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5. CLEANUP AND REHABILITATION PROGRAMS

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5. CLEANUP AND REHABILITATION PROGRAMS

5.1 APPROACH TO PROBLEM

The nuclear testing at Enewetak Atoll of the 1950's has left behind it a large number of adverse environmental impacts. These take the form of debris of all kinds - on the inslands, in the lagoons and along the ocean shore - some of which is radioactive. In addition, some of the soil has been made radioactive causing it to be unsafe for habitations and for planting subsistence or commercial crops. Purely physical damage to the environment ranges from abandoned structures used to house test personnel, to the disappearance of two small islands and the formation of major craters on several others.

The objective of the program proposed in this statement is that of removing debris and radioactivity to the extent that the people of Enewetak can return to their ancestral atoll, and can be self sustaining economically and nutritionally. This section is devoted to an analysis of the specific problems associated with these goals and the formulation of equally specific procedures for solving the problems.

The approach to the problems requiring solution has been through the following steps:

- Identifying the nonradiological and radiological hazards present on the atoll, their biological effects, the evaluation of risks and the protective guidelines proposed by the Energy Research and Development Administration (ERDA), formerly the Atomic Energy Commission (AEC).

- Listing the various methods by which the hazards of radioactive and nonradioactive debris can be reduced to acceptable levels.

- Specifying the diet and agricultural practices which must be observed in order to reduce the radioactivity ingested by the Enewetak people.

- Identifying the distribution of the population around the atoll as a second means of reducing exposure to radioactivity.

- Analyzing the available procedures for cleanup and disposal of radioactive materials and other debris.

- Synthesizing a number of programs or "cases" for accomplishing the objectives.

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- Comparative evaluation of all of the "cases" to select the optimum one for the situation existing on Enewetak Atoll.

As in many programs of this nature, a number of demands exist that are mutually contradictory. This leads, of course, to solutions which are less than perfect, but the most important consideration in choosing between alternatives has been the health and safety of the Enewetak people.

5.2 NONRADIOLOGICAL HAZARDS

The nonradiological hazards existing on the islands are of much lesser magnitude than the radioactive. As a result, the procedures for removing and disposing of nonradiological hazards are much simpler and can be covered in relatively short order.

5.2.1 Physical Removal of Nonradioactive Materials

The extent of removal of nonradiological materials and structures from the islands provides several options. The debris that ~~could~~ can be removed includes dilapidated building, towers, antennas, concrete slabs, derelict boats, scrap metal, and other assorted rubble. Some of these constitute definite physical hazards. For example, buildings on the verge of collapse, loose and swinging cables, loose or torn sheet metal, exposed broken pipe ends, etc., have been noted in surveys of the islands. Structures such as concrete pits and open manholes constitute what could be considered attractive nuisances and would pose hazards, primarily to small children. Other material, such as concrete slabs are not especially hazardous, but may be obstructive and interfere with the proposed use of the land, for agriculture or residence. Finally, some of the debris is neither hazardous nor obstructive but simply unsightly. An example is the rusting bow of a freighter on the reef at Japtan.

Different levels of nonradiological cleanup are conveniently defined by differentiating among the structures and materials according to whether they provide physical hazard, obstruction to better land use, or detriment to environmental aesthetics. Three levels of activity are possible:

- Level 1. No removal of any nonradiological scrap.

- Level 2. Removal of physical hazards and obstructive structures and material.

- Level 3. Same as Level 2 plus removal of unsightly debris.

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5.2.2 Disposal of Nonradioactive Materials

5.2.2.1 Salvage. The disposal of nonradioactive debris does not have the many problems connected with the disposal of radioactive materials. Salvageable material will be collected and stockpiled in designated areas as the cleanup progresses. This material will be used by the Enewetak people and it would be carefully monitored to make certain that no radioactive substances are included.

5.2.2.2 Combustibles. Combustible nonradioactive debris would be hauled to a burn pit on each island where it would be burned to ashes. The ashes would be gathered and stockpiled for future use as a soil conditioner. The pit would then be backfilled with native material and the area regraded to its natural contours. Some of the nonradioactive vegetation removed during cleanup also would be shredded to a very small size to be used as additional organic matter in the soil.

5.2.2.3 Fish Reefs. Nonradioactive debris that remained after salvage material and combustibles had been segregated would be removed and dumped into the lagoon at selected spots to form artificial reefs to enhance the breeding of fish and other marine life.

5.3 RADIOLOGICAL HAZARDS

Detrimental effects have been observed incidental to the use of radiation since soon after it was first discovered. These effects range from a temporary reddening of the skin to an increased incidence of cancer. A recent review (BEIR, 1972) on the biological effects of ionizing radiation serves as the basis of risk analysis in the current document. Other studies reporting similar data are UNSCEAR, 1972 and ICRP-14, 1969.

5.3.1 Sources of Radiological Hazards

Radiological hazards arise from exposure to radiocontaminants which may be located both inside and outside the human body. The radiological dose estimates, based on anticipated dietary and living patterns of the people of Enewetak, ranked (NVO-140, 1973) in order of decreasing importance: 1) the internal dose from radionuclides in ingested terrestrial foods, 2) the external dose from radionuclides in the soil, 3) the internal dose from radionuclides in ingested marine foods, and 4) the internal dose from radionuclides inhaled into the body. Externally, the important sources of radiation on Enewetak Atoll are ^{137}Cs, ^{60}Co, and ^{55}Fe radionuclides in the soil. The lateral and vertical distributions of these vary considerably over the Atoll (NVO-140, 1973). Important

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internal sources of radiation are ^{137}Cs and ^{90}Sr, which concentrate in muscular and bony tissue respectively, and ^{239}Pu, deposited in the lung.

5.3.2 Criteria for Evaluating Hazard Control

Guidelines for safe exposures to radioactivity on the atoll are given in terms of the maximum annual dose received by an individual and are also evaluated in terms of long-term health effects. The main objective of radiological cleanup is to reduce the radioactivity of the Atoll to levels at which the population can be expected to have annual exposures below the value of these guidelines.

5.3.2.1 Long Term Health Effects. Quantitative evaluation of low levels of absorbed radiation on human health continues to be a subject of medical research. Present knowledge is based on the response to high levels of radiation of research animals, of persons undergoing medical treatment with radioactivity, and of a few victims of radioactivity accidents. Direct determination of the human health response to low levels of radiation, such as are discussed in this report, is complicated by the requirement to study radiation effects on large populations for statistically meaningful results, by the long time delay between radiation exposure, and appearance of such effects as neoplasms, by difficulty in distinguishing between effects attributable to radiation and effects not related to radiation, and because such effects as cancer susceptibility are widely varying functions of age, sex, genetic constitution, diet, personal habits, socio-economic factors, and other variables (BEIR, 1972). Because of this, present risk estimates are based predominantly on conservative extrapolations from data obtained at high doses.

The data upon which health risk estimates are based exhibit statistical variations so that, usually, the uncertainty in estimating a particular risk value is expressed by a range of values for the risk. In view of the many uncertainties related to this study, the risk models adopted result from very conservative assumptions.

For long term exposures to low levels of radiation, such as may apply to some aspects of residence on Enewetak Atoll, the model assumes a linear relationship between dose and effect, with no threshold. The assumption of "no threshold" implies that zero dose is the only dose that yields no adverse health effects. The less conservative assumption that a threshold dose exists, below which no health effects will be observed, has not been used.

The health effects of radiation on a population can be divided into two categories: somatic and genetic effects. Somatic effects relate to the body or its organs while genetic effects are evidenced only in the

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germ plasm. For stated exposure conditions, the BEIR risk-estimate of somatic effect predominate, relative to other effects of radiation. They are therefore of primary concern in establishing protective criteria. Also, the BEIR, 1972 report states that the rate of cancer induction is the only somatic risk that needs to be considered. Consequently, in estimating the risk to the Enewetak Atoll people from exposure to radiation, only cancer induction has been considered.

Induced cancer can be fatal or nonfatal. The risk guidelines listed in Table 5-1 are estimated to apply equally to either fatal or nonfatal effects (BEIR, 1972) so that the total number of effects resulting from a given dose would be twice the number of either. To calculate the number of either effect, using the data of Table 5-1, find the product of (1) the cancer incidence rate (Column 2), (2) the exposed population expressed as millions, and (3) the average dose for an individual for each critical organ. These products are then summed to obtain the total number of cases.

The effects of the induced cancers, or even the cancers themselves, may appear immediately or several decades after exposure (BEIR, 1972, p. 91). Since effects are not expected to show up in the earlier years with the same frequency as in later years, and since the appropriate frequency distribution is not known, the number of effects expected to occur during the entire risk period are calculated instead of the number of effects expected to occur in any one year. The guideline values given in Table 5-1 are maximal and the number of incidents of induced cancer or fatalities may be as low as zero.

5.3.2.2 Annual Dose Limits. The primary sources of recommendations for radiation protection standards and guidance are the International Commission on Radiological Protection (ICRP), the National Council on Radiation Projection and Measurements (NCRP), and the Federal Radiation Council (FRC). The standard-setting responsibilities of the FRC were transferred to the Environmental Protection Agency (EPA) in 1969. The recommendations of these groups are all compatible with each other.

These groups have recommended maximum permissible doses for workers exposed to radiation, for individual members of the public, and for a suitable sample of an exposed population. In addition, they have recommended dose rate limits for exposure of various critical organs. These recommended dose rate limits are presented with the understanding that radiation exposures should always be kept as low as can readily be achieved.

