	—	—	—	—
Subtotal - Reactor Disass. & Assembly	665	2383	2721	1935	794	—	3741	3427	5529	3899	3799		2622				
Shuffle Fuel and Sip	975 (64 assemblies)	1189	1248	1272	700	—	477	1139	701	1920	1209	—	1536 (all assemblies)	—	—	—	—
Cavity Decontamination	96	149	393	203	120	—	—	—	—	—	177	—	82	—	—	—	—
Total Refueling	1768	3721	4362	3410	1615	—	4218	4566	6230	5819	5221	—	4240	—	—	—	—

SCIENTECH has provided support to a number of clients in assessing the effects of regulation on nuclear power plants under construction, in operation, and during long forced outages. Expert testimony concerning the effects of regulation on nuclear power plants has been developed by SCIENTECH for presentation to state public utility commissions, the Federal Energy Regulatory Commission, and civil courts. SCIENTECH has conducted in-depth examinations of hardware, programmatic and organizational changes made by plant operators in response to regulation by the NRC. Specific examples involving cost considerations include:

Evaluation of the effects of safety regulation on the construction cost and schedule of the Seabrook nuclear plant. Client: United Illuminating Co., and other minority owners.

Study of the effects of changing safety requirements on the safety, cost and schedule of the Palo Verde Nuclear Power Project. Client: El Paso Electric Company.

Evaluation of the 1979 shutdown of Beaver Valley 1 because of NRC concerns about the adequacy of the plant seismic design. Client: Pennsylvania Power and Light.

Analysis of the effects of changes in NRC requirements on the cost and schedule of design, construction, and startup of the Clinton Nuclear Power Plant. Client: Illinois Power Company.

Study of the effects on safety, cost and schedule of the South Texas Project resulting from changes in safety requirements and practices of the NRC. Client: Houston Lighting and Power Company.

Evaluation of the effects on safety, cost and schedule of the Shearon Harris Nuclear Power Plant resulting from changes in safety requirements and practices of the NRC. Client: Carolina Power and Light Company.

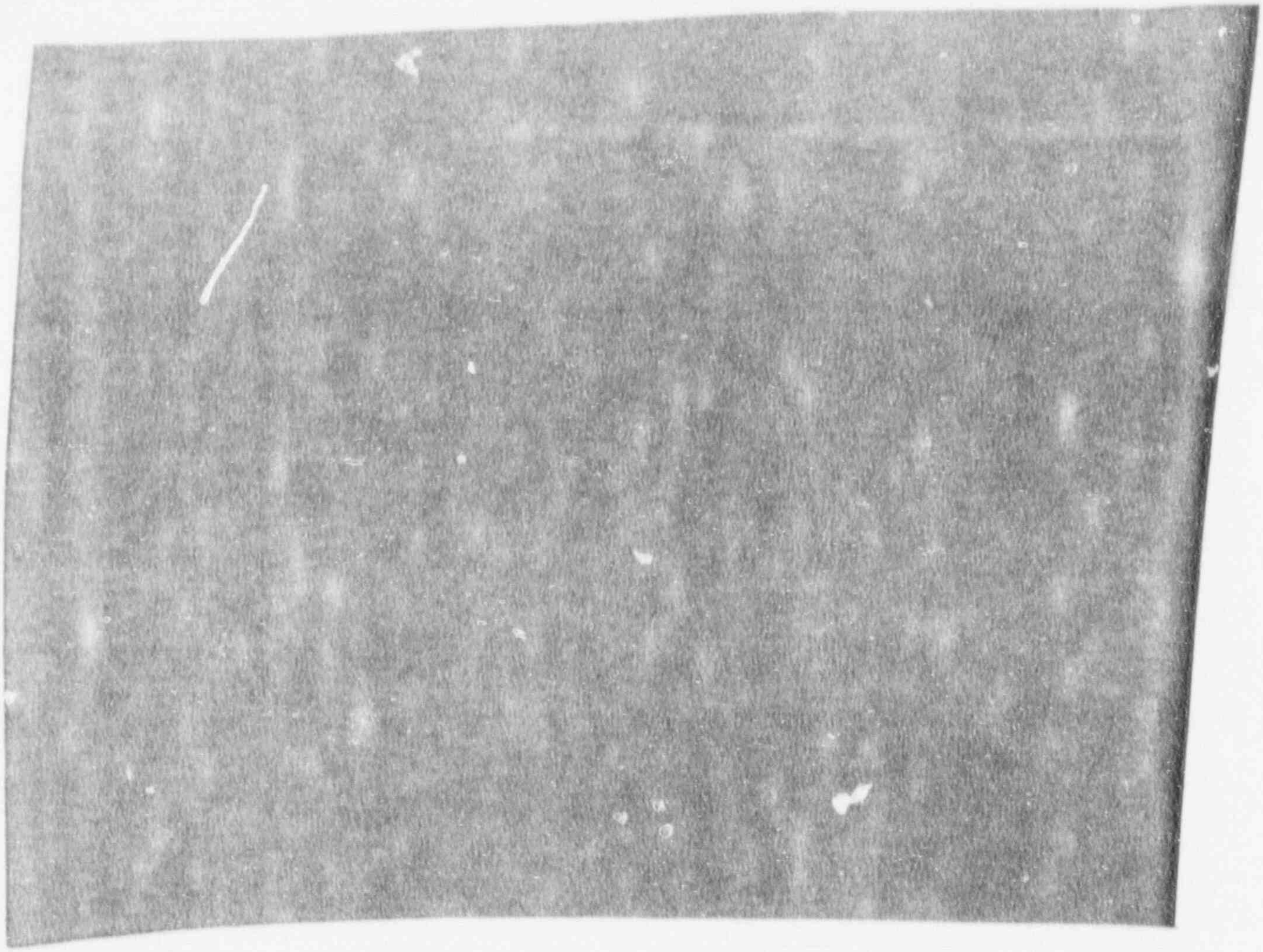
Evaluation of the effects of NRC regulatory programs on the extended outage of the Pilgrim Nuclear Station from 1986 to 1988. Client: Boston Edison Company.

Evaluation of the application and interpretation of NRC regulations in the construction of the River Bend Nuclear Power Plant. Client: Gulf States Utilities Company.

Evaluation of the effects on safety, cost and schedule of Limerick Unit 1 resulting from changes in safety requirements and practices of the NRC. Client: Philadelphia Electric Company.

Evaluation of the effects on safety, cost and schedule of Vogtle Unit 1 resulting from changes in safety requirements and practices of the NRC. Client: Georgia Power Company

[redacted]



3. Has JFA's proposed personnel ever costed hardware backfits at nuclear power reactors? Can you identify such an activity in one of their resumes or provide us with a copy of a study that does so?

Response:

[redacted]

4. Do any of the proposed personnel have Q clearances? Other clearance that might provide access where safeguards issues are of concern?

Response:

None of the personnel proposed by SC&A currently hold a security clearance.

[redacted]

5. For JFA - Our reading of the proposal was that with the exception of your involvement with SC&A on 10 CFR Part 20, JFA has had no involvement with NRC rulemakings. Is that a fair interpretation?

Response:

[redacted]

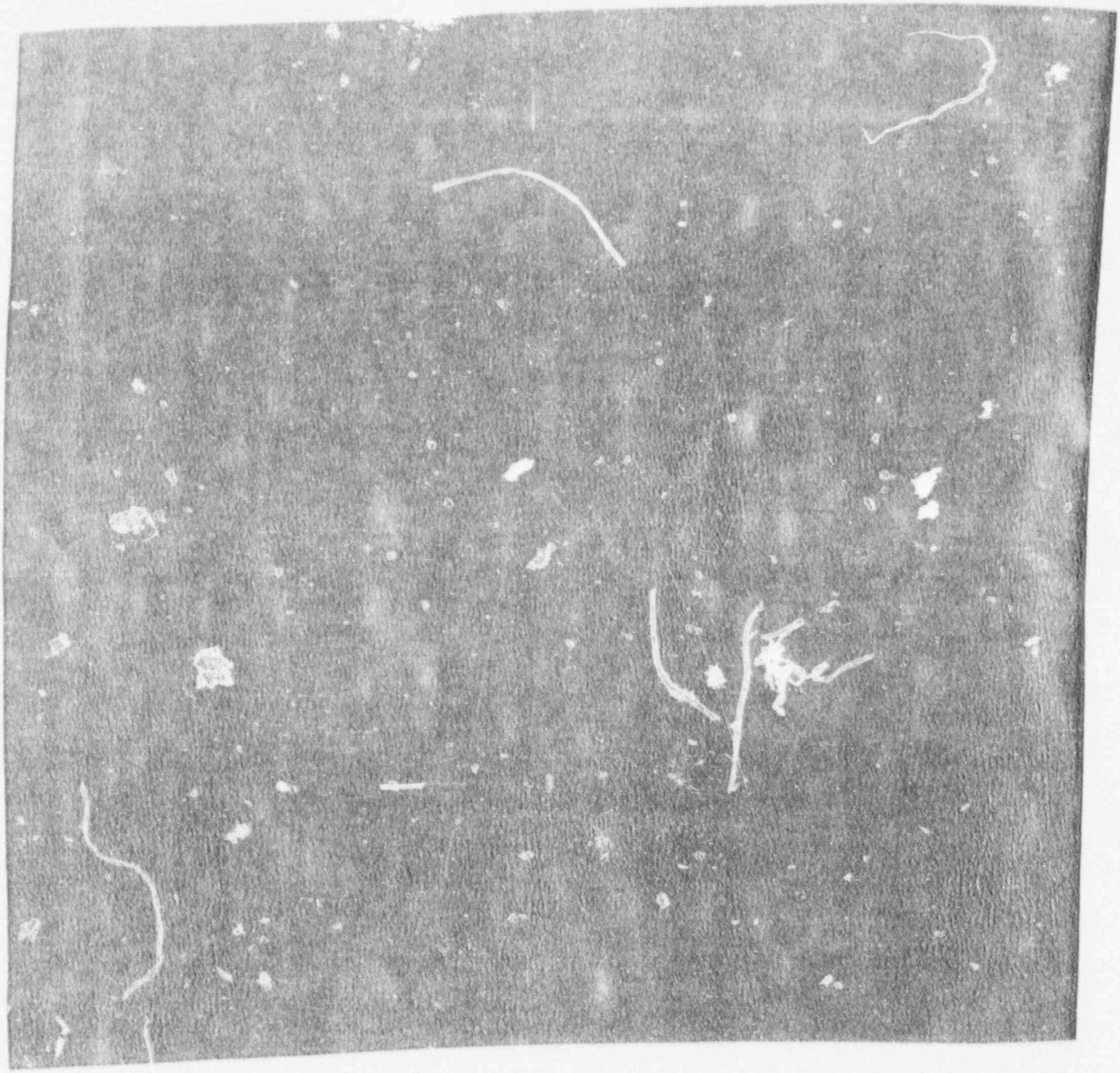
6. For SC&A - Can you give us an indication of your direct involvement with NRC licensees or their umbrella organizations such as NUMARC. For example, what percentage of your business does this client base represent?