TABLE 5-1: OCCURRENCE OF RADIATION INDUCED SOMATIC CANCER EFFECTS ON HUMANS

Critical Organ	Radiation Induced Incidence of Cancer* Cases/(Million Persons)(Rem)
Whole Body	50 - 165
Bone	25
Lung	25

*Cancer Cases induced by a population dose of one million person-rems. A population dose of one million person-rems does not necessarily mean an equal dose to each individual in the exposed population, but is, rather, the sum of individual doses over the exposed population.

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The recommendations are based on the conservative assumption of a nonthreshold linear relationship between radiological dose and the health effect. The assumption of no threshold means that any nonzero dose yields a nonzero effect detrimental to health. Evaluation of risks using this assumption probably results in overestimates of risks.

Values for annual dose limits in various situations are listed in Table 5-2. These limits represent the recommendations of the FRC. For application to the Enewetak Atoll, the United States Atomic Energy Commission Task Group Report recommends that the values needed to evaluate cleanup alternatives should be the FRC guides, reduced by 50 percent for annual doses to individuals, and by 20 percent for the 30-year gonadal doses, because of uncertainties in field measurements. These values are shown in Table 5-3. These reductions in the average population dose are made because of the uncertainty concerning dose estimates which depend greatly on the foods that the people will choose to eat and the way they will choose to live. In addition, these recommendations follow the general guidance of the FRC to provide allowances for exposures from beneficial nonmedical uses of radioactive materials.

5.4 LIMITING AND CONTROLLING HAZARDS

The methods examined for limiting radiological hazards on Enewetak Atoll are: (1) the control of the diet of the Enewetak people and, by implication, their agricultural and food gathering practices; (2) the control of residence of the population throughout the islands of the atoll; and (3) the cleanup of radioactive materials.

5.4.1 Control of Diet and Food Sources

5.4.1.1 Internal Dose and Food Source. Radiocontaminants in foods come directly from the soil in which food plants are growing. Radiological surveys of Enewetak Atoll have found evidence of uptake of ^{137}Cs and ^{90}Sr, among other radionuclides, in both edible and inedible plants. Indigenous plants used for food that incorporate radionuclides from the soil include coconuts, pandanus, breadfruit, and arrowroot. Human internal radiation exposure is directly related to the amount of fruit of these plants ingested by the individual. The surveys also report radionuclides in the flesh and organs of indigenous fauna, such as terns, rats and land crabs. Internal doses will increase as a result of eating flesh from local birds and crabs, or from domestic animals such as poultry and swine, which have foraged on radioactive plants. Consequently, an effective dose reduction procedure would be simply to restrict the islanders' use of these foods. Lacking such controls, the penalty would be the accumulation of large radioactive doses for the individual utilizing such food sources.

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TABLE 5-2: FRC RADIATION PROTECTION GUIDES (REM/YR)

Critical Organs	Individual in Population	Population Group
Whole Body	0.5	0.17
Bone	1.5	0.5
Bone, Alternate Guide (1)	0.003 μg of ^{226}Ra in adult skeleton	0.001 μg of ^{226}Ra in adult skeleton
Bone Marrow	0.5	0.17
Gonads	-	0.17(2)
Thyroid (3)	1.5	0.5

For the conditions and qualifications of this table, see Report Nos. 1 and 2 of the Federal Radiation Council (FRC). The responsibility for establishing generally applicable environmental standards was assigned to the Environmental Protection Agency in 1970, but the guides here are still generally known as FRC Radiation Protection Guides. The philosophy represented by these guides is that the dose given in the table should not be exceeded without careful consideration of the reasons for doing so, and that every effort should be made to encourage the maintenance of radiation doses as far below this guide as is practicable.

NOTES:

(1) The biological equivalents of the indicated amounts of ^{226}Ra may be substituted.

(2) Actually 5 rem per human generation period, assumed to be 30 years.

(3) Based upon a child's thyroid weighing 2g and other factors listed in Paragraphs 2.10 to 2.14 of FRC Report No. 2.

TABLE 5-3: DOSE GUIDELINES FOR ENEWETAK ATOLL (REM/YR)

Critical Organs	Individual in Population (AEC Task Group Report)
Whole Body	0.25
Bone	0.75
Bone Marrow	0.25
Gonads	4 rems in 30 years
Thyroid	0.75

These guides are Atomic Energy Commission Task Group Report recommendations applicable to the Enewetak Atoll situation. In general, they adopt the radiation protection guides of the Federal Radiation Council (FRC), except for all individual dose limits and for population group gonad dose limits. The FRC individual dose guides are reduced by 50 percent and the FRC population group gonad dose guide is reduced by 20 percent to allow for uncertainties in dose predictions.

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5.4.1.2 Possible Food Sources. The results of the radiological survey show high levels of contamination on the northern islands and low levels on the southern islands. Thus, one option would be to allow the people to eat food grown only on the southern islands. However, it is most likely that the people will eat largely imported foods for the next few years (Kiste, 1974; Tobin, 1973; Marsh, 1973) as it will require several years for trees to provide sufficient fruit for all. To furnish the Enewetak people the purchasing power for imported foods, one source of revenue could be coconut agriculture to produce copra (Enewetak Master Plan, Tab D Vol. II. It may be desirable to use the northern islands for coconut agriculture, although exercise of this option may require that coconut seedlings be planted in soil that is not contaminated with radionuclides. Consideration is also being given to the possibility of continued cultivation of land on Ujelang to alleviate problems of this nature.

5.4.1.3 Subsistence and Commercial Agricultural Patterns. As noted earlier, the driEnjebi desire to live on the northern islands, particularly the island of Enjebi. If these people were to live on those islands, care would have to be taken to ensure that at least pandanus and breadfruit are grown in nonradioactive soil. That is, a village site on Enjebi drawing on food resources grown in Enjebi soil, would require pandanus and breadfruit, which are either grown in nonradioactive soil on Enjebi or are imported to Enjebi. To provide the farm plots for pandanus and breadfruit, the existing soil will have to be removed and nonradioactive soil be put in place of it in sufficient volume to contain the roots of these plants. (As will be discussed later, it does not appear possible to remove sufficient radioactive soil from Enjebi to permit people to live there or to grow food there for some time to come.)

To summarize, the options for food source control that appear acceptable for further discussion include:

- No control over food sources.
- People living on Enjebi would use food grown anywhere on Enjebi, other than pandanus and breadfruit. Pandanus and breadfruit eaten by the residents of Enjebi would either be grown in farm plots or imported.
- Food for all the people would either be imported or grown only on the southern islands, except for coconut agriculture on the northern islands. Coconut culture includes growing both subsistence and commercial coconuts.
- All food, including coconuts, must either be imported or grown only on southern islands.

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5.4.2 Population Distribution

Another means of controlling the dose accumulated by the Enewetak population would be to limit the time which ~~they~~ inhabitants spend in the vicinity of radiation sources, principally by postponing the use of some islands for residence. By limiting the islands available for residence, the population will receive less dose from external sources than they otherwise would. Also, the chance of ingesting food containing higher levels of radioactivity would be decreased.

5.4.2.1 Possible Distributions. The possible population distributions which have been considered are:

- All of the people of Enewetak would be free to choose their place of residence on any island of the atoll.
- The people would be limited to residence on the south islands, Jinedrol clockwise through Kidrenen, (Alvin through Keith).
- The people would be limited to the same group as in 2. above (Alvin through Keith), plus Enjebi (Janet) in the north.

5.4.2.2 The Problem of Enjebi. Because the only difference between 2 and 3 above involves the island of Enjebi, the reason for making this distinction must be justified. Earlier in Section 3, it was explained that the people of Enewetak were historically divided into driEnewetak and driEnjebi, the first named occupying the largest island in the south, and the other the largest in the north. This traditional pattern was disrupted by the invasion of the atoll by U.S. troops in World War II and has never been fully restored. Restoration of the traditional pattern would require that the people of Enjebi reside on that island once again. However, since Enjebi was ground zero for, or within the fireball of, a number of nuclear explosions, the residual radioactivity of this soil is high enough to produce a sizeable external dose. In addition, all vegetation grown on the island would contain radioactive elements which would increase the internal dosage. The facts have ~~been~~ are to be weighed against the strong desire of the driEnjebi to return to their ancestral island.

5.4.3 Cleanup and Disposal

The simplest method, in concept, of limiting radiological hazards is that of ~~cleaning~~ collecting and disposing of all radioactive materials. Further, a fundamental requirement in any cleanup and disposal is that radioactive materials are to be removed and disposed of in such fashion that they do not become further hazards in another time and place.

5.4.3.1 Physical Removal of Radioactive Materials. Control of both external and internal dose may be directly achieved by removing the radiation sources from areas to which the island inhabitants have direct access. Complete removal of radiation sources would require:

- Radioactive soil removal.
- Radioactive scrap removal.
- Plutonium removal.

5.4.3.1.1 Removal of Radioactive Soil. Removing soil containing radionuclides, especially ^{137}Cs and ^{90}Sr, has dubious value, since extensive land removal and replacement operations could result in serious ecological damage of unknown proportions. For example, the replacement soil could contain chemical, mineral or biological materials having characteristics which were inimical to the growth of the food plants. Such a result would be counterproductive at best, and possible irrevocably destructive. Also there is no guarantee that sufficient soil could be removed/replaced to assure radiological safety to residents, ~~so that operations performed for this purpose are not considered here.~~

5.4.3.1.2 Removal of Radioactive Scrap. The optional levels of effort in the removal of radioactive scrap are minimal in number. Either none is removed or all of it is removed from all the islands. The differentiation that can be made in considering nonradioactive scrap (physical hazards, obstructive debris, and unsightly debris), does not extend to radioactive scrap. In general, no radioactive scrap should be left on the atoll and thus be available to the world scrap market. Programs not involving radioactive scrap removal must be eliminated from consideration for this reason.

5.4.3.1.3 Removal of Plutonium. The removal of plutonium bearing soil options are determined by a number of factors including the difficulty in removing the plutonium, the potential use of the land, and the size of the tract involved. Decision making would depend largely on a team of experts to interpret field radiation and radio activity measurements, to advise on cleanup actions, and to provide necessary health physics support. Paramount would be ~~the~~ possible potential hazard to the Enewetak people. The scraping and removal of plutonium bearing soil would be performed repetitively. After each scraping, the soil would be sampled and monitored for Pu concentration. Scraping and sampling would be repeated until the attendant scientific advisor had determined that the concentration was reduced to an acceptable level.

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The Pu decontamination actions possible are listed below:

- < 40 pCi/gm of soil - corrective action not required.
- 40 to 400 pCi/gm of soil - corrective action determined on a case-by-case basis considering all radiological conditions.
- >400 pCi/gm of soil - corrective action required.

The islands on which Pu cleanup actions are required are shown in Table 5-4. It is also possible to take no cleaning action and to quarantine the islands where Pu is present at 40 pCi/gm of soil or greater.

5.4.3.2 <u>Disposal of Radioactive Materials</u>. The quantity of radioactive debris on the islands of the Atoll is estimated to be 7,262 cu yds. It is composed of scrap metal and concrete on the islands of Bokoluo, Enjebi, Lujor, Eleleron, Aomon, Bijire and Runit. There is, in addition, a considerable amount of soil that is radioactive. The amount to be removed has been the subject of considerable study and it has been decided that nearly 80,000 cu yds would be removed for disposal, as a minimum.

This had led to the important problem of how to dispose of the radioactive scrap and soil in such a manner that it could not cause harm to humans at some later date. There are several methods which have been suggested including ocean dumping, crater dumping, crater containment, and disposal in the continental U.S. (Conus). These are discussed in the following sections.

5.4.3.2.1 Ocean Dumping. Dumping in the deep open ocean (1,000 fathoms minimum depth) was considered, but rejected for several reasons. It would be impossible to guarantee the integrity of any container filled with Pu bearing soil and other radioactive debris for even one half life of the material (about 24,000 years for ^{239}Pu). In addition, the characteristics of ocean currents, from the bottom to the top, in a selected location would delay the program, as well as increase its cost considerably. The present estimated cost for ocean disposal of these materials is about 50 percent higher than that for crater containment.

The requirements established by U.S. law and regulation are even more stringent than those resulting from international agreements. It is possible that adverse legal actions could be taken and the required permit not be issued, even after the necessary studies had been completed.

5.4.3.2.2 Crater Dumping. In this method, the radioactive debris and soil would simply be dumped into the Cactus and Lacrosse craters on Runit with no preparatory or closing operations. This procedure would

TABLE 5-4: ISLANDS REQUIRING PLUTONIUM CLEANUP PROCEDURES

Island		Remarks	Level of Pu Concentration*
Local Name	Code Name		
Boken	IRENE	Isopleth J (See Tab A, Volume II)	1, 2
Runit	YVONNE	Northern half, Pu burial grounds	1, 2
Lujor	PEARL	Hot spot	1, 2
Aomon	SALLY	Pu burial grounds	1
Bokuluo	ALICE		2
Bokombako	BELLE		2
Kirunu	CLARA		2
Louj	DAISY		2
Mijikadrek	KATE		2
Kidrinen	LUCY		2
Aej	OLIVE		2
Eleleron	RUBY		2

*Actions assumed for specific ranges of Pu concentration are tabulated as follows:

Level	Concentration (pCi Pu/g Soil)	Action
1	>400	Soil removal by repetitive scraping
2	$40 \le C \le 400$	Individual case consideration

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TABLE 5-5: RECOMMENDED CORRECTIVE ACTION PROGRAMS

Habitation Plans / Cleanup Actions	A No restrictions on island or food usage	B Live on southern islands and Enjebi; visit northern islands; food from southern islands or Enjebi ~~except~~ plus coconut from 12 N.E. islands and pandanus and breadfruit from Enjebi farm plots or imported	C Live on southern island; visit northern islands; food from southern islands ~~except~~ plus coconut from 12 N.E. islands	D Live on southern islands; visit on southern islands; use food grown on only southern islands
I. No cleanup.	Case 1 AEC Option I[a]			Case 2[b] AEC Option II
II. Removal of all scrap and Pu concentrations greater than 40 pCi/g from residence and agriculture islands[c]. concentrations from four islands.		Case 4 AEC Option IV	Case 3 Conforms with Task Group Recommendations	
III. Total cleanup of residence and agriculture islands[d].	Case 5 Approximately AEC Option V			

[a] "Report by the AEC Task Group on Recommendations for Cleanup and Rehabilitation of Enewetak," June 19, 1974.

[b] Case 2 differs from other programs in Row 1 by removal of physical hazard and obstructive debris categories of nonradioactive scrap on southern islands.

[c] Plutonium concentrations refer to burial grounds and soil dispersions of concentration in excess of 40 pCi/g. Areas of soil concentration in excess of 400 pCi/g should be removed without question; areas of soil concentration between 40 and 400 pCi/g should be considered on an individual basis.

[d] Removal of all scrap from all residence islands specified in each column and removal of specific amounts of soil in specific areas to achieve external and internal doses no greater than would be absorbed from naturally occurring sources.

have the disadvantage that the crater area would have to be quarantined for an indefinite period. Also, it is not in keeping with the expressed desire of the Enewetak people that all contaminated items be removed from the atoll.

Although the cost of crater dumping is approximately only 5% of the crater entombment procedure described later, it has been rejected from further consideration as the contaminated materials would ~~be a~~ remain a ~~constant~~ potential threat to the safety of the Enewetak people. The debris-laden craters would require continuous surveillance and policing to enforce a quarantine on the area which would be necessary for the safety of the atoll population. In addition, the craters would be neither lined nor capped in this option and there would be nothing to prevent the migration of the radionuclides into ocean and lagoon waters through cracks and fissures in the crater walls, or to prevent redistribution on land as a result of wave action or storms.

5.4.3.2.3 Crater Containment. Crater containment also utilizes the Runit craters for disposal but with additional measures taken to prevent human contact with the radioactive material, or the entry of the material into the food chain. The crater bottoms and sides would be sealed with concrete. The plutonium contaminated soil would then be mixed with cement and water to form a soil-cement slurry which would be placed in the crater. Radioactive debris would be dumped into the lined crater along with the slurry. This would be done in such a manner that erosive water velocities are held to the lowest practicable level in order to reduce the transport potential of the plutonium in the soil. Crater containment also has the further advantages of:

- Reducing the availability of small contaminated particles and contaminated scrap by binding them in a cementations matrix.
- Providing a coating for the sand and plutonium particles to shield and reduce the hazards of alpha emissions.
- Dispersing the radioactive material within disposal criteria in a relatively uniform manner within the larger mass of material available.
- Placing the material in a semipermanent location where it would be least available to man but where it could be observed and retrieved if necessary or desirable.

It should be noted that the containment is not required nor intended to be leak proof. An 18-inch thick concrete cap or lid would be placed over the entire mass for erosion resistance and to seal off the radioactive

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material. During the disposal operations, Lacrosse crater (and Cactus crater if necessary) would be protected from tidal currents and wind generated waves by temporary dikes.

5.4.3.2.4 Conus Disposal. This term designates the procedure of disposing of radioactive materials in the continental United States. These materials, including soils, would be sealed in containers and shipped from the atoll to one of the low-grade disposal areas in the western part of the United States. There are two radioactive waste burial areas which have been identified in the western United States, both near Richland, Washington. One is operated by the AEC for waste from the AEC's Richland operations, but which does not accept offsite-generated waste. The other is operated by a private firm licensed by the State of Washington. Under proposed regulations, this latter burial ground may not be permitted to accept plutonium-contaminated waste.

If either of these sites were available to receive the plutonium bearing soil and radioactive debris from Enewetak, they could be reached by a combination of ocean, Columbia River, railroad, and truck transports. This method would move the contaminated material away from the atoll, however, it has serious disadvantages. The procedural or legal difficulties could be considerable and the cost would be approximately three times that of crater containment (Table 5-18).

Transport of this material by vessel would be required to comply with current regulations (46 CFR 146.19).

5.5 PROGRAM SYNTHESIS

5.5.1 Possible combinations of residence, agriculture and cleanup levels were examined. Some combinations were found to be mutually exclusive and others were rejected for basic deficiencies. Of those remaining, a matrix was constructed, Table 5-5, and five combinations chosen for detailed analysis of dose reduction, health effects, cost and general acceptability. These five, identified as "cases" are indicated in ~~Table 5-6~~ the and discussed in detail in the following sections.

The matrix arrangement is such that the following trends are apparent:

- The level of cleanup effort increases from top to bottom.
- Restrictions on living conditions and agricultural practices increase from left to right.
- The level of population dose decreases from top to bottom.

5.5.2 Case 1 - No Restrictions on Island Residence or Food Usage. No Cleanup

In this case no cleanup action would be taken. All nonradioactive scrap and radioactive materials would remain in place. Two mutually exclusive possibilities would result, i.e., (1) not to return to the atoll or (2) to return.