Response:

At one time, SC&A offered to the utility industry a workshop describing the quality assurance aspects of radiation measurements. Workshops were held at approximately six utilities. The most recent workshop was held in 1987, and there are no immediate plans to conduct any additional workshops. SC&A conducted three studies for the National Environmental Studies Project of the Atomic Industrial Forum, a nuclear industry trade group (now defunct), the last of which was completed in 1988. SC&A also conducted a study for the Electric Power Research Institute which was completed in 1986 on the deposition of sludge in steam generators. More recently, SC&A conducted a study for the Nuclear Utility Management and Resources Council (NUMARC) on the environmental impact of nuclear power plant life extension. This work was completed in April 1989. SC&A is expected to be awarded a subcontract by the New York University (NYU), under an Electric Power Research Institute (EPRI) contract, to assist NYU in the conduct of an epidemiologic study of nuclear power plant radiation workers.

SC&A has also conducted work for the DOE Office of Civilian Radioactive Waste Management (OCRWM) under a subcontract with Roy F. Weston. SC&A performed work on the OCRWM Program Management System and on the OCRWM Safety Plan. The most recent work performed was in 1988.

[redacted]



8. In the technical proposal [redacted] SC&A employees are identified as either full time associates or associates of SC&A. Can you explain precisely what this employment relationship is? Are all of these employees physically housed in a central SC&A office? If some are housed elsewhere are they all local to the Washington DC area?

Response:

SC&A has operated since its inception in 1981 using the Associate System. Associates are paid an hourly rate and are not entitled to fringe benefits. Thus, they are like independent contractors. However, they all have formal working agreements with SC&A, and several of them have been working with the company for several years. Most of our work has been similar to the proposed work for the NRC -- namely, relatively quick-response technical and analytical support to government agencies. Therefore, in reviewing the answer to our question, it should be kept in mind that this Associate System has worked for us in successfully performing more than 150 tasks for our clients, including approximately 15 for the NRC (approximately 12 relating to cost impacts under subcontract to Science and Engineering Associates).

Most of the work is performed at the offices of each of the Associates. Meetings are held, as necessary, between the Task Leader and the other Associates working on a task, either at the office of the Task Leader or at SC&A's office facilities in McLean. Communications regarding the task occur on a daily basis between the Task Leader and the Project Director (who may be the same individual for certain tasks), and between the Task Leader and the other Associates working on the task. These conversations are normally held on the telephone, with face-to-face meetings scheduled only as required. If working papers need to be exchanged, they are transmitted by regular mail, by overnight mail, by Facsimile machine, by computer modem, or by messenger, depending on cost-benefit considerations.

Nearly all of the Associates possess desktop computers equipped with modems, the majority have facsimile machines or have close access to one, and several have personal copying machines. The Associates generally compose their own work on these machines, and the files (whether text or data) are readily exchanged over telephone wires for review and consultation by the Task Manager and Project Director. The firm also maintains a pool of private word processing contractors who prepare reports for the Associates who do not compose their own text on desktop computers. These private word processing contractors may also be used to bring draft text to final form from corrections made by hand. All or our Associates use work processing software which is compatible with SC&A's software, and with that of our word processing contractors.

Publications used as references in a task are generally ordered by the Task Leader from the National Technical Information Service, or from one of the government agencies' technical libraries (i.e., EPA, NRC, or DOE). Copies are made and distributed to each of the Associates working on the task who needs to refer to the material.

Draft reports are assembled by the Task Leader or Project Director at SC&A's office facility using, as needed, the individual contributions of the Associates (or subcontractors). The draft report is reviewed by the Project

Manager and comments and corrections are supplied to the Project Director. After the appropriate changes have been made, it is sent to the client with the Project Manager's approval. A similar procedure is used for the final report.

In summary, the work itself is assigned by the Task Leader or Project Director to the Associates, who work alone at their own facilities on discrete work packages. Communications are held by telephone as often as necessary between the Associates and the Task Leader, and in person at the SC&A central office facility when the need arises. Working papers and interim products are exchanged using state-of-the-art office technology as often as necessary for consultation, review and approval. The Project Manager schedules meetings at the SC&A central office facility if it is determined from the telephone conversations, or from the review of interim products, that face-to-face discussions are necessary.

The above procedures are identical to those used for similar technical work performed in a central office environment, except for the absence of daily face-to-face discussions. We have found that for the technical work that we perform, and for the work expected under the subject procurement, the discrete work package approach is almost always employed, rendering frequent personal interactions unnecessary. In fact, we have found that the convenience of closeness is far outweighed by the costs of commuting and the waste associated with "conversations at the water cooler." In other words, we believe that this system is more efficient, with benefits to the client, the company, and the Associates.

Another factor that contributes to the success of this system for SC&A is the experience level of our Associates. The average number of years of experience of the SC&A Associates proposed for this solicitation is approximately 17. Therefore, SC&A Associates are seasoned professionals who are accustomed to working independently.

It has been our experience that the level of commitment of Associates to our projects is equivalent to that of employees. When a task is initiated, a commitment is made to the company by the Associate for the level of effort and schedule required to complete the task. On only one occasion has an SC&A Associate been unable to complete the commitment made to the company, and a replacement was found immediately.

[redacted]

9. Can the proposed team demonstrate experience with pathway modelling (e.g. IMPACTS BRC Code for waste disposal) that could be used in analyzing below regulatory concern petitions?

Response:

SC&A has extensive experience in pathways modeling and BRC issues, and we are very familiar with the IMPACTS-BRC computer code and other codes that can be used to (1) identify candidate BRC waste streams and (2) evaluate petitions for compliance with the individual and cumulative dose criteria proposed in the NRC policy statements and upcoming revisions to the proposed criteria. The following sub-sections describe our experience, understanding, and expertise in pathway modeling, followed by a more detailed description of our capabilities and experience in pathways modeling specifically for BRC petitions or rulemakings.

PATHWAYS MODELING EXPERIENCE

The following presents a summary of our pathway modeling experience.

Airborne Emissions from Direct Discharges to Atmosphere and Via Resuspension from Waste Piles

SC&A conducted a pathways analysis for the EPA for emissions of radionuclides to the atmosphere from 12 source categories, including nuclear power reactors, nuclear fuel cycle facilities, and NRC byproduct and source material licensees.

The pathways analysis included the following elements:

- identification of all sources of radioactive emissions to the atmosphere from the facilities within each source category;
- analysis of data on emission quality and rates from each source identified and characterization of sources of emissions;
- characterization of environmental pathways leading to human exposure;
- development of individual and population doses and health risks caused by the emissions from both individual facilities and the entire source category; and
- characterization of control technology used or available for use to reduce emissions

Doses and health effects caused by airborne releases of radionuclides were evaluated for the following source categories:

- Department of Energy Facilities;
- NRC- and Agreement State-Licensed Non-LWR-Fuel Cycle Facilities;

- LWR-Fuel Cycle Facilities;
- High-Level Waste Disposal Facilities;
- Elemental Phosphorus Plants;
- Coal-Fired Utility and Industrial Boilers;
- Title I (DOE) and Title II (Licensed) Uranium Mill Tailings Disposal Sites;
- Licensed Uranium Mills;
- DOE Radon Sites;
- Underground Uranium Mines;
- Active and Inactive Surface Uranium Mines; and
- Phosphogypsum Waste Stacks.

Calculations of doses were performed with the AIRDOS-EPA computer program, using ICRP-30 dose conversion factors for air immersion, ground-surface, inhalation, and ingestion pathways. Health effects were assessed using the BEIR-II dose-response relationship. Doses calculated with this methodology were compared with independent dose estimates, and the discrepancies were noted and explained. Supplemental control technologies were reviewed, in some specific cases, to establish the efficacy of further reducing doses.

The results are summarized in a three volume EPA report - EPA/520/1-89-005, 006-1, and 007, published in October 1989.

In support of this EPA rulemaking, SC&A developed for the agency a pathways model for determination of compliance with the standards for radionuclides under the Clean Air Act. This code, called COMPLY, is intended to replace the more complex model, AIRDOS-EPA/RADRISK. Moreover, the EPA Science Advisory Board recommended that the uncertainty in doses and risks resulting from pathways modeling in the development of the standards be quantified. SC&A assisted the Agency in this quantification of uncertainty by characterizing the sensitivity of selected factors used in the risk assessment, and, using Monte Carlo techniques, by evaluating the overall uncertainty of the doses and risks calculated by COMPLY, as a surrogate for the more detailed pathways analysis using AIRDOS- EPA/RADRISK. The uncertainty analysis included the development of uncertainty distributions for all of the key calculational parameters, including source term, atmospheric dispersion and deposition factors, environmental transport and reconcentration factors, usage factors, dose conversion factors and risk conversion factors.

As discussed below, IMPACTS BRC contains default files for all of these parameters. Accordingly, our work on the uncertainty of these parameters has direct applicability in understanding the uncertainties associated with the use of IMPACTS BRC.

Exposure to Residual Radioactivity

SC&A developed the REUSIT computer code for the EPA to estimate the maximum annual radiation dose to individuals at decontaminated and decommissioned sites and facilities. This new pathways model considers initially contaminated surface soil, subsurface soil, and buildings. The environmental media modeled include the atmosphere, surface soil, subsurface soil, groundwater, and surface water. The environmental exposures include external exposure from contaminated ground and from immersion in contaminated air and water, and internal exposure from inhalation of suspended surface soil and from ingestion of contaminated water, crops, animal- derived foods and aquatic fo s. Contamination of internal building surfaces, in ventilation systems and on residual equipment is taken into account. The exposures in buildings include external exposure from all types of building contamination and internal exposure from inhalation of contaminated dust.

Enhances Sources of Naturally Occurring Radioactive Materials

In support of EPA's low-level radioactive waste program, SC&A assessed the risk to public health from diffuse naturally occurring radioactive materials (NORM wastes). These are the large volumes of wastes and potentially recyclable materials that contain Ra-226 concentrations below 2,000 pCi/g.

The following NORM wastes were examined in the risk assessment:

- Mineral processing wastes;
- Water treatment processing sludges;
- Petroleum pipe scale;
- Coal ash;
- Phosphogypsum piles;
- Fertilizer; and
- Uranium overburden.