5.5.2.1 Discussion. If the islanders were to return to Enewetak Atoll, they would be exposed to the possibility of injury to themselves and their children as a result of hazardous debris and exposure to residual radiation, none of which would be cleaned up. The possibility of injury from radiation exposure would be predominant as Case 1 imposes no restriction on sources of food, whether terrestrial or marine, and no limitations on traveling or location of habitation (Figure 5-1). Under these conditions it can be expected that the radiological dose to the people would exceed the recommended ~~AEC criteria~~ ERDA guidelines.

5.5.2.2 Conclusions. In view of the existing hazards to which the Enewetak people would be exposed should they return to the atoll under Case 1 conditions, it is recommended that they do not return.

5.5.3 Case 2 - Living, Terrestrial Food Sources, Travel, and Cleanup Restricted to Southern Islands

Case 2 would establish the requirement for a long term quarantine of certain islands in the atoll. With a quarantine in effect, the radiological dose to the islanders would be well below the ERDA guidelines, but if access to certain islands, especially Runit, were uncontrolled a potential for radiological exposures exceeding the ~~criteria~~ guidelines would exist.

5.5.3.1 Habitation Plan

- Residences restricted to southern islands, Jinedrol through Kidrenen, and the same limitation imposed on interisland visiting.
- All terrestrial foods including birds and bird eggs would be grown on or collected from the southern islands only.
- Coconuts for subsistence or for copra would be grown only on the southern islands. Any use of coconuts from the northern sector, Bokoluo through Runit, would be specifically prohibited.
- Domestic animals and fowl for consumption would be reared only on the southern islands.

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FIG. 5-1 - ENEWETAK ATOLL
CASE 1

- Coconut crabs would be taken for consumption from the southern islands only.

- Wells intended for providing groundwater for human consumption or agricultural use would be drilled only in the southern islands, Jinedrol through Kidrenen. Prior to being approved for use, water from each well would be checked for salinity, bacteria count, and radioactivity.

- Lagoon fishing would be unrestricted.

5.5.3.2 Cleanup Actions. Under the conditions presented in Case 2, there would be no cleanup of any radioactive materials on the atoll as cleanup is restricted to the southern islands where no radioactive contamination occurred. In Table 5-~~8~~5, Case 2 provides an exception to the cleanup actions generally meant by Row 1. The level of cleanup of nonradioactive materials would be limited to the southern islands, Jinedrol through Kidrenen (Figure 5-2), and would include:

- Removal of all physical hazards.

- Removal of all debris which would obstruct the development of villages and agricultural areas.

- Disposal of unsalvable noncombustible debris by dumping in the lagoon.

5.5.3.3 Conclusions. Case 2 limits all foods sources to the southern islands which action is difficult to justify as some of the northern islands are only lightly contaminated. Also, it is difficult to justify limiting travel to the southern islands since ambient gamma levels on the northern islands do not represent a significant external exposure potential for occasional visitation. Case 2 does leave the problems of contaminated scrap on many islands of the atoll, and the Pu in the soil on Runit, Boken, Lujor, and in the burial sites on Aomon, unresolved. It also leaves the generally contaminated areas on Bokoluo, Bokombako, Kirunu, and Lujor as they presently exist. There is also a question as to the ability of such a limited land area to support 400 people, with a continuous upward population growth rate.

A selection of Case 2 would necessitate the establishment of off-limits areas in perpetuity, at least for Runit, since the metallic Pu can be expected to be on the surface of the island indefinitely. Under present conditions, there is a potential for exceeding established standards through inhalation, and the possibility of spreading contamination if access to the island is not controlled as it is at the present time.

FIGURE 5-2: ENEWETAK ATOLL
CASE 2

Since Case 2 offers no solution to these problems, it is not recommended as a course of action.

5.5.4 Case 3 - Living on Southern Islands, Food from Southern Islands plus Coconuts from 12 Northern Islands. Travel Unrestricted. Material and Some Plutonium Cleanup

Case 3 permits partial use of areas of the atoll having low radioactive levels, leaves no hazardous legacies for the indefinite future, and permits living patterns which, with high confidence, are expected to result in population doses well below the ERDA guidelines. This case does restrict habitation to the southern islands, Jinedrol through Kidrenen, and does not recommend specific action against radioactivity in the soils of Bokoluo, Bokombako, and Kirunu (Figure 5-3).

5.5.4.1 Habitation Plan. In Case 3, the Enewetak people would live and obtain food as follows:

- Residence would be restricted to the southern islands, Jinedrol through Kidrenen.
- Runit would be quarantined until complete Pu cleanup is effected and crater containment has been completed. Other travel would be unrestricted.
- Pandanus, breadfruit, arrowroot and other subsistance foods would be cultivated on the southern islands only.
- Coconuts would be grown on the southern islands and in the northern islands of Mijikadrek through Billae only. No cultivation would be permitted on the northwest islands of Bokoluo through Enjebi and on Runit.
- Domestic meat would be raised on the southern islands only (Jinedrol-Kidrenen).
- Coconut crabs would be taken from the southern islands only.
- Lagoon fishing and wild bird and bird egg gathering would be unrestricted (except on Runit).

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FIGURE 5-3. ENEWETAK ATOLL
CASE 3

5.5.4.2 Cleanup Actions. The following actions would be taken to clean up the atoll:

- Physical hazards would be removed from all islands.
- Obstructions to development of habitations and agriculture would be removed.
- Radioactive scrap would be removed from all islands in the atoll.
- Boken, Lujor, and Runit plutonium concentrations greater than 400 pCi/g would be excised and all other concentrations between 400 and 40 pCi/g would be dealt with on an individual basis. Concentrations of less than 40 pCi/g would not be disturbed. Cleanup of Pu is expected to be performed iteratively until a sufficiently low concentration level is attained. Some 79,000 cu yds of soil would be involved in this removal.
- Plutonium would be removed from the three burial crypts on Aomon.
- Unsalvable nonradioactive and noncombustible material would be disposed of by dumping in the lagoon at selected locations for forming artificial reefs.
- Radioactive materials would be disposed of as discussed in Section 5.4.3.2.3, namely by containment in Cactus and, if necessary, Lacrosse craters on Lujor.

5.5.4.3 Conclusions. Case 3, by virtue of the fact that it requires removal of only the most seriously contaminated materials, is less expensive than succeeding Cases 4 and 5. Although this case recommends that Enjebi not be utilized for habitation, it does impose far less stringent limitations on interisland visitations and the growing of commercial crops. With respect to the latter, it provides for the clearance of obstructions which would deny use of some of the land. Case 3 also provides for the removal of contaminated scrap to negate the possibility of any reaching the world's markets. Although Case 3 is composed of all actions described in Case 2, it also provides for further actions in establishing and maintaining radiological safeguards.

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In addition to the quarantine of Runit, (Paragraph 5.5.4.1), Case 3 recommends that studies be conducted as follows:

- A test planting program on Enjebi to determine when exposure would be within acceptable criteria without the removal of soil.
- A program to determine radioactivity levels in coconut and other food crops produced on Lujor, Kirunu, Bokoluo, Bokombako, and Runit (after plutonium cleanup).
- As an alternate to the preceding program, soil removal on Enjebi, followed by a test planting series to determine whether exposure for Enjebi residents would be within acceptable criteria.
- The assembly of a team of experts to make and interpret field radiation and activity measurements, advise on cleanup actions involving plutonium and other radionuclides, and provide necessary health physics support for protection of workers, decontamination of workers and equipment, and packaging and handling of collected contaminated materials. It is recommended that this program be conducted under the auspices of ERDA.
- A comprehensive underground water lens sampling and analysis program for a minimum period of 1 year. Bacterial content, salinity, and radionuclide content would be measured every twelve months. However, the primary emphasis would be on the development of understanding those processes which are operating or can be made to operate to reduce the ecological half-life of ^{90}Sr and ^{137}Cs below the radioactive half-life on the northern islands.

Case 3 reasonably insures a safe habitation plan for the proposed return of the islanders and provides a means of eventual improvement of the environment for the benefit of all of the Enewetak people. Further, the controlling criteria for radiation exposure developed by the AEC Task Group can be best met by this particular alternative. This is most likely to provide the lowest possible exposure in accordance with accepted guidelines.

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5.5.5 Case 4 - Living on Southern Islands and Enjebi; Subsistance and Commerical Crops on Southern Islands and, Under Controlled Conditions, on Enjebi; Material, Soil and Some Plutonium Cleanup

Assuming the effectiveness of the corrective measures to be suggested, Case 4 would still result in annual and 30-year gonadal doses (Task Group Report, 1974) at or above the ERDA guidelines for those who would live on Enjebi, and would be well above those predicted for Case 3. The success of this case would depend upon the following factors (Figure 5-4):

- Importation of food for the Enjebi inhabitants. While this is the most dependable method, it would be a long-term burden on the driEnjebi which would eventually become objectionable to them.

- Removal of soil and replacement with imported soil. This method is not as certain a safeguard against internal exposure as the importation of food, but in theory it is possible that it would reduce the dose from pandanus and breadfruit to levels comparable to those found on the southern islands. All this depends upon providing sufficient imported soil to encompass the entire root system of the mature trees, and that factors do not exist which would lead to recontamination. In any event, there is reasonable doubt that safe levels could be attained by soil replacement alone.

- The water supply for these crops must not have radioactivity levels higher than those in the southern islands. ~~When added to Case 3 conditions~~, The ~~actions comprising~~ living pattern of Case 4 would be as ~~follows:~~ described in the following subsection.

5.5.5.1 Habitation Plan. If the cleanup actions to be described in Paragraph 5.5.5.2 should prove to be as effective as predicted, the Enjebi people could be permitted to return to their island with the following conditions applying:

- Residence would be restricted to the southern islands, Jinedrol through Kidrenen and Enjebi.