An assessment was made of the volumes of these materials generated over a twenty-year period, and the potential radiation exposures to the public resulting from the use and discharge of these materials. The risk assessment addressed all major pathways of exposure, including direct radiation, inhalation of resuspended material, surface water runoff, leachate to groundwater, ingestion of foods, and exposure to indoor radon progeny. The risk assessment will be used to determine the need to initiate a rulemaking specifically for NORM wastes.

Experience with IMPACTS BRC

Several of SC&A's personnel have prior experience with IMPACTS and IMPACTS BRC, [redacted] participated in a number of low level radioactive waste performance assessment projects for the Pennsylvania Department of Environmental Resources (PADER) and the Northeast Compact. Performance assessment work for PADER included the evaluation of performance assessment codes, including IMPACTS, PRESTO and FEMWATER/FEMWASTE. On the NE Compact project, the IMPACTS BRC code was applied to waste generated in the NE in order to evaluate the potential impacts of BRC on the volume of low-level radioactive waste projected for the compact. In addition, [redacted] represented PADER on the EG&G Performance Assessment Technical Coordinating Committee and gave performance assessment lectures to health physics graduate students at Rutgers University. The lectures were based heavily on the IMPACTS code described in NUREG/CR-4370.

In addition to our experience with using IMPACTS BRC, we are also experienced in the key data bases, models and assumptions used in IMPACTS BRC. IMPACTS BRC calculates the radiation exposure to individuals and populations for waste streams and disposal methods defined by the user. The disposal methods include:

- on-site incineration followed by disposal of ash in a sanitary landfill;
- municipal incineration followed by disposal of ash in a sanitary landfill;
- on-site incineration followed by disposal of ash in a hazardous waste disposal facility;
- hazardous waste incineration followed by disposal of waste in a hazardous waste landfill;
- direct disposal in a sanitary landfill; and
- direct disposal on-site.

The program allows a number of regional environments to be assumed and a broad range of radiological, chemical and physical waste characteristics and pre-processing assumptions. Through the use of "decision indices," IMPACTS BRC allows the user to manipulate specific waste form, packaging, disposal technology, sites, demography, and a number of other parameters which may need to be accommodated on a generic bases or in response to a specific petition.

The doses are calculated for workers, transporters, individual members of the public (including an inadvertent intruder) and the general public. Whole body and organ doses are calculated for a number of pathways including:

- direct radiation;
- waterborne;
- groundwater;
- food; and
- resuspension.

As part of the work performed by [redacted] for the State of Pennsylvania and for the NE Compact Commission, it was necessary to evaluate the default source term data base incorporated into IMPACTS and IMPACTS BRC.

In support of the PADER project, [redacted] of our project team performed an evaluation of the groundwater transport models incorporated into IMPACTS and IMPACTS BRC.

APPENDIX A: ADDITIONAL PERSONNEL

Based on our discussions with the NRC during the meeting held on October 25, 1989, and the evaluations panel's written questions, we are proposing additional personnel for the project team. Resumes of the additional personnel are included with this submission. The addition of these individuals will assure that we have all of the experience and expertise needed to provide the rulemaking and regulatory support called for in this procurement.

APPENDIX B: NON-REACTOR LICENSEES

Sections of the reports contained in this appendix are included to demonstrate our knowledge of non-power reactor licensees and of the considerations that are important to safety and credible accident scenarios at fuel-cycle facilities.

CHAPTER 2. FACILITY DESCRIPTIONS *

2.1 INTRODUCTION

The NESHAP applies to approximately 6,000 NRC-licensed and non-DOE Federal facilities that possess unsealed sources of radioactive materials. The NRC-licensed facilities include material licensees and facilities engaged in the uranium fuel cycle. NRC-licensed facilities include facilities licensed by the Agreement States but exclude low-energy accelerators and facilities regulated under 40 CFR Part 191, Subpart B.

The major types of facilities covered by the standard are described in the following sections. The discussion focuses on the physical forms of the radionuclides used and the handling and processing that the materials undergo. These factors are major determinants of the quantities of materials handled that become airborne.

2.2 NRC MATERIAL LICENSEES

2.2.1 Users and Producers of Radionuclides for Medical Purposes

The users and producers of radioactive materials for medical purposes constitute by far the largest category of facilities handling unsealed radioactive sources. Approximately two-thirds of the 6,000 facilities covered by the NESHAP are engaged in some aspect of the production and distribution of radiopharmaceuticals or in the medical application of these materials. Medical uses of radiopharmaceuticals include biomedical research and patient administration of radiopharmaceuticals for both diagnostic and therapeutic purposes.

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*Excerpted from EPA 520/1-89-001, prepared by D. Goldin of SC&A for the EPA.

2.2.1.1 Radiopharmaceutical Users

The types of facilities that use radionuclides for medical purposes include hospitals, clinics, and biomedical research facilities. The radionuclides used directly in patient therapy and diagnosis are termed "radiopharmaceuticals," while those used in research are referred to as "radionuclides." For simplicity, the term "radiopharmaceuticals" will be used to refer to the radioactive materials used in both patient administration and research.

The radiopharmaceuticals used at medical facilities occur in all three basic physical states: solid, liquid, and gas. The physical state of a particular radiopharmaceutical product is determined by (1) the chemical form of the radionuclide and (2) the solution or other mixture, if any, in which the radionuclide is dispensed. Both the radionuclide and the substance in which it is mixed are chosen to suit specific therapeutic, diagnostic, and research purposes.

The mixing of the radionuclide with some other substance means that the physical state of a radiopharmaceutical product may be different than the physical state of the radionuclide itself. In this document, discussions of the form of a particular radionuclide refer to the radionuclide product. The physical states of these products are important in assessing the potential for airborne release.

Most radionuclides used in medical facilities occur in liquid form. These liquids may be administered either orally or intravenously. Orally administered radionuclides are usually in the form of aqueous solutions. Many of these chemicals are ionic salts and thus occur in liquid form as saline solutions. Radionuclides that are administered intravenously may occur as solutions, colloids, or suspensions.

Solutions consist of molecules of solids or gaseous substances dissolved in a liquid. Colloids involve the dispersion of larger particles (on the order of 10 nanometers to 1 micrometer in diameter) in a liquid medium; the larger particles are prevented from aggregating and settling by being coated with a layer of gelatin (as is done with gold-198). Suspensions are similar to colloids but involve the radionuclide labeling of still larger particles (greater than 10 micrometers in diameter) of substances such as human serum albumin.

Gaseous radionuclides usually occur naturally in elemental form (e.g., xenon-133), and are administered to patients as a pure gas or as a gas diluted by air. Patients normally inhale the gas from a bag or from a gas "generator" through a respirator.

Solid radionuclides occur as gelatin capsules containing liquid solutions of the radionuclide chemical. In some cases, the solution is absorbed in dry filler material. Solid radionuclides are administered orally to patients.

The number of radionuclides with medical applications is extensive and increasing. In the areas of diagnosis and therapy, the most commonly used radiopharmaceuticals include chromium-51; cobalt-57, -58, and -60; gallium-67 and -68; technetium-99m; iodine-123, -125, and -131; selenium-75, xenon-127 and -133; and thallium-201. Biomedical researchers employ tritium, carbon-14, phosphorus-32, and sulfur-35 extensively. The radiopharmaceuticals used in medical applications may be obtained from radiopharmaceutical manufacturers or independent radiopharmacies, or they may be produced on site from radiopharmaceutical generators. Because of the relatively short half-lives of the radionuclides used in medicine, shipments from vendors are received frequently (weekly or daily), and storage times are minimal.

Radiopharmaceuticals purchased from vendors may be in the form of pre-packaged dose kits, radiopharmaceutical generators, or bulk supplies from which individual doses are extracted and prepared. Handling of prepackaged dose kits may involve no more than removing the material from the package and administering the radiopharmaceutical to the patient either orally or by intravenous injection.

Handling of materials obtained in the form of bulk stocks or radiopharmaceutical generators is more involved. In general, these materials are received and stored in a central area where individual doses are prepared. In the case of liquids, dose preparation involves extracting the required quantity from the stock solution by syringe or pipette and diluting the material in a suitable sterile medium. These operations are conducted in a fume hood, and the dose is administered to the patient either intravenously or orally.

Preparation of doses from radiopharmaceutical generators, of which molybdenum-99/technetium-99m generators are the most common, involves elution of the product from the generator and division of the elute into individual doses. The procedures for eluting a generator depend on whether it is a wet or dry column design. In a wet column generator, an evacuated extraction vial is attached to the end of the generator column with a sterile needle. Using the vacuum within the vial, the solvent is pulled from the generator reservoir through the column and into the vial. The procedure for a dry column generator is similar. However, since dry generators do not have a reservoir of solvent, solvent must be added to the column prior to elution. The charge vial is attached to one end of the generator, and then the evacuated extraction vial is attached to the other end. The solution is drawn through the generator column and collected in the elution vial. These elution procedures and dose divisions are conducted in a fume hood, with the generator shielded to prevent external irradiation of the technicians.

Handling of radionuclides for biomedical research is more varied than that of radiopharmaceuticals used for patient administration. Depending on the specific radionuclides used and the goal of the experiment, the materials may simply be extracted from bulk stocks and administered, or the radionuclides may be subjected to additional chemical or physical processing.

2.2.1.2 Radiopharmaceutical Producers and Suppliers

Radiopharmaceutical manufacturers produce the radionuclide-labeled compounds, diagnostic kits, and radionuclide generators used in biomedical research and medical diagnosis and therapy. The radiopharmaceutical products may be shipped directly to medical users, or they may be shipped to independent radiopharmacies where individual doses are prepared from the bulk supplies or generators and distributed to medical users. Individual radiopharmaceutical manufacturers may specialize in only a few widely used radiopharmaceuticals or may produce many of the radionuclides used in biomedical research and patient diagnosis and therapy.

The radionuclides used in radiopharmaceuticals are produced either in nuclear reactors or in accelerators. Radiopharmaceutical manufacturers may operate their own production facilities or may purchase the bulk radionuclides from an outside vendor. In producing the bulk radionuclides, a suitable target is first prepared and then bombarded with neutrons or positive ions in the reactor core or accelerator. Once irradiation is complete, the target is removed from the production device, and the product is recovered and purified in a hot cell by appropriate chemical processing.

The production of the labeled compounds used in radiopharmaceuticals and biomedical research is essentially a wet chemistry process. Depending on the specific radiopharmaceutical, workers conduct these operations within laboratory fume hoods or gloveboxes. The final products are generally assembled and packaged in assembly line operations.