- Pandanus and breadfruit would be cultivated in the south and in imported soil on Enjebi (Paragraph 5.5.5.2).

- Other subsistence crops, e.g., arrowroot, papaya, etc., would be grown only in the south and on Enjebi.

FIGURE 5-4: ENEWETAK ATOLL
CASE 4

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- Coconuts could be grown on the northern islands of ~~Mijikadrek~~ Enjebi through Billae and on the southern islands. They are specifically prohibited on the northwest islands (Bokoluo-Boken).

- Domestic meat would be raised on the southern islands and on Enjebi.

- Coconut crabs would be taken only from the southern islands.

- Interisland travel would be unrestricted.

- Wild bird and bird egg gathering would be unrestricted.

- Lagoon fishing would be unrestricted.

5.5.5.2 Cleanup Actions. Actions are categorized as follows (removal of approximately 318,000 cu yds of soil is required):

- Removal of physical hazards from all islands.

- Removal of debris and structures obstructive to the use of the land by the people.

- Removal of plutonium contaminated soil from Boken, Lujor, and Runit and removal of plutonium crypts on Aomon.

- Scraping and removal of soil in pandanus and breadfruit growing areas (along the lagoon shore and on the northwest shore) of Enjebi to a minimum depth of 30 cm.

- Scraping and removal of soil in commercial coconut grove areas on Enjebi to a depth of 15 cm.

- Scraping and removal of soil in other subsistence agricultural areas on Enjebi to a depth of 15 cm.

- Replacing soil from scraped areas with at least equal depths of imported soil.

5.5.5.3 Conclusions. In Case 4 predicted doses would equal or exceed the upper limit of the ERDA guidelines (Task Group Report, 1974). This factor, when weighed with the great uncertainty in achieving even this dose reduction, makes it very difficult to justify the return of the driEnjebi to their home island. Case 4 is not recommended as a course of action.

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5.5.6 Case 5 - Unrestricted Living, Food Sources and Travel, Total Cleanup of Residence and Agricultural Islands

In addition to the removal and replacement of soil on Enjebi as in Case 4, Case 5 provides for the removal of soil to specific depths on Lujor, Bokoluo, Bokombako, and Kirunu. The islands designated for agricultural development in the Master Plan (Tab D, Appendix) would also be treated to a soil removal and replacement operation similar to that described for Enjebi. There would be no restriction on living patterns or food sources in Case 5 (Figure 5-5).

5.5.6.1 Habitation Plan. If the actions to be described in Paragraph 5.5.6.~~1~~ 2 would achieve a level of exposure reduction as large as the calculated result, the entire atoll could be used in accordance with Table 4-1, (Tab D, Appendix) ~~Vol. II, EIS~~. Agriculturally, this would mean that pandanus and breadfruit would be permitted to grow only in soil having a ^{90}Sr content of less than 4.6 pCi/g. Assuming that these conditions would be met, the following would apply:

- The people would be able to live on any island in the atoll ~~as designated in Table 4-1 of the Master Plan.~~
- Coconut, pandanus, and breadfruit could be cultivated on those islands designated in Table 4-1.
- Domestic meat could be raised on any island.
- Coconut crabs could be collected on any island.
- Wild birds and bird eggs could be gathered on any island.
- Interisland travel would be unrestricted.
- Lagoon fishing would be unrestricted.

5.5.6.2 Cleanup Actions. The following cleanup actions would be undertaken (removal and replacement of about 779,000 cu yds of soil is involved in these cleanup actions):

- Removal of physical hazards from all islands.
- Removal of debris and structures obstructive to the use of the land by the people.
- Removal of unsightly debris.

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FIGURE 5-5:
ENEWETAK ATOLL CASE 5

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- Removal of plutonium contaminated soil from Boken, Lujor, and Runit and the removal of plutonium crypts on Aomon.

- Scraping and removal of 10 cm of soil from Lujor and Kirunu, 14 cm of soil from Bokombako, and 47 cm from Bokoluo.

- Scraping and removal of 30 cm of soil from areas where pandanus and breadfruit would be grown on Enjebi, Alembel, Aomon, Bijire, Lojwa, Lujor, Aej, Ananij and Runit.

- Scraping and Removal of 15 cm of soil where commercial coconut crops will be grown on the same islands.

- Scraping and removal of 15 cm of soil in other subsistence agricultural areas on Enjebi.

- Replacing soil from scraped areas with at least equal depths of imported soil.

5.5.6.3 Conclusions. Case 5 is clearly more difficult and more expensive than the other cases as it requires removal and replacement of much more soil in the cleared areas (Case 3: 79,000 cu yds; Case 4: 318,000 cu yds; Case 5: 779,000 cu yds). Consideration of the actions in Case 5 as a viable alternative is clouded by uncertainties regarding the exposure reduction that can be achieved through partial soil removal and selective soil replacement. In view of these considerations and the additional high cost of the operation, Case 5 is not recommended as a course of action.

5.6 EVALUATION OF ALTERNATIVE PROGRAMS

Several considerations are treated quantitatively here to assist in selecting a suitable course of action in cleanup and rehabilitation of Enewetak Atoll and in resettlement of the Enewetak on the atoll. These considerations include estimated dose and the associated radiological risk and the financial costs of alternative programs. The effectiveness of each alternative program in reducing the estimated potential population radiological dose are evaluated by calculating whole body, bone, and lung dose for each program (see Paragraph 5.6.1). These doses are estimated on two time bases: a 30-year dose and a maximum annual dose. Relative values of radiological risks for each alternative program is estimated in Paragraph 5.6.2. Estimates of the financial costs of selected alternative programs and associated disposal methods are discussed in Paragraph 5.6.3.

5.6.1 Dose Estimates

Estimates of doses that individuals in the Enewetak Atoll population may incur after they have resettled on the atoll are presented for various alternative programs in Tables 5-6 and 5-7. In both tables, the dose estimates are given for the whole body, the bone (mineral) and the lungs. These estimates are based on information contained in the AEC Radiological Survey of Enewetak Atoll, NVO-140, 1973 and in the AEC Task Group Report, June 19, 1974.

Particular considerations in calculating these dose estimates are:

- No contribution to dose is assumed from groundwater since it will be monitored and will not be used unless it meets established guidelines for radioactive and nonradioactive impurities.

- Bone marrow dose estimates are not given because the ratio of bone marrow dose to the AEC guidelines of 0.25 rem/yr is essentially the same as the ratio of mineral bone dose estimates to the AEC guideline of 0.75 rem/yr. The basis for this conclusion derives from observing that when ^{90}Sr deposition is the principal source of bone and bone marrow exposure, as on Enewetak, it is traditionally accepted that the marrow dose is one-third the bone dose. AEC data show that contributions due to sources other than ^{90}Sr do not add significantly to bone or bone marrow dose estimates. Consequently, it makes no significant difference whether bone or bone marrow is the organ used for radiological hazard analysis since dose estimates and dose guidelines occur in essentially the same ratio, 3 to 1 respectively, for the two organs.

- Separate dose estimates are not provided for the traditionally more sensitive members of the population (fetus and newborn). The AEC Task Group Report (Tab B, Vol. 2 of the EIS) and NVO-140, page 505, show that calculations based on the most sensitive individual do not result in significant differences in close estimates.

- The dose estimates are maximums expected in the population for an individual free to move about and eat foods obtained within the restrictions of each habitation plan/cleanup action combination. These estimates are developed to provide a means for estimating radiological health effects and risks for each combination of interest. Dose estimates for individuals subjected to more restrictive and adverse combinations of habitation and

TABLE 5-6: ESTIMATED 30-YEAR INTEGRATED DOSES TO INDIVIDUALS[a]
(REM)

Habitation Plans / Cleanup Actions	A No restrictions on island or food usage	B Live on southern islands and Enjebi; visit northern islands; food from southern islands or Enjebi except coconut from 12 N.E. islands and pandanus and breadfruit from Enjebi farm plots or imported[b]	C Live on southern islands; visit northern islands; food from southern islands except coconut from 12 N.E. islands[c]	D Live on southern islands; visit on southern islands; use food grown on only southern islands
I. No cleanup.	Case 1 WB = 6 B = 60 L = 0.1	WB = 3 (6 on Enjebi) B = 10 (20 on Enjebi) L = 0.06 (0.1 on Enjebi)	WB = 1 B = 5 L = 0.04	Case 2 WB = Background[d] B = Background L = Background
II. Removal of all scrap and Pu concentrations greater than 40 pCi/g from residence and agriculture islands.	WB = 6 B = 60 L = Background	Case 4 WB = 3 (6 on Enjebi) B = 10 (20 on Enjebi) L = Background	Case 3 WB = 1 B = 5 L = Background	Same as Case 2
III. Total cleanup of residence and agriculture islands.	Case 5 WB = Background B = Background L = Background	Habitation restriction not required. See Case 5	Habitation restrictions not required. See Case 5	Habitation restrictions not required. See Case 5

LEGEND

WB = Whole Body Dose
B = Bone Dose
L = Lung Dose

[a] Doses calculated to one significant figure based on data from NVO-140 and AEC Task Group Report.

[b] Doses calculated from an assumed population distribution of 44 percent of the Atoll population on Enjebi and the balance of the population on the southern islands.

[c] Doses calculated from island area weighted distribution of coconuts; 33 [40] percent from Mijikadrek to Billae and Biken, ~~17 percent from Enjebi~~, and 50 [60] percent from the southern islands.

[d] Background means that the dose is estimated to be no greater than would be absorbed from naturally occurring sources, either externally or internally. Estimates for background 30-year doses are: WB = 1 rem, B = 4 rem, and L = 0.0009 rem.