Radiopharmaceutical generators are designed and produced as closed aseptic systems using some type of chromatographic column. Typically, this chromatographic column consists of an inorganic ion exchange resin to which the generator (parent) radionuclide is bound. As the parent radionuclide decays, the decay product, which has different chemical/physical properties, is produced. The decay product is eluted from the column by the user at specified intervals. Generators are manufactured in a hot cell, where the parent radionuclide is packed in the column, and the column of the generator is surrounded by absorbent materials and shielding. The absorbent materials minimize the consequences of accidental breakage; the shielding reduces the radiation exposure of users. Once the generator is loaded, final assembly and packaging are carried out on an assembly line.

Independent radiopharmacies are a relatively recent phenomenon. Generally located in large cities, these facilities serve as distribution facilities. Radiopharmacies purchase bulk stocks and generators from radiopharmaceutical manufacturers and provide hospitals and clinics with individually prepared doses on an as-needed basis. The dose preparation procedures at these facilities do not differ from those at medical facilities that obtain their radiopharmaceuticals directly from the manufacturers.

2.2.2 Sealed Source Manufacturers

While facilities that use only sealed radiation sources are not covered by the NESHAP, the industrial facilities that produce sealed sources are subject to the standard. The facilities described in this section fall into two broad classes: those that manufacture encapsulated alpha, beta, or gamma-emitting radiation sources; and those that manufacture self-luminous devices.

2.2.2.1 Manufacturers of Sealed Radiation Sources

Sealed radiation sources are widely used in medical, industrial, and residential applications. Medical applications include gamma-emitting devices used in diagnostic and therapeutic procedures and sources used in patient implants. Industrial applications include nondestructive imaging and inspections, static eliminators, industrial gages, irradiation devices, and well-logging devices. The main radionuclides used in these devices iridium-142, krypton-85, americium-241, cesium-137, and cobalt-60. Smoke detectors, using alpha-emitting americium-241 sources, are the most widely used sealed sources in residential applications.

The manufacture of sealed sources is essentially a repackaging and redistribution process. Bulk radionuclides, in the form of pellets or foils, are received from a vendor in an approved shipping package. The shipping package is opened, and the required quantity of the radioactive material is removed and transferred to a container. The container is then sealed by welding or brazing. Most such devices are double encapsulated; i.e., an inner capsule contains the radioactive material and an outer container protects the inner container. Double encapsulation increases the assurance of safe handling. The outer container may also be brazed or welded, or simply screwed shut. All operations are performed in hot cells to protect the workers.

At some facilities, the bulk material purchased from the vendor is subjected to physical and/or chemical processing to alter the form of the material prior to encapsulation. For example, most cobalt-60 sources contain cobalt in the form of metal foils or microspheres. The cobalt is received from the vendor in the form of cobalt metal, and the material is processed by heating the metal to the melting point in a fluidizing furnace to form the desired microspheres. Similarly, manufacturers of smoke detectors generally obtain the bulk americium-241 in the form of oxide powder. This powder is compacted to form wafers, sintered in an induction furnace, ground to specifications, and hot-rolled with gold foil to produce the encapsulated material for incorporation into the device.

2.2.2.2 Manufacture of Self-Illuminating Devices

Self-illuminating devices include watches, compasses, signs, and aircraft instrumentation. Historically, radium-226 was used in radio-luminescent products. However, the well-documented hazards of working with radium and the advent of other materials with inherently superior characteristics have largely eliminated the use of radium. Today, tritium and, to a much lesser extent, krypton-85 and promethium-147 are used in the production of self-luminous devices.

Two general types of self-illuminating devices are made: those in which the radio-luminous material is incorporated into a paint which is used to coat the dial and/or instrument hands; and those in which a radioactive gas (tritium or krypton) is contained in a phosphor-coated glass ampule.

Manufacturers of self-illuminating devices obtain the bulk radionuclides in either gaseous or (rarely) liquid form from a vendor.

In the case of devices incorporating self-luminous paint, the manufacturing process involves the incorporation of the radionuclide in the paint and the application of the paint to the device. In the case of self-illuminating sources, the gaseous radionuclide (tritium or krypton-85) is transferred to the glass ampule and sealed. Both processes are carried out in areas with high ventilation rates or in fume hoods to protect the workers.

2.2.3 Test and Research Reactors

The NRC licenses approximately 70 academic, research, and industrial facilities to operate test and research reactors. Test and research reactors are used as teaching devices, to study reactor designs, to conduct research on the effects of radiation on materials, and to produce radioactive materials used by sealed source and radiopharmaceutical manufacturers.

The design of such reactors and their sizes vary widely. Approximately 15 research reactors are used primarily as teaching devices and have very low power outputs (less than 15 watts). The nuclear cores of these reactors have their uranium fuel dispersed and fixed in a plastic matrix. Given the design and use of these teaching reactors, airborne releases cannot occur during normal operations.

Research and test reactors used for experimental and production purposes include both light-water pool and heavy-water tank-type designs, ranging in power from 100 kilowatts to 10 megawatts. All of these facilities use highly enriched uranium fuel, either in metal or mixed carbide fuel elements.

In these reactors, experiments and/or production activities are conducted by remotely inserting the target containing the material to be irradiated into the experimental ports or beam holes that penetrate the reactor core. The target material is subjected to the neutron flux of the reactor core for an appropriate period of time and then withdrawn via shielded transport devices (called "rabbit systems") to a hot cell. The irradiated material is examined or the product is recovered in the hot cell. Product recovery may be as simple as dissolving a soluble salt in water, or it may involve evaporation, precipitation, extraction, distillation, and/or ion exchange.

Potential airborne releases from such facilities include the fission products in the core of the reactor, activation products generated during the operation of the reactor, and releases from the disassembly and recovery of target materials in the hot cell. In general, the activation products, along with any gaseous fission products escaping the coolant, are released directly to the atmosphere from the facility exhaust. Materials that become airborne during processing in the hot cell will be vented through the hot cell's exhaust system. The effluent from the hot cell is generally filtered through high efficiency particulate air (HEPA) filters before release.

2.2.4 Non-Light-Water Reactor Fuel Fabricators

Only a few facilities produce the metal and mixed carbide fuel used in test and research reactors.

The non-oxide fuel fabrication process begins with highly enriched uranium metal. The uranium metal may be mixed with an alloying metal in an induction furnace. The fuel is then either rolled, punched, drilled, or crushed and compacted, and machined and shaped into the proper dimensions. Once the fuel is properly formed, it is enclosed in aluminum or stainless steel. The enclosing process may involve injection casting, loading into a can or mold, or simply covering the fuel with side plates and rolling the metals together. Finished fuel elements are then inspected and cleaned prior to assembly into fuel bundles.

The production of mixed carbide fuel starts with highly enriched uranium dioxide-thorium dioxide powder (UO_2-ThO_2). This powder is mixed with graphite and heated to form uranium-thorium carbide kernels. These kernels are formed into microspheres by heating to a temperature in excess of the kernels' melting point. The microspheres are then coated with carbon and silicon layers in a fluidized bed furnace. Fuel rods are formed by injecting the coated kernels and a matrix material into a hot mold. The finished rods are then inserted into a graphite block to form the final fuel assembly.

2.2.5 Source Material Licensees

Two types of facilities are included in the category of "Source Material Licensees" which is subject to the NESHAP: those involved in the extraction of metals from uranium- and thorium-bearing ores, and those using depleted uranium metal or thorium in various products.

Approximately 10 facilities are engaged in the recovery of metals from source materials. In general, the products extracted from the uranium- and thorium-bearing ores are refractory metals, their oxides (columbium/niobium, zirconium, tantalum, and hafnium), or the rare earths (cerium, neodymium, dysprosium, etc.). These extraction operations involve processes typical of metal mining and beneficiation. Depending upon the specific facility and the products under recovery, the processing may involve wet chemical or solvent extraction, smelting, and high temperature sintering.

Facilities that manufacture products incorporating source materials include munitions producers using depleted uranium in armor-piercing projectiles, manufacturers that make lanterns and gas lights using thorium mantles, aerospace manufacturers using depleted uranium for stabilizers and ballast, and welding rod manufacturers that use thorium in the metallic form. Such manufacturers generally receive the material in the physical form in which it is used (e.g., depleted uranium in the form of metal billets). The processing is confined to such metallurgical operations as casting, forging, machining, and polishing.

2.2.6 Waste Receivers/Shippers and Disposal Facilities

The radioactive wastes generated by facilities that use radionuclides must be disposed of in an approved manner. In general, wastes with high specific activities (such as uranium-contaminated scrap at non-oxide fuel fabrication facilities) will be recycled and recovered. However, virtually every user of unsealed radioactive materials will generate solid, low-level radioactive wastes which require active disposal. Such wastes may be incinerated on site or packaged and shipped off site to a licensed low-level waste disposal facility.

Waste receivers and shippers (sometimes called "waste brokers") are primarily collection and shipping agents for facilities generating low-level wastes. Most such receiving/shipping facilities simply collect the wastes in shipping containers approved by the Department of Transportation from a number of waste generating facilities, monitor the packages for contamination, and hold the wastes at a warehouse until they arrange a shipment to a licensed disposal site. The licenses of most such receiving and shipping facilities do not allow the facility to repack or even open the waste packages. However, several such facilities have been licensed to open, compact, and repackage waste materials before shipment.

Currently, there are three low-level radioactive waste disposal facilities which are accepting shipments for burial: the Barnwell facility in South Carolina, the Beatty facility in Nevada, and the Richland facility in Washington. Waste shipments are checked for damage and contamination upon receipt and then placed in excavated trenches. When a burial trench is filled with waste it is backfilled with soil.

2.3 URANIUM FUEL CYCLE FACILITIES

The uranium fuel cycle includes uranium mills, uranium hexafluoride conversion facilities, uranium enrichment facilities, light-water reactor fuel fabricators, light-water power reactors, and fuel reprocessing plants. With the exception of the uranium enrichment facilities that are owned by the Federal government and operated by contractors under the supervision of the Department of Energy (DOE), these facilities are licensed by the Nuclear Regulatory Commission (NRC) or the Agreement States.

2.3.1 Uranium Mills

Uranium mills extract uranium from ores which contain only 0.01 to 0.3 percent U_3O_8. Uranium mills, typically located near uranium mines in the western United States, are usually in areas of low population density. The product of the mills is shipped to conversion plants, where it is converted to volatile uranium hexafluoride (UF_6) which is used as feed to uranium enrichment plants.

As of December 1988, of 27 uranium mills in the United States licensed by the NRC or agreement states, four were operating, eight were shut down, 14 were being decommissioned, and one had been built but never operated. The eight shut down mills could resume operations, but the 14 mills that are being decommissioned will never operate again.

The operating mills have a capacity of 9,600 tons of ore per day. The number of operating mills is down considerably from 1981, when 21 mills were processing approximately 50,000 tons of ore per day. This reduction reflects the decrease in the demand for yellowcake. The mined ore is stored on pads prior to processing. Crushing and grinding and a chemical leaching process separate the uranium from the ore. The uranium product is dried and packaged following recovery from the leach solution. The waste product (mill tailings) is piped as a slurry to a surface impoundment area (tailings pile).

Radioactive materials released to the air during these operations include natural uranium and thorium and their respective decay products (e.g., radium, lead, radon). These radionuclides, with the exception of radon, are released as particulates.

2.3.2 Uranium Conversion Facilities

The uranium conversion facility purifies and converts uranium oxide (U_3O_8 or yellowcake) to volatile uranium hexafluoride (UF_6),the chemical form in which uranium enters the enrichment plant.

There are currently two commercial uranium hexafluoride (UF_6) production facilities operating in the United States, the Allied Chemical Corporation facility at Metropolis, Illinois and the

Kerr-McGee Nuclear Corporation facility at Sequoyah, Oklahoma. The Allied Corporation facility, a dry-process plant in operation since 1968, has a capacity to produce about 12,600 mt of uranium per year in the form of UF_6. The Kerr-McGee Nuclear Corporation facility is a wet-process plant in operation since 1970, with a capacity of about 9,100 mt per year (AEC74, Do88).

Two industrial processes are used for uranium hexafluoride production, the dry hydrofluor method and the wet solvent extraction method. Each method produces roughly equal quantities of uranium hexafluoride; however, the radioactive effluents from the two processes differ substantially. The hydrofluor method releases radioactivity primarily in the gaseous and solid states, while the solvent extraction method releases most of its radioactive wastes dissolved in liquid effluents.

2.3.2.1 Dry Hydrofluor Process

The hydrofluor process consists of reduction, hydrofluorination, and fluorination of the ore concentrates to produce crude uranium hexafluoride. Fractional distillation is then used to obtain purified UF_6. Impurities are separated either as volatile compounds or as a relatively concentrated and insoluble solid waste that is dried and drummed for disposal.

2.3.2.2 Solvent Extraction Process

The solvent extraction process employs a wet chemical solvent extraction step at the start of the process to prepare high purity uranium for the subsequent reduction, hydrofluorination, and fluorination steps. The wet solvent extraction method separates impurities by extracting the uranium from the organic solvent, leaving the impurities dissolved in a aqueous solution. The raffinate is impounded in ponds at the plant site.

2.3.3 Fuel Fabrication Facilities

Light water reactor (LWR) fuels are fabricated from uranium which has been enriched in U-235. At a gaseous diffusion plant natural uranium in the form of UF_6 is processed to increase the U-235 content from 0.7% up to 2% to 4% by weight. The enriched uranium hexafluoride product is shipped to LWR fuel fabrication plants where it is converted to solid uranium dioxide pellets and inserted into zirconium alloy (Zircaloy) tubes. The tubes are fabricated into fuel assemblies which are shipped to nuclear power plants. There are seven licensed uranium fuel fabrication facilities in the United States which fabricate commercial LWR fuel. Of the seven, only five had active operating licenses as of January 1, 1988. Of those five facilities, two use enriched uranium hexafluoride to produce completed fuel assemblies and two use uranium dioxide. The remaining facility converts UF_6 to UO_2 and recovers uranium from scrap materials generated in the various processes of the plant.

The processing technology used for uranium fuel fabrications consists of three basic operations: (1) chemical conversion of UF_6 to UO_2; (2) mechanical processing including pellet production and fuel-element fabrication; and (3) recovery of uranium from scrap and off-specification material. The most significant potential environmental impacts result from converting UF_6 to UO_2 and from the chemical operations involved in scrap recovery.

2.3.4 Nuclear Power Facilities

As of December 1986, there were 100 operable nuclear power reactors in the United States, with a total generating capacity of 85,177 MWe. With only one exception (a high temperature gas cooled reactor), all of these nuclear power reactors are either boiling water reactors (BWR) or pressurized water reactors (PWR). Pressurized water reactors comprise approximately two-thirds of the light-water generating capacity.

A light water-cooled nuclear power station generates electricity using the same basic principles as a conventional fossil-fueled (oil or coal) power station except that the source of heat used to produce steam is provided by nuclear fission instead of combustion.

In a boiling water reactor, the coolant boils as it passes through the reactor. The resulting steam is passed through a turbine and a condenser. The condensed steam is then pumped back into the reactor. The energy removed from the steam by the turbine is transformed into electricity by a generator.

The process is the same in a pressurized water reactor except that the reactor coolant water is pressurized to prevent boiling. Energy is transferred through a heat exchanger (steam generator) to a secondary system where the water does boil. Reactor coolant water is kept at high pressures by maintaining a closed system and electrically heating water in a tank called the pressurizer. After passage through the steam generator, the water is returned to the reactor. Secondary steam turns the turbine, is cooled in the condenser, and is pumped back into the steam generator.

During the fission process, radioactive fission products are produced and accumulate within the nuclear fuel. In addition, neutrons produced during fission interact within the fuel and coolant to produce radioactive activation products. A reactor may experience periodic fuel failure or defects which result in the leakage of some of the fission and activation products out of the fuel and into the coolant. Accordingly, a typical light water reactor will experience build-up of radioactive fission and activation products within the coolant. For both PWRs and BWRs the radioactive contaminants which accumulate within the coolant are the source of radioactive emissions from the facility.

2.4 DEPARTMENT OF DEFENSE FACILITIES

The Department of Defense (DOD) operates a number of facilities that use unsealed sources of radioactive materials. In addition to three research and test reactors and numerous medical facilities, these include army bases that perform research and evaluation of munitions using depleted uranium and naval shipyards that service the Navy's nuclear-powered fleet.

The army bases that conduct research and development of munitions using depleted uranium metal are licensed by the NRC. Activities conducted at these facilities involve test firings and evaluations of various experimental and stockpile depleted uranium munitions such as armor piercing shells. At facilities performing research and development, activities can include the small-scale fabrication of depleted uranium projectiles. This fabrication can include forging, shaping, and grinding of depleted uranium metal.

Nine naval shipyards construct, refuel, maintain, and overhaul the submarines and ships of the Navy's nuclear-powered fleet: Mare Island Naval Shipyard in Villejo, CA; General Dynamic's Electric Boat Division, Groton, CT; Pearl Harbor Naval Shipyard, Pearl Harbor, HI; Portsmouth Naval Shipyard, Kittery, ME; Ingallas Shipbuilding Division, Pascagoula, MI; U.S. Naval Station and Naval Shipyard, Charleston, SC; Newport News Shipbuilding and Drydock Co., Newport News, VA; Norfolk Naval Shipyard, Portsmouth, VA; and Puget Sound Naval Shipyard, Bremerton, WA.

In addition to the normal shipyard functions of construction, maintenance and overhaul, these shipyards construct, test, refuel, and maintain the pressurized water reactors used to power the nuclear fleet. The primary source of radioactive emissions at naval shipyards is from the facilities that process and package radioactive wastes. These facilities handle solid low-level radioactive wastes such as contaminated rags, paper, filters, ion exchange resins, and scrap materials. Waste materials are sorted, surveyed, and packaged for shipment to disposal sites.
All effluent air systems at waste handling facilities are monitored during operation and equipped with HEPA filters. Environmental monitoring at these waste handling facilities indicates that the concentration of activity in the effluent air is actually lower than the background activity in the intake air (RI82).

5. RISK ASSESSMENT *

For each component of the fuel cycle, and for the source terms associated with the accidents discussed in Section 4, the population dose commitment has been evaluated using the methodology discussed in Section 3.2. For each accident, the critical organ (organ receiving maximum dose) population dose is given together with the population dose to the total body (T.B.). Combining these results with the accident likelihoods also given in Section 4, the expectation value of the population dose commitment is derived and normalized to the annual operation of the generic 1000 MWe LWR using the mass flow factors given in Section 2.2. The normalized population dose commitments in man-rem are then converted to normalized health risks (somatic effects) using the methodology discussed in Section 3.3. All of these results are presented in Tables 5-1 through 5-8 for each component of the supporting LWR fuel cycle.

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*Excerpted from "Scoping Assessment of the Environmental Health Risk Associated with Accidents in the LWR Supporting Fuel Cycle," prepared by S. Cohen of SC&A for the EPA.

TABLE 5-1

ENVIRONMENTAL RISKS FROM ACCIDENTS IN URANIUM MILLING

Accident	Population Dose for Generic Plant (man-rem)	Accident Likelihood (plant-year)$^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-year (man-rem)	Health Risk per 1000 MWe-year (# of excess cancers)
B.1 Fire in Solvent Extraction Circuit	1.6 (lung) 1.0×10^{-1} (T.B.)	3×10^{-3} to 4×10^{-4}	4.8×10^{-3} to 6.4×10^{-4} 3.0×10^{-4} to 4.0×10^{-5}	6.0×10^{-4} to 8.0×10^{-5} 3.8×10^{-5} to 5.0×10^{-6}	3.8×10^{-8} to 5.0×10^{-9}
E.1 Release of Tailings Slurry from Tailings Pond	2.9 (bone) 1.9×10^{-1} (T.B.)	$\sim 4 \times 10^{-2}$	1.2×10^{-1} 7.6×10^{-3}	1.5×10^{-2} 9.5×10^{-4}	5.5×10^{-7}
E.2 Release of Tailings Slurry from Tailings Distribution Pipeline	1.3×10^{-1} (bone) 8.3×10^{-3} (T.B.)	$\sim 1 \times 10^{-2}$	1.3×10^{-3} 8.3×10^{-5}	1.6×10^{-4} 1.0×10^{-5}	5.8×10^{-9}
Totals (bone) (T.B.)			1.2×10^{-1} 8.0×10^{-3} to 7.7×10^{-3}	1.5×10^{-2} 1.0×10^{-3} to 9.7×10^{-4}	5.9×10^{-7} to 5.6×10^{-7}