TABLE 5-7: ESTIMATED MAXIMUM ANNUAL DOSES TO INDIVIDUALS[a] (REM)

Habitation Plans / Cleanup Actions	A No restrictions on island or food usage	B Live on southern islands and Enjebi; visit northern islands; food from southern islands or Enjebi except coconut from 12 N.E. islands and pandanus and breadfruit from Enjebi farm plots or imported	C Live on southern islands; visit northern islands; food from southern islands except coconut from 12 N.E. islands	D Live on southern islands; visit on southern islands; use food grown on only southern islands
I. No cleanup.	Case 1 WB = 0.3 B = 2 L = 0.004	WB = 0.1 (0.3 on Enjebi) B = 0.5 (1 on Enjebi) L = 0.002 (0.004 on Enjebi)	WB = 0.05 B = 0.2 L = 0.001	Case 2 WB = Background[b] B = Background L = Background
II. Removal of all scrap and Pu concentrations greater than 40 pCi/g from residence and agriculture islands.	WB = 0.3 B = 2 L = Background	Case 4 WB = 0.1 (0.3 on Enjebi) B = 0.5 (1 on Enjebi) L = Background	Case 3 WB = 0.05 B = 0.2 L = Background	Same as Case 2
III. Total cleanup of residence and agriculture islands.	Case 5 WB = Background B = Background L = Background	Habitation restrictions not required. See Case 5	Habitation restrictions not required. See Case 5	Habitation restrictions not required. See Case 5

LEGEND

WB = Whole Body Dose
B = Bone Dose
L = Lung Dose

[a] Doses calculated to one significant figure based on data from NVO-140 and AEC Task Group Report. AEC guidelines for maximum annual dose are: WB = 0.25, B = 0.75. See Table 5-6 for assumptions used in dose calculations for columns B and C.

[b] Background means that the dose is estimated to be no greater than would be absorbed from naturally occurring sources, either externally or internally. Estimates for annual background dose are: WB = 0.04 rem, B = 0.1 rem, and L = 3×10^{-5} rem.

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AEC Task Group Report but are not considered in the alternative programs in this EIS. These more adverse Task Group Report combinations are extremely unlikely when considering historic living patterns on the atoll and the stated preferences of the Enewetak Atoll people for use of the various islands. Furthermore, it has been determined that consideration of these other combinations would increase already unacceptable doses but would not change the acceptability of recommended alternative programs.

Table 5-6 lists estimates of doses absorbed over a period of 30 years. These estimates can be considered the higest that any generation would receive. The maximum annual doses listed in Table 5-7, include recognition that the maximum for each component of radionuclide contribution to total dose occurs at different times during the 30-year period. Data and methods used to obtain the estimates in Table 5-6 and 5-7 are discussed in Paragraphs 5.6.1.1 through 5.6.1.3.

Comparison of these results with the dose guidelines recommended by the AEC Task Group Report, 1974 (see Table 5-3) is shown in Table 5-8. This comparison is given as the ratio of estimated individual dose to the appropriate dose guideline. For habitation plan A with cleanup actions I or II, the maximum annual whole body dose for an average individual on the atoll is about 20 percent higher than the AEC guideline. For habitation plan B, the maximum annual whole body dose for an average individual is well below the AEC guideline; but for an individual residing on Enjebi, the whole body dose under these conditions is estimated to be 20 percent higher than the AEC guideline. For other combinations of cleanup actions and habitation plans, the maximum annual doses are well within the guidelines recommended by the AEC.

Regarding bone doses, estimates for habitation plan A exceed the AEC guideline of 0.75 rem/yr, except for cleanup action III, even when the distribution of population is taken into account. For habitation plan B, the bone dose appears to be satisfactory in comparison to the guideline except for an individual residing on Enjebi. Other combinations result in maximum annual doses well within AEC guidelines.

5.6.1.1 Internal 30-Year Doses. Data for internal doses to whole body and bone are presented in Table 5-9. These data were used in developing the estimates in Table 5-6. In addition, data from Tables 1 and 2 of the AEC Task Group Report were used in deriving these estimates. In particular, living patterns A and D in Tables 1 and 2 of the Task Group Report were used for estimating whole body and bone doses in Column B of Table 5-6. These patterns correspond to life styles likely to be adopted by people living and growing food on the southern islands and by people living and growing food on Enjebi, respectively. An appropriate combination of these patterns reflecting the spatial distribution of the population is used for the final evaluations in Tables 5-6 and 5-7.

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TABLE 5-8: RATIOS OF ESTIMATED MAXIMUM ANNUAL DOSES TO RECOMMENDED ANNUAL DOSE GUIDELINES FOR INDIVIDUALS[a]

Habitation Plans / Cleanup Actions	A No restrictions on island or food usage	B Live on southern islands and Enjebi; visit northern islands; food from southern islands or Enjebi ~~except~~ plus coconut from 12 N.E. islands and pandanus and breadfruit from Enjebi farm plots or imported[b]	C Live on southern islands; visit northern islands; food from southern islands ~~except~~ plus coconut from 12 N.E. islands[c]	D Live on southern islands; visit on southern islands; use food grown on only southern islands
I. No cleanup.	Case 1 RWB = 1.2 RB = 2.7	RWB = 0.4 (1.2 on Enjebi) RB = 0.7 (1.3 on Enjebi)	RWB = 0.2 RB = 0.3	Case 2 b
II. Removal of all scrap and Pu concentrations greater than 40 pCi/g from residence and agriculture islands.	RWB = 1.2 RB = 2.7	Case 4 RWB = 0.4 (1.2 on Enjebi) RB = 0.7 (1.3 on Enjebi)	Case 3 RWB = 0.2 RB = 0.3	b
III. Total cleanup of residence and agriculture islands.	Case 5 b	b	b	b

LEGEND

RWB = Ratio of Maximum Annual Dose to Recommended Limit for Whole Body Dose (0.25 rem/yr).
RB = Ratio of Maximum Annual Dose to Recommended Limit for Bone Dose (0.75 rem/yr).

[a] Applicable to average individual on entire atoll, except where noted. People should not return if the ratios are greater than unity.

[b] The ratios are effectively less than or equal to the ratio of background dose to recommended guideline where RWB ≤ 0.16 and RB ≤ 0.13.

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TABLE 5-9: INTERNAL DOSES DERIVED FROM INGESTION OF FOODS GROWN ON GIVEN ISLANDS

Island Group	Area (Acres)	Remarks	Foods	30-Year Doses[a] (Rem) Whole Body (^{137}Cs)	Bone (^{90}Sr)
Bokoluo to Boken, inclusive (Alice through Irene)	104.87	Northern islands showing greatest radioactivities of Enewetak Atoll survey	Coconuts Pandanus and Breadfruit Other	0.95 6.15 2.45	8.6 93.4 24.0
Sum				9.55	126.0
Bokombako (Belle)	30.50	Same as above	Coconuts Pandanus and Breadfruit Other	2.18 13.80 5.42	14.9 156.5 40.6
Sum				21.40	212.0
Enjebi (Janet)	290.58	Same as above	Coconuts Pandanus and Breadfruit Other	0.71 4.60 1.80	5.2 55.5 14.7
Sum				7.10	75.4
Mijikaidrek to Van, inclusive, plus Biken (Kate through Van plus Leroy).	524.31	Northeastern (Biken is south-western) islands with intermediate levels of radioactivity	Coconuts Pandanus and Breadfruit Other	0.27 1.71 0.03	2.2 24.0 6.5
Sum				2.67	32.7
Jinedrol to Kidrenen, inclusive (Alvin through Keith)	804.58	Southern islands with very low levels of radioactivity	Coconuts Pandanus and Breadfruit Other	0.04 0.06 0.04	0.28 0.48 1.34
Sum				0.14	2.10
Enewetak Lagoon	--	Marine Source	Seafood	0.05[b]	0.84[b]

[a] "Enewetak Radiological Survey," NVO-140 (1973), Table 202, p. 604, except where noted.

[b] Ibid., Table 162, p. 540. The values taken correspond to whole body and bone doses from all nuclides, not just ^{137}Cs and ^{90}Sr.

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by people living and growing food on the southern islands and by people living and growing food on Enjebi, respectively. An appropriate combination of these patterns reflecting the spatial distribution of the population is used for the final evaluations in Tables 5-6 and 5-7.

The contributions of radionuclides in coconuts, pandanus and breadfruit, and other components of the Enewetak diet are given for each of several island groups in Table 5-9. The islands are grouped in decreasing order of contamination as follows:

- Bokoluo to Boken plus Bokombako
- Enjebi
- Mijikaidrek to Van plus Biken
- Jinedrol to Kidrenen

These data were used in the construction of area weighted food and island contributions to the internal dose estimates in Column C of Table 5-6.

Variation in the time of exposure among foodstuffs influences the cumulative internal dose. As a period of about 7 to 10 years is required for the maturation of seedling pandanus, breadfruit, and coconut trees, and few fruit bearing plants are now available on Enewetak Atoll, these foods can not contribute to the internal dose until the maturation period has passed. For simplicity, the maturation period is assumed to be 8 years in the calculation of doses for Tables 5-6 and 5-7.

Values for the lung dose contributions are comprised of two components: dose from inhalation of plutonium and whole body dose. In every case of Table 5-6, the magnitude of the inhalation dose is insignificant compared to the whole body dose. Estimates of inhalation dose to the lungs were based on the data in Table 204 of NVO-140, 1973, using living patterns I and III. These estimates are noted in Table 5-6. Due to the small magnitude found for the plutonium contribution to the lung dose, the time dependent character of the inhalation dose is not significant to the calculation of maximum annual dose.

5.6.1.2 External 30-Year Doses. External dose contributions from gross gamma radiation fields of different isopleths on different island groups are listed in Table 5-10. Area weighted averages of the exposure rates of isopleths and of the external dose estimates by island group areas were used in determining the external dose contributions to the estimates given in Table 5-6.

The sources of external exposure are assumed to disappear by their nuclear decay alone. No credit is assumed in the estimation of integral doses for any removal from the local environment by weathering or other natural processes.

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TABLE 5-10: CALCULATIONS OF EXTERNAL DOSES TO INDIVIDUAL RESIDING ON GIVEN ISLANDS

Island Group	Land Area (Acres)	Cleanup Action[a] (Code)	Isopleths: Code	Isopleths: Area (Acres)	Isopleths: Exposure Rate[b] (μR/hr)	Remarks	Thirty Year External Dose (rem)
Bokoluo to Boken plus Bokombako, Lajor and Runit	281.66	Row I	K J I H G F ≤E	2.09 7.15 63.62 54.22 84.63 84.87 44.48	390 195 98 50 24 12 6	Dose calculated by isopleth area weighted and normalized (to Enjebi) exposure rates; Enjebi external dose taken from AEC pattern III[c]; all locations assumed equally accessible	6.4
		Row II				Radiological cleanup does not appreciably reduce external dose in Row I	6.4
		Row III				Removal of at least isopleths F through K	Background[d]
Enjebi	298.58	Row I	I H G F ≤E	5.98 138.15 28.51 34.09 23.85	98 50 24 12 6	Enjebi external dose taken from AEC pattern III[c]	4.0
		Row II				Same remark as for Row II cleanup of Bokoluo to Boken plus Bokombako, Lajor and Runit	4.0
		Row III				Removal of at least isopleths F through I	Background[d]
Mijikadrek to Billae and Biken	378.92	Row I	G F ≤E	17.49 77.83 283.60	24 12 6	Same remark as for Row I cleanup of Bokoluo to Boken plus Bokombako, Lajor and Runit	1.1
		Row II				Same remark as for Row II cleanup of Bokoluo to Boken plus Bokombako, Lajor and Runit	1.1
		Row III				Removal of at least isopleths F and G	Background[d]
Jinedrol to Kidrenen	804.58	Row I	≤E	804.58	6	External dose of southern islands taken from pattern I;[c] estimated to be approximately that of background	0.8
		Row II				Same remark as for Row II cleanup of Bokoluo to Boken plus Bokombako, Lajor and Runit	0.8
		Row III				Little radiological cleanup required	Background[d]

[a] Cleanup actions referenced as follows:

Code	Cleanup Action
Row I	No radiological cleanup
Row II	Cleanup of all radioactive scrap Removal of plutonium burial sites Removal of plutonium bearing soil with concentration in excess of 400 pCi/g Removal of plutonium bearing soil with concentration between 40 and 400 pCi/g considered on case by case basis
Row III	Complete radiological cleanup such that the expected dose is not greater than would be absorbed from naturally occurring sources

[b] Exposure rate is related to individual annual dose by

Exposure rate (μR/hr) $\approx 8.4 \times 10^{-3}$ rem/yr (1 person - 1 yr)

[c] "Enewetak Radiological Survey," NVO-140 (1973), Table 204, p. 613. Living pattern I corresponds to people living, growing food, and visiting on only the southern islands Jinedrol to Kidrenen. Living pattern III corresponds to people living and growing food on only Enjebi, and visiting northern islands.

[d] Background means that the dose is estimated to be no greater than would be absorbed from naturally occurring sources.

This table will have to be less reduced as lettering is beginning to run together.

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5.6.1.3 Maximum Annual Dose. The dose rate is not constant during the 30-year period for which "generation" doses are calculated. Consequently the maximum annual dose during this period is calculated for comparison with the annual exposure guidelines recommended by the AEC.

The internal dose rate is dependent on the particular radionuclide as well as its retention characteristics within the body. Consequently, the time dependence and the point in time of the maximum dose rate is different for each combination of radionuclide, environmental pathway, and target organ for which the dose is being calculated. Because of uncertainties inherent in some of these time constants, the internal contribution to the maximum annual dose rate is the sum of the individual maxima disregarding their separation in time. This results in a slightly conservative estimate of the maximum annual dose. The times of these maxima are shown in Table 5-11. As discussed in Paragraph 5.6.1.1, the maturation time for pandanus, breadfruit, and coconut trees is taken to be 8 years for simplicity. The maxima for these exposure pathways are then adjusted accordingly.

The external dose contribution is simply corrected for its radiological decay with no credit being assumed for any weathering, erosion, or other natural process that might increase its rate of disappearance. The sum of the internal and external contributions represents the total of the maximum annual dose. The results are presented in Table 5-7. Referring to Case 1 in Table 5-7, higher maximum annual doses could be estimated as shown in Table 3 of the AEC Task Group Report. However, these higher doses represent highly unlikely living patterns and, even if included, would only have increased the unacceptability of this case.

5.6.2 Comparison of Risks for Alternative Programs

Each alternative program considered for cleanup and habitation can be associated with a level of radiological risk for the people of Enewetak Atoll. A semi-quantitative measure of this risk is provided by estimating the number of health effects* expected from the radiological exposure in each alternative. The risk criteria given in Table 5-1 are used as the basis for making these estimates, assuming a total atoll population of 1,000 receiving the 30-year integrated doses given in Table 5-6 for each alternative. Table 5-12 lists the estimated health effects.

*As indicated in NCRP Report No. 43, Review of the Current State of Radiation Protection Philosophy, January 15, 1975, it is very unreasonable to interpret these upper limit estimates as actual risk. Because of the extreme conservatism in these estimates, they should be used only as general guidelines in any risk analysis.

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TABLE 5.11: INFORMATION FOR CALCULATING MAXIMUM INTERNAL ANNUAL DOSES

Radionuclide	Critical Organ	T_{max} [a] (yrs)	T_{max} + 8 yr[b] (yrs)	Dose Period T[c] (yrs)	Dose Conversion Factor[d]	
					K	1/K
^{90}Sr	Bone	4.82	-	30	23.10	0.0433
			-	22	18.22	0.0549
		-	13	30	25.65	0.0390
^{137}Cs	Whole Body	1.83	-	30	21.11	0.0474
			-	22	17.75	0.0563
		-	10	30	25.17	0.0397
Pu	Lung	19.00	-	30	28.01	0.0357

[a] The time at which the internal exposure rate becomes maximum for a particular radionuclide and target organ is denoted by T_{max}, and is calculated from the formula

$$T_{max} = \frac{\ln(\lambda_m/\lambda_r)}{\lambda_m - \lambda_r},$$

where λ_m is the biological decay constant for man, and λ_r is the radioactive decay constant for the radionuclide.

[b] Assumed 8-year maturation periods for pandanus, breadfruit, and coconut seedling trees.

[c] The period of time over which the dose rate is integrated is denoted by T.

[d] An empirical factor used to relate the maximum annual dose to an integrated dose for a longer period is denoted by K. The relation is given by

$$D_{T_{max}} = \frac{D_T}{K}.$$

The factor K is determined from equations given in NVO-140, pp. 537-38.

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TABLE 5-12: ESTIMATED NUMBER OF HEALTH EFFECTS[a] FROM 30-YEAR DOSES TO POPULATION OF 1,000

Habitation Plans / Cleanup Actions	A No restrictions on island or food usage	B Live on southern islands and Enjebi; visit northern islands; food from southern islands or Enjebi except coconut from 12 N.E. islands and pandanus and breadfruit from Enjebi farm plots or imported	C *plus* Live on southern islands; visit northern islands; food from southern islands ~~except~~ coconut from 12 N.E. islands	D Live on southern islands; visit on southern islands; use food grown on only southern islands
I. No cleanup.	H(WB) ≤ 0.3 to 1 H(B) ≤ 2 H(L) ≤ ~~0.1~~ *0.003* H(Total) ≃ 3	H(WB) ≤ 0.2 to 0.5 H(B) ≤ 0.3 H(L) ≤ 0.002 H(Total) ≃ 0.8	H(WB) ≤ 0.05 to 0.2 H(B) ≤ 0.1 H(L) ≤ 0.001 H(Total) ≃ 0.3	Case 2 Background[b]
II. Removal of all scrap and Pu concentrations greater than 40 pCi/g from residence and agriculture islands.	H(WB) ≤ 0.3 to 1 H(B) ≤ 2 H(L) ≃ Background[b] H(Total) ≃ 3	Case 4 H(WB) ≤ 0.2 to 0.5 H(B) ≃ 0.3 H(L) ≃ Background[b] H(Total) ≃ 0.~~9~~ *8*	Case 3 H(WB) ≃ 0.05 to 0.2 H(B) ≃ 0.1 H(L) ≃ Background[b] H(Total) ≃ 0.3	~~Background[b]~~ *Same as Case 2*
III. Total cleanup of residence and agriculture islands.	Case 5 Background[b]	Same as Case 5	Same as Case 5	Same as Case 5

LEGEND

H(WB) = Maximum Expected Whole Body Health Effects
H(B) = Maximum Expected Bone Health Effects
H(L) = Maximum Expected Lung Health Effects
H(Total) = Maximum Expected Total Health Effects

[a] Health effects mean somatic cancer inductions that result in fatality, calculated to one significant figure. The number of fatal and nonfatal cases is estimated to be twice the number of fatal cases. See Table 5-8 for dose response rates used to estimate health effects. *These effects would be in addition to those from background radiation*

[b] ~~Background effects for 30-year doses of~~ *(Health effects for 30-year background doses of)* WB = 1 rem, B = 4 rem and L = 0.0009 rem are: H(WB) ≃ 0.05 to 0.2, H(B) ≤ 0.1, H(L) ≤ 0.00002, H(Total) ≃ 0.3

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As indicated in Table 5-12, the total number of health effects per 1,000 people is the sum of health effects estimated for whole body, bone and lung doses. This total is the maximum estimated health effect* or risk. The actual risk may actually be zero or negligible when compared to effects resulting from natural or background exposure.