TABLE 5-2

ENVIRONMENTAL RISXS FROM ACCIDENTS IN URANIUM HEXAFLOURIDE CONVERSION

Accident	Population Dose for Generic Plant (man-rem)	Accident Likelihood $(\text{plant-yr.})^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
A.1 Uranyl Nitrate Evaporator Explosion	720 (lung) 4.0 (T.B.)	10^{-3} to 10^{-4}	7.2×10^{-1} to 7.2×10^{-2} 4.0×10^{-3} to 4.0×10^{-4}	1.7×10^{-2} to 1.7×10^{-3} 9.5×10^{-5} to 9.5×10^{-6}	7.1×10^{-7} to 7.1×10^{-8};
A.2 Hydrogen Explosion in Reduction	720 (lung) 4.0 (T.B.)	5×10^{-2} to 10^{-3}	36 to $7.2_1 \times 10^{-1}$ 2.0×10^{-1} to 4.0×10^{-3}	8.6×10^{-1} to 1.7×10^{-2} 4.8×10^{-3} to 9.5×10^{-5}	3.6×10^{-5} to 7.1×10^{-7}
B.1 Fire in Solvent Extraction Operation	6.2 (lung) 3.9×10^{-1} (T.B.)	$\sim 4 \times 10^{-4}$	2.5×10^{-3} 1.6×10^{-4}	6.0×10^{-5} 3.8×10^{-6}	3.8×10^{-9}
C.1 Release from a Hot UF_6 Cylinder	79 (lung) 4.3×10^{-1} (T.B.)	$\sim 3 \times 10^{-2}$	2.4 1.3×10^{-2}	5.7×10^{-2} 3.1×10^{-4}	2.4×10^{-6}
C.2 Valve Rupture in Distillation Step	29 (lung) 1.6×10^{-1} (T.B.)	$\sim 5 \times 10^{-2}$	1.5 8.0×10^{-3}	3.6×10^{-2} 1.9×10^{-4}	1.5×10^{-6}
E.1 Release of Raffinate from Waste Retention Pond	3.7 (bone) $3.1 \times 10\text{-}1$ (T.B.)	$\sim 2 \times 10^{-2}$	7.4×10^{-2} 6.2×10^{-3}	1.8×10^{-3} 1.5×10^{-4}	8.0×10^{-8}
Totals (lung) (T.B.)			41 to 4.7 2.3 to 10^{-1} to 3.2×10^{-2}	9. $\times 10^{-1}$ to 1.1×10^{-1} 5.[illegible] $\times 10^{-3}$ to 7.6×10^{-4}	4.1×10^{-5} to 4.8×10^{-6}

TABLE 5-3

ENVIRONMENTAL RISKS FROM ACCIDENTS IN ENRICHMENT

Accident	Population Dose For Generic Plant (man-rem)	Accident Likelihood $(\text{plant-yr.})^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
B.1 Catastrophic Fire	930 (lung) 4.9 (T.B.)	3×10^{-2} to 4×10^{-4}	28 to 3.7×10^{-1} 1.5×10^{-1} to 2.0×10^{-3}	2.2×10^{-1} to 2.9×10^{-3} 1.2×10^{-3} to 1.6×10^{-5}	9.2×10^{-6} to 1.2×10^{-7}
C.1 Release from a Hot UF_6 Cylinder	130 (lung) 7.5×10^{-1}	$\sim 4 \times 10^{-1}$	64 3.0×10^{-1}	5.1×10^{-1} 2.4×10^{-3}	2.1×10^{-5}
C.2 Leaks or Failure of Valves or Piping	1.4 (lung) 7.7×10^{-3} (T.B.)	~ 1.8	2.5 1.4×10^{-2}	2.0×10^{-2} 1.1×10^{-4}	8.4×10^{-7}
D.1 Criticality	4.6×10^{-1} (thyroid) 1.2×10^{-2} (T.B.)	$\sim 8 \times 10^{-5}$	3.7×10^{-5} 9.6×10^{-7}	2.5×10^{-7} 7.6×10^{-9}	2.1×10^{-11}
Total (lung) (T.B.)			95 to 87 4.6×10^{-1} to 3.2×10^{1}	7.5×10^{-1} to 5.3×10^{-1} 3.7×10^{-3} to 2.5×10^{-3}	3.1×10^{-5} to 2.2×10^{-5}

TABLE 5-4

ENVIRONMENTAL RISKS FROM ACCIDENTS IN URANIUM FABRICATION

Accident	Population Dose for Generic Plant (man-rem)	Accident Likelihood (plant-yr.)$^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 Mwe-yr. (# of excess cancers)
A.1 Hydrogen Explosion in Reduction Furnace	16 to 1.6×10^{-2} (lung) 7.4×10^{-2} to 7.4×10^{-5} (T.B.)	5×10^{-2} to 2×10^{-3}	8.0×10^{-1} to 3.2×10^{-5} 3.7×10^{-3} to 1.5×10^{-7}	3.2×10^{-2} to 1.3×10^{-6} 1.5×10^{-4} to 6.0×10^{-9}	1.3×10^{-6} to 5.4×10^{-11}
B.1 Major Facility Fire	1.6×10^{4} to 16 (lung) 74 to 7.4×10^{-2}	$\sim 2 \times 10^{-4}$	3.2 to 3.2×10^{-3} 1.5×10^{-2} to 1.5×10^{-5}	1.3×10^{-1} to 1.3×10^{-4} 6.0×10^{-4} to 6.0×10^{-7}	5.4×10^{-6} to 5.4×10^{-9}
B.2 Fire in a Roughing Filter	3.8 to 3.8×10^{-3} (lung) 1.8×10^{-2} to 1.8×10^{-5} (T.B.)	$\sim 10^{-2}$	3.8×10^{-2} to 3.8×10^{-5} 1.8×10^{-4} to 1.8×10^{-7}	1.5×10^{-3} to 1.5×10^{-6} 7.2×10^{-6} to 7.2×10^{-9}	6.3×10^{-8} to 6.3×10^{-11}
C.1 Release from a Hot UF_6 Cylinder	1600 to 1.6 (lung) 7.8 to 7.8×10^{-3} (T.B.)	$\sim 3 \times 10^{-2}$	48 to 4.8×10^{-2} 2.3×10^{-1} to 2.3×10^{-4}	1.9 to 1.9×10^{-3} 9.2×10^{-3} to 9.2×10^{-6}	7.9×10^{-5} to 7.9×10^{-8}
C.2 Failure of Valves or Piping	460 to 4.6×10^{-1} (lung) 2.2 to 2.2×10^{-3} (T.B.)	$\sim 4 \times 10^{-3}$	1.8 to 1.8×10^{-3} 8.8×10^{-3} to 8.8×10^{-6}	7.2×10^{-2} to 7.2×10^{-5} 3.5×10^{-4} to 3.5×10^{-7}	3.0×10^{-6} to 3.0×10^{-9}
D.1 Criticality	32 (thyroid) 1.1 (T.B.)	$\sim 8 \times 10^{-4}$	2.6×10^{-2} 8.8×10^{-4}	1.0×10^{-3} 3.5×10^{-5}	7.4×10^{-8}
E.1 Waste Retention Pond Failure	5.7×10^{-1} (bone) 3.5×10^{-2} (T.B.)	2×10^{-2} to 2×10^{-3}	1.1×10^{-2} to 1.1×10^{-3} 7.0×10^{-4} to 7.0×10^{-5}	4.4×10^{-4} to 4.4×10^{-5} 2.8×10^{-5} to 2.8×10^{-6}	1.6×10^{-8} to 1.6×10^{-9}
Totals (lung) (thyroid) (T.B.)			54 to 5.3×10^{-2} 2.6×10^{-2} 2.6×10^{-1} to 1.2×10^{-3}	2.1 to 2.1×10^{-3} 1.0×10^{-3} 1.0×10^{-2} to 4.8×10^{-5}	8.9×10^{-5} to 1.6×10^{-7}

TABLE 5-5

ENVIRONMENTAL RISKS FROM ACCIDENTS IN FUEL REPROCESSING

Accident	Population Dose for Generic Plant (man-rem)	Accident Likelihood (plant-yr.)-1	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
A.1 Explosion in High Aqueous Waste Concentration					
a. Normal HEPA Filtration	230,000 (G.I.) 430 (T.B.)	~ 10^{-5}	2.3 4.3×10^{-3}	5.3×10^{-2} 1.0×10^{-4}	3.3×10^{-6}
b. HEPA Filter Failure	3.3×10^5 (G.I.) 9.5×10^3 (T.B.)	~ 10^{-8}	3.3×10^{-3} 9.5×10^{-5}	7.7×10^{-5} 2.2×10^{-6}	5.5×10^{-9}
A.2 Explosion in Low Aqueous Waste Concentrator					
a. Normal HEPA Filtration	15,000 (G.I.) 28 (T.B.)	~ 10^{-4}	1.5 2.8×10^{-3}	3.5×10^{-2} 6.5×10^{-5}	2.2×10^{-6}
b. HEPA Filter Failure	1.6×10^4 (G.I.) 4.8×10^1 (T.B.)	~ 10^{-7}	1.6×10^{-3} 4.8×10^{-6}	3.7×10^{-5} 1.1×10^{-7}	2.3×10^{-9}
A.3 Explosion in High Aqueous Feed Tank					
a. Normal HEPA Filtration	840,000 (G.I.) 1,600 (T.B.)	~ 10^{-5}	8.4 1.6×10^{-2}	2.0×10^{-1} 3.7×10^{-4}	1.2×10^{-5}
b. HEPA Filter Failure	8.4×10^5 (G.I.) 1.7×10^3 (T.B.)	~ 10^{-7}	8.4×10^{-2} 1.7×10^{-4}	2.0×10^{-3} 3.8×10^{-6}	1.2×10^{-7}
A.4 Explosion in Waste Calciner					
a. Normal HEFA Filtration	2.3×10^6 (G.I.) 4,300 (T.B.)	~ 10^{-6}	2.3 4.3×10^{-3}	5.3×10^{-2} 1.0×10^{-4}	3.3×10^{-6}
b. HEFA Filter Failure	2.4×10^6 (G.I.) 1.3×10^4 (T.B.)	~ 10^{-9}	2.4×10^{-3} 1.3×10^{-5}	5.6×10^{-5} 3.0×10^{-7}	3.6×10^{-9}

TABLE 5-5

(continued)

Accident	Population Dose For Generic Plant (man-rem)	Accident Likelihood (plant-yr.)$^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
A.5 Explosion in Iodine Adsorber	1.9×10^3 (thyroid) 4.8 (T.B.)	$\sim 2 \times 10^{-4}$	3.8×10^{-1} 9.6×10^{-4}	8.8×10^{-3} 2.2×10^{-5}	5.6×10^{-7}
B.1 Solvent Fire in Codecontamination Cycle					
a. Normal HEPA Filtration	14,000 (G.I.) 23 (T.B.)	10^{-4} to 10^{-6}	1.4 to 1.4×10^{-2} 2.3×10^{-3} to 2.3×10^{-5}	3.3×10^{-2} to 3.3×10^{-4} 5.3×10^{-5} to 5.3×10^{-7}	2.0×10^{-6} to 2.0×10^{-8}
b. HEPA Filter Failure	1.5×10^4 (G.I.) 5.6×10^1 (T.B.)	10^{-7} to 10^{-9}	1.5×10^{-3} to 1.5×10^{-5} 5.6×10^{-6} to 5.6×10^{-8}	3.5×10^{-5} to 3.5×10^{-7} 1.3×10^{-7} to 1.3×10^{-9}	2.2×10^{-9} to 2.2×10^{-11}
B.2 Solvent Fire in Plutonium Extraction Cycle					
a. Normal HEPA Filtration	1.5×10^{-2} (bone) 3.1×10^{-4} (T.B.)	10^{-4} to 10^{-6}	1.5×10^{-6} to 1.5×10^{-8} 3.1×10^{-8} to 3.1×10^{-10}	3.5×10^{-8} to 3.5×10^{-10} 7.2×10^{-10} to 7.2×10^{-12}	8.6×10^{-13} to 8.6×10^{-15}
b. HEPA Filter Failure	2.6×10^4 (bone) 5.2×10^2 (T.B.)	10^{-9} to 10^{-11}	2.6×10^{-5} to 2.6×10^{-7} 5.2×10^{-7} to 5.2×10^{-9}	6.0×10^{-7} to 6.0×10^{-9} 1.2×10^{-8} to 1.2×10^{-10}	4.1×10^{-11} to 4.1×10^{-13}
B.3 Ion-Exchange Resin Fire					
a. Normal HEPA Filtration	190 (G.I.) 3.6×10^{-1} (T.B.)	10^{-1} to 10^{-4}	19 to 1.9×10^{-2} 3.6×10^{-2} to 3.6×10^{-5}	4.4×10^{-1} to 4.4×10^{-4} 8.4×10^{-4} to 8.4×10^{-7}	2.7×10^{-5} to 2.7×10^{-8}
b. HEPA Filter Failure	8.3×10^4 (bone) 1.8×10^3 (T.B.)	10^{-6} to 10^{-9}	8.3×10^{-2} to 8.3×10^{-5} 1.8×10^{-3} to 1.8×10^{-6}	1.9×10^{-3} to 1.9×10^{-6} 4.2×10^{-5} to 4.2×10^{-8}	1.3×10^{-7} to 1.3×10^{-10}

TABLE 5-5

(continued)

Accident	Population Dose for Generic Plant (man-rem)	Accident Likelihood (plant yr.) $^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
C.1 Fuel Assembly Rupture and Release in Fuel Receiving and Storage					
a. Normal HEPA Filtration	6.8 (G.I.) 1.3×10^{-2} (T.B.)	10^{-1} to 10^{-2}	6.8×10^{-1} to 6.8×10^{-2} 1.3×10^{-3} to 1.3×10^{-4}	1.6×10^{-2} to 1.6×10^{-3} 3.0×10^{-5} to 3.0×10^{-6}	1.0×10^{-6} to 1.0×10^{-7}
b. HEPA Filter Failure	6.8×10^{5} (G.I.) 1.3×10^{3} (T.B.)	10^{-4} to 10^{-5}	6.8×10^{1} to 6.8 1.3×10^{-1} to 1.3×10^{-2}	1.6 to 1.6×10^{-1} 3.0×10^{-3} to 3.0×10^{-4}	1.0×10^{-4} to 1.0×10^{-5}
C.2 Dissolver Seal Failure					
a. Normal HEPA Filtration	1.6×10^{-1} (lung) 2.1×10^{-2} (T.B.)	$\sim 10^{-5}$	1.6×10^{-6} 2.3×10^{-7}	3.7×10^{-8} 5.3×10^{-9}	3.4×10^{-12}
b. HEPA Filter Failure	1.6×10^{4} (lung) 2.3×10^{3} (T.B.)	$\sim 10^{-8}$	1.6×10^{-4} 2.3×10^{-5}	3.7×10^{-6} 5.3×10^{-7}	3.4×10^{-10}
C.3 Release from a Hot UF_6 Cylinder	3.2×10^{2} (lung) 1.5 (T.B.)	$\sim 5 \times 10^{-2}$	1.6×10^{1} 7.5×10^{-2}	3.7×10^{-1} 1.7×10^{-3}	1.5×10^{-5}
D.1 Criticality					
a. Normal HEPA Filtration	3.0×10^{-2} (T.B.)	8×10^{-3} to 3×10^{-5}	2.4×10^{-4} to 9.0×10^{-7}	5.6×10^{-6} to 2.1×10^{-8}	2.2×10^{-9} to 8.4×10^{-12}
b. HEPA Filter Failure	2.5×10^{-1} (lung) 3.5×10^{-2} (total body)	8×10^{-6} to 3×10^{-8}	2.0×10^{-6} to 7.5×10^{-9} 2.8×10^{-7} to 1.1×10^{-9}	4.7×10^{-8} to 1.7×10^{-10} 6.5×10^{-9} to 2.6×10^{-11}	4.2×10^{-12} to 1.6×10^{-14}
Totals (G.I.) (lung) (T.B.)			1.0×10^{2} to 2.1×10^{1} 16 2.7×10^{-1} to 1.2×10^{-1}	2.4 to 5.0×10^{-1} 3.7×10^{-1} 6.3×10^{-3} to 2.8×10^{-3}	1.7×10^{-4} to 4.7×10^{-5}

TABLE 5-6

ENVIRONMENTAL RISKS FROM ACCIDENTS IN MIXED OXIDE FUEL FABRICATION

Accident	Population Dose For Generic Plant (man-rem)	Accident Likelihood $(\text{plant-yr.})^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
A.1 Explosion in Oxidation-Reduction Scrap Furnace					
a. Normal HEPA Filtration	1.5 (bone) 3.1×10^{-2} (T.B.)	5×10^{-2} to 2×10^{-3}	7.5×10^{-2} to 3.0×10^{-3} 1.6×10^{-3} to 6.2×10^{-5}	3.3×10^{-3} to 1.3×10^{-4} 7.0×10^{-5} to 2.7×10^{-6}	6.7×10^{-8} to 2.6×10^{-9}
b. HEPA Filter Failure	1.5×10^{5} (bone) 3.1×10^{3} (T.B.)	5×10^{-5} to 2×10^{-6}	7.5 to 3.0×10^{-1} 1.6×10^{-1} to 6.2×10^{-3}	3.3×10^{-1} to 1.3×10^{-2} 7.0×10^{-3} to 2.7×10^{-4}	6.7×10^{-6} to 2.6×10^{-7}
B.1 Major Facility Fire					
a. Normal HEPA Filtration	7.6×10^{1} (bone) 1.6 (T.B.)	$\sim 2 \times 10^{-4}$	1.5×10^{-2} 3.2×10^{-4}	6.5×10^{-4} 1.4×10^{-5}	1.3×10^{-8}
b. HEPA Filter Failure	7.6×10^{6} (bone) 1.4×10^{5} (T.B.) (plus 25 short-term deaths)	$\sim 2 \times 10^{-7}$	1.5 2.8×10^{-2}	6.5×10^{-2} 1.2×10^{-3}	1.2×10^{-6} (plus 2.2×10^{-7} short-term deaths)
B.2 Fire in Waste Compaction Glove Box					
a. Normal HEPA Filtration	1.5×10^{-1} (bone) 3.1×10^{-3} (T.B.)	$\sim 10^{-2}$	1.5×10^{-3} 3.1×10^{-5}	6.5×10^{-5} 1.3×10^{-6}	1.3×10^{-9}
b. HEPA Filter Failure	1.5×10^{4} (bone) 3.1×10^{2} (T.B.)	$\sim 10^{-5}$	1.5×10^{-1} 3.1×10^{-3}	6.5×10^{-3} 1.3×10^{-4}	1.3×10^{-7}
B.3 Ion-Exchange Resin Fire					
a. Normal HEPA Filtration	4.5×10^{-1} (bone) 9.2×10^{-3} (T.B.)	10^{-1} to 10^{-4}	4.5×10^{-2} to 4.5×10^{-5} 9.2×10^{-4} to 9.2×10^{-7}	2.0×10^{-3} to 2.0×10^{-6} 4.0×10^{-5} to 4.0×10^{-8}	4.0×10^{-8} to 4.0×10^{-11}
b. HEPA Filter Failure	4.5×10^{4} (bone) 9.2×10^{2} (T.B.)	10^{-4} to 10^{-7}	4.5 to 4.5×10^{-3} 9.2×10^{-2} to 9.2×10^{-5}	2.0×10^{-1} to 2.0×10^{-4} 4.0×10^{-3} to 4.0×10^{-6}	4.0×10^{-6} to 4.0×10^{-9}

TABLE 5-6

(continued)

Accident	Population Dose for Generic Plant (man-rem)	Accident Likelihood $(\text{plant-yr.})^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
B.4 Dissolver Fire in Scrap Recovery					
a. Normal HEPA Filtration	7.6 (bone) 1.6×10^{-1} (T.B.)	$\sim 10^{-2}$	7.6×10^{-2} 1.6×10^{-3}	3.3×10^{-3} 7.0×10^{-5}	6.7×10^{-8}
b. HEPA Filter Failure	7.6×10^{5} (bone) 1.6×10^{4} (T.B.)	$\sim 10^{-5}$	7.6 1.6×10^{-1}	3.3×10^{-1} 7.0×10^{-3}	6.7×10^{-6}
C.1 Glove Failure					
a. Normal HEPA Filtration	6.1×10^{-4} (bone) 1.3×10^{-5} (T.B.)	~ 1	6.1×10^{-4} 1.3×10^{-5}	2.7×10^{-5} 5.7×10^{-7}	5.4×10^{-10}
b. HEPA Filter Failure	6.1×10^{1} (bone) 1.3 (T.B.)	$\sim 10^{-3}$	6.1×10^{-2} 1.3×10^{-3}	2.7×10^{-3} 5.7×10^{-5}	5.4×10^{-8}
C.2 Severe Glove Box Damage					
a. Normal HEPA Filtration	3.0 (bone) 6.1×10^{-2} (T.B.)	$\sim 10^{-2}$	3.0×10^{-2} 6.1×10^{-4}	1.3×10^{-3} 2.7×10^{-5}	2.6×10^{-8}
b. HEPA Filter Failure	3.0×10^{5} (bone) 6.1×10^{3} (T.B.)	$\sim 10^{-5}$	3.0 6.1×10^{-2}	1.3×10^{-1} 2.7×10^{-3}	2.6×10^{-6}
D.1 Criticality					
a. Normal HEPA Filtration	13 (thyroid) 3.8×10^{-1} (T.B.)	8.0×10^{-3} to 3.0×10^{-5}	1.0×10^{-1} to 3.9×10^{-4} 3.0×10^{-3} to 1.1×10^{-5}	4.3×10^{-3} to 1.7×10^{-5} 1.3×10^{-4} to 4.8×10^{-7}	3.1×10^{-7} to 1.2×10^{-9}
b. HEPA Filter Failure	2.0×10^{4} (bone) 4.2×10^{2} (T.B.)	8.0×10^{-6} to 3.0×10^{-8}	1.6×10^{-1} to 6.0×10^{-4} 3.4×10^{-3} to 1.3×10^{-5}	7.0×10^{-3} to 2.6×10^{-5} 1.5×10^{-4} to 5.7×10^{-7}	1.4×10^{-7} to 5.3×10^{-10}
Totals (bone) (thyroid) (T.B.)			2.5×10^{1} to 1.3×10^{1} 1.0×10^{-1} to 3.9×10^{-4} 5.2×10^{-1} to 3.2×10^{-1}	1.1 to 5.5×10^{-1} 4.3×10^{-3} to 1.7×10^{-5} 1.9×10^{-2} to 1.2×10^{-2}	2.2×10^{-5} to 1.1×10^{-5} (plus 2.2×10^{-7} short-term deaths)