*As indicated in NCRP Report No. 43, Review of the Current State of Radiation Protection Philosophy, January 15, 1975, it is very unreasonable to interpret these upper limit estimates as actual risk. Because of the extreme conservatism in these estimates, they should be used only as general guidelines in any risk analysis.

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risk. The actual risk may actually be zero or negligible when compared to effects resulting from natural or background exposure.

Reviewing Table 5-12, it can be seen that several alternative programs result in health effects which are estimated to be no greater than those induced by naturally occurring background radiation. These programs, yielding the greatest reduction in radiological risk, also are either the most restrictive in terms of habitation plans or the most costly in terms of cleanup. For example, Case 2 restricts the Enewetak Atoll people to the southern islands with no agriculture or visitation on the northern islands and Case 5 places no restriction on residence, agriculture or visitation of the people but imposes enormous costs as is shown in later discussion.

Short of reducing radiological risk to background levels, it can be seen that Cases 3 and 4 offer compromises which increase the extent of Enewetak Atoll people's agricultural, residence and visitation activities without causing significant increases in risk. The Case 3 risk estimate indicates that, as a maximum, the number of health effects ~~would~~ [might] increase to twice the background level although the actual number of added health effects may be no greater than those observed in the background cases. For Case 4 the total number of health effects (Case 4 plus background) is estimated to be no more than about 4 times the background case. Again it should be noted that actual number of added health effects may be no greater than the background effects; however, as suggested by the Case 4 risk estimates, the Enewetak people will be exposed to ~~somewhat~~ [a] increased ~~population doses~~ [radiological risk] because of the Enjebi agricultural activities.

As shown in Table 5-12, the cleanup actions introduced when going from Row I to Row II do not significantly reduce the overall estimate of radiological risk for any given habitation plan. These added cleanup actions consist of radioactive scrap removal and ~~[illegible]~~ removal of plutonium concentrations ~~between 10 and 100 pCi/g of soil, as individual situations warrant~~ [in accordance with Pu cleanup guidelines]. Such cleanup results in negligible dose reduction since these actions mitigate the external and inhalation pathway doses which contribute only small fractions to the total dose. This result does not mean that cleanup actions defined by Row II should be omitted. They are desirable from the standpoint of eliminating the possibility of undue individual exposure and the accessibility ~~of~~ [to] radioactivity anywhere on the atoll.

In summary, the radiological risks displayed in Table 5-12 suggest that further consideration of alternative programs can be restricted to Cases 1 through 5. Case 1 represents the risk, clearly unacceptable, associated with unrestricted use of the atoll and no cleanup action and

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Case 5 represents the case of essentially complete removal of risk to allow unrestricted use. Cases 2, 3 and 4 represent compromises on use, cleanup and risk between Cases 1 and 5. These factors are summarized in Table 5-13 along with cost data to provide a basis for overall consideration of each case. The cost data are developed in Section 5.6.3. Reviewing Table 5-13, the best combination of features is found in Case 3. In this case cleanup is practically complete; the problems of contaminated pandanus and breadfruit are minimized; restriction on population movement is ~~reasonably~~ minimal, except for the restriction of no residences or agriculture on Enjebi; the 30-year doses are ~~[illegible]~~ low; ~~and~~ the maximum annual doses fall within AEC guidelines; and the increased radiological risk, expressed as health effects, is no more than equal to the ~~[illegible]~~ risk from background radiation.

5.6.3 Estimated Costs

The estimated costs for cleanup operations involved in Cases 1 through 5 are summarized in Table 5-~~17~~ 14. These estimates were based on the assumption that work would begin in late 1975 using estimated values of services and products applicable to 1976. These values were determined from contracts and recent historical purchasing data.

Base camp rehabilitation includes the cost of renovating the existing structures on Enewetak and any new construction connected with the establishment of the camp. Cleanup costs are those associated with the actual radiological and physical cleanup work on the individual islands. They include estimated travel times from the base camp to the work sites, as well as a contingency for time lost due to weather conditions. The technical support costs are those which are associated with planning, engineering, and estimating activities pertinent to the cleanup program. The costs included in logistical support are for air transportation, helicopter operation, barging and shipping, interisland marine operations, packing and crating of equipment and supplies, general services for Government agencies, operation of off-site offices in Oakland and Honolulu, and the hiring and processing of personnel. Maintenance and operations costs included all base camp operations associated with the program as well as procurement and maintenance of equipment.

To obtain a broader view of overall costs, twelve million for rehabilitation and resettlement should be added to the estimate of any of the five cases. This estimate is based on the tentative budget allocated by the Trust Territory of the Pacific Islands for this purpose. This estimate does not include provision for administrative or agricultural maintenance costs beyond the first 2 years of the operation.

TABLE 5-13

Missing

TABLE 5-18: SUMMARY OF ESTIMATED COSTS ($000)

Program Activity	Case 2	Case 3	Case 4	Case 5
Field Construction				
Base Camp Rehabilitation	4,405	4,488	4,488	4,488
Radiological Cleanup	0	3,384	7,768	14,121
*Physical Cleanup	1,502	2,089	2,085	6,343
Technical Support	97	97	97	97
Logistical Support	6,933	10,193	13,992	23,318
Maintenance and Operations Including Equipment	12,566	15,326	19,966	33,245
Total Program	25,503	35,577	48,396	81,612

The above estimated costs are based on the assumption that operations will begin late in 1975. Disposal costs are shown separately and are additive to these totals.

*Level 2 for Cases 2, 3, and 4; Level 3 for Case 5.

Estimates for the costs of disposal operations are summarized in Table 5-13. These estimates were based on considerations of material quantities, methods of preparation, and transportation distances. Assuming the work will be started in late 1975, these estimates reflect 1976 prices.

Major factors influencing the costs in the ocean dumping and Conus disposal options are material preparation and transportation distance. In the crater disposal option, the contaminated materials are left on Runit. Transportation requirements are minimal for this option and no particular preparation of materials is required. Material preparation is a major factor in the crater entombment option, although transportation requirements are minimal. The option calling for stockpiling of contaminated materials on Runit is a temporary measure, and ultimately involves the cost of one of the other options.

Material quantities vary strongly among the different cases for soil that is removed, but is constant among cases for radioactive scrap. Measured estimates of these quantities are tabulated as follows (Engineering Study, 1973):

Case	Contaminated Soil (cu yds)	Contaminated Scrap (cu yds)	Noncontaminated Scrap (cu yds)
1	-	-	-
2	-	-	58,000
3	79,000	7,262	73,000
4	318,000	7,262	80,000
5	779,000	7,262	126,000

A summary of the cleanup physical details and costs for each island is given in Table 5-15. The physical details include the acreage, the radioactivity levels, the plutonium concentrations, the columns of radioactive, nonradioactive, and cosmetic debris. Estimated costs are shown for debrushing, scraping, replacing soil, and removing radioactive and nonradioactive debris. Costs for disposal are not included; these are tabulated in Table 5-13.

TABLE 5-~~18~~ 15: DISPOSAL COSTS – RADIOACTIVE SOIL AND CONTAMINATED DEBRIS ~~($1000)~~

Method	Case 2	Case 3	Case 4	Case 5
Material Volume ~~x~~, 10^3 Cubic Yards	0	87.3	327.3	787.3
Material Disposal Cost, $1000				
Crater Dumping	0	320.0	19,425.0*	75,652.0*
Ocean Dumping	0	9,989.0*	43,281.0*	110,360.0*
Conus Disposal	0	18,910.0*	78,966.0*	197,342.0*
Crater Entombment	0	6,968.0	26,558.0	92,243.0

Check # of cu yds

*Includes additional support costs due to schedule extension required for completion of operation.

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TABLE 5-13 SUMMARY OF CASE STUDIES

Item	Case 1	Case 2	Case 3	Case 4	Case 5
Residence Islands	No Restrictions	South Only	South Only	South plus Enjebi	No Restrictions
Interisland Visitation	No Restrictions	South Only	No Restrictions *	No Restrictions	No Restrictions
Sources of Pandanus and Breadfruit	No Restrictions	South Only	South Only	South and farm plots on Enjebi	~~South Only~~ No Restrictions
Sources of Coconuts	No Restrictions	South Only	South and agriculture islands in north	South and Enjebi through Billae	~~South Only~~ No Restrictions
Physical Cleanup	None	~~Physical~~ hazardous and obstructive debris ~~categories of~~ nonradioactive scrap	~~Physical~~ hazardous and obstructive debris categories of nonradioactive scrap and all radioactive scrap	~~Physical~~ hazardous and obstructive debris categories of nonradioactive scrap ~~and~~ All radioactive scrap	~~Physical~~ hazardous, ~~and~~ obstructive, and unsightly ~~debris categories~~ ~~of~~ nonradioactive scrap ~~and~~ all radioactive scrap
Plutonium Cleanup	None	None	All concentrations ≥ 400 pCi/g and concentrations between 40 and 400 pCi/g as considerations warrant