TABLE 5-7

ENVIRONMENTAL RISKS FROM ACCIDENTS IN PLUTONIUM STORAGE

Accident	Population Dose for Generic Plant (man-rem)	Accident Likelihood (plant-yr.)$^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
D.1 Criticality					
a. Normal HEPA Filtration	2.8 (bone) 8.8×10^{-1} (T.B.)	$\sim 8 \times 10^{-5}$	2.2×10^{-4} 7.0×10^{-5}	3.9×10^{-7} 1.2×10^{-7}	5.2×10^{-11}
b. HEPA Filter Failure	2.8×10^{5} (bone) 5.7×10^{3} (T.B.)	$\sim 8 \times 10^{-8}$	2.2×10^{-2} 4.6×10^{-4}	3.9×10^{-5} 8.1×10^{-7}	7.8×10^{-10}
Totals (bone) (T.B.)			2.2×10^{-2} 5.3×10^{-4}	3.9×10^{-5} 9.3×10^{-7}	8.3×10^{10}

TABLE 9-8

ENVIRONMENTAL RISKS FROM ACCIDENTS IN TRANSPORTATION

Accident	Population Dose for Generic Shipment (man-rem)	Accident Likelihood (shipment)$^{-1}$	Population Dose Expectation Value (man-rem)	Population Dose per 1000 MWe-yr. (man-rem)	Health Risk per 1000 MWe-yr. (# of excess cancers)
1. Leakage of coolant from irradiated fuel cask	7.2×10^{-4} (bone) 5.8×10^{-4} (T.B.)	$\sim 3 \times 10^{-4}$	2.2×10^{-7} 1.8×10^{-7}	2.0×10^{-6} 1.7×10^{-6}	6.8×10^{-10}
2. Improperly closed plutonium oxide container	56 (bone) 1.1 (T.B.)	1×10^{-3} to 4×10^{-4}	5.6×10^{-2} to 2.2×10^{-2} 1.1×10^{-3} to 4.4×10^{-4}	1.6×10^{-1} to 6.2×10^{-2} 3.1×10^{-3} to 1.2×10^{-3}	3.1×10^{-6} to 1.2×10^{-6}
3. Release from a collision involving natural UF_6	38,000 (lung) 200 (T.B.)	$\sim 4 \times 10^{-6}$	1.5×10^{-1} 8.0×10^{-4}	1.6 8.4×10^{-3}	6.7×10^{-5}
4. Release from a collision involving enriched UF_6	1.4×10^{5} (lung) 660 (T.B.)	$\sim 6 \times 10^{-6}$	8.4×10^{-1} 4.0×10^{-3}	2.6 1.2×10^{-2}	1.1×10^{-4}
5. Release from a collision involving irradiated fuel	190,000 (G.I.) 19,000 (T.B.)	9×10^{-6} to 2×10^{-8}	1.7 to 3.8×10^{-3} 1.7×10^{-1} to 3.8×10^{-4}	16 to 3.5×10^{-2} 1.6 to 3.5×10^{-3}	1.5×10^{-3} to 3.4×10^{-6}
6. Release from a collision involving irradiated fuel followed by release of fuel from the cask	200,000 (G.I.) 27,000 (T.B.) (plus 14 short-term deaths)	9×10^{-8} to 2×10^{-10}	1.8×10^{-2} to 4.0×10^{-5} 2.4×10^{-3} to 5.4×10^{-6}	1.7×10^{-1} to 3.7×10^{-4} 2.2×10^{-2} to 5.0×10^{-5}	1.8×10^{-5} to 4.0×10^{-8} (plus 1.2×10^{-5} to 2.6×10^{-8} short-term deaths)
7. Release from a collision involving plutonium oxide	7.0×10^{4} (bone) 1.4×10^{3} (T.B.)	3×10^{-6} to 2×10^{-9}	2.1×10^{-1} to 1.4×10^{-4} 4.2×10^{-3} to 2.8×10^{-6}	5.8×10^{-1} to 3.9×10^{-4} 1.2×10^{-2} to 7.8×10^{-6}	1.2×10^{-5} to 7.7×10^{-9}
8. Criticality of unirradiated fuel	3.8 (T.B.)	5×10^{-8} to 2×10^{-10}	1.9×10^{-7} to 7.6×10^{-10}	1.4×10^{-6} to 5.7×10^{-9}	5.6×10^{-10} to 2.3×10^{-12}
9. Criticality of enriched UO_2	11.6 (thyroid) 4.0 (T.B.)	8×10^{-9} to 5×10^{-11}	9.3×10^{-7} to 5.8×10^{-10} 3.2×10^{-7} to 2.0×10^{-10}	5.3×10^{-6} to 3.3×10^{-9} 1.8×10^{-6} to 1.1×10^{-9}	9.4×10^{-10} to 5.8×10^{-13}
10. Criticality of PuO_2	1.2×10^{6} (bone) 25,000 (T.B.)	3×10^{-8} to 2×10^{-11}	3.6×10^{-2} to 2.4×10^{-5} 7.5×10^{-4} to 5.0×10^{-7}	1.0×10^{-1} to 6.6×10^{-5} 2.1×10^{-3} to 1.4×10^{-6}	2.0×10^{-6} to 1.3×10^{-9}
Total				4.2 (lung) 16 to .035 (G.I.) 1.7 to 2.5×10^{-4} (T.B.)	1.7×10^{-3} to 1.8×10^{-4} (plus 1.2×10^{-5} to 2.6×10^{-8} short-term deaths)

TABLE 5-9

TOTAL ENVIRONMENTAL HEALTH RISKS FROM ACCIDENTS IN THE LWR SUPPORTING FUEL CYCLE

Fuel Cycle Component	Population Dose per 1000 MWe-yr. (man-rem)	Somatic Health Risk per 1000 MWe-yr. (# of excess cancers)
Uranium Mining	0	0
Uranium Milling	.015 (bone) .001 (T.B.)	5.9×10^{-7} to 5.6×10^{-7}
UF_6 Conversion	.97 to .11 (lung) .0056 to .00076 (T.B.)	4.1×10^{-5} to 4.8×10^{-6}
Enrichment	.75 to .53 (lung) .0037 to .0025 (T.B.)	3.1×10^{-5} to 2.2×10^{-5}
Uranium Fuel Fabrication	2.1 to .0021 (lung) .010 to 4.8×10^{-5} (T.B.)	8.9×10^{-5} to 1.6×10^{-7}
Reprocessing	.37 (lung) 2.4 to .50 (G.I.) .0063 to .0028 (T.B.)	1.7×10^{-4} to 4.7×10^{-5}
Mixed Oxide Fabrication	1.1 to .55 (bone) .019 to .012 (T.B.)	2.2×10^{-5} to 1.1×10^{-5}
Plutonium Storage	3.9×10^{-5} (bone) 9.3×10^{-7} (T.B.)	8.3×10^{-10}
Transportation	4.2 (lung) 16 to .035 (G.I.) 1.7 to .025 (T.B.)	1.7×10^{-3} to 1.8×10^{-4}
Totals	8.4 to 5.2 (lung) 18 to .54 (G.I.) 1.1 to .57 (bone) 1.8 to .044 (T.B.)	2.1×10^{-3} to 2.7×10^{-4}

TABLE 5-10

COMPARISON BETWEEN ENVIRONMENTAL HEALTH RISKS FROM ACCIDENTS AND FROM NORMAL OPERATIONS OF THE LWR FUEL CYCLE

	Risks from Normal Operations		Risks from Accidents
Fuel Cycle Component	Population Dose per 1000 MWe-year (man-rem)	Health Risk per 1000 MWe-year (# of excess cancers)	Health Risk per 1000 MWe-year (# of excess cancers)
Uranium Mining	1.4×10^3 (lung) 2.2×10^3 (bone) 7.2×10^2 (T.B.)	3.3×10^{-1}	0
Uranium Milling	4.0×10^3 (lung) 4.4×10^3 (bone) 1.7×10^3 (T.B.)	8.0×10^{-1}*	5.9×10^{-7} to 5.6×10^{-7}
UF_6 Conversion	0.81 (lung) 2.0×10^{-2} (T.B.)	3.9×10^{-5}	4.1×10^{-5} to 4.8×10^{-6}
Enrichment	1.1 (lung) 1.9×10^{-2} (T.B.)	5.1×10^{-5}	3.1×10^{-5} to 2.2×10^{-5}
Uranium Fuel Fabrication	1.3 (lung) 6.2×10^{-3} (T.B.)	5.4×10^{-5}	8.9×10^{-5} to 1.6×10^{-7}
Reprocessing	1500 (thyroid) 730 (T.B.)	3.6×10^{-1}**	1.7×10^{-4} to 4.7×10^{-5}
Mixed Oxide Fabrication	2.7 (bone) .057 (T.B.)	5.5×10^{-5}	2.2×10^{-5} to 1.1×10^{-5}
Plutonium Storage	0	0	8.3×10^{-10}
Transportation	0.35 (T.B.)	1.4×10^{-4}	1.7×10^{-3} to 1.8×10^{-4}
Totals	1500 (thyroid) 5400 (lung) 3200 (T.B.)	1.5	2.1×10^{-3} to 2.7×10^{-4}
Reactor	36 (thyroid) 0.94 (T.B.)	2.5×10^{-3}	

* Control of the tailings pile (covering the pile after the mill has been shut down) would reduce this value to 7.3×10^{-2}

** Control of C-14 emissions to 1% of normal release coupled with proposed EPA radiation protection control on Kr-85, I-129 and plutonium would reduce this value to 1.3×10^{-2}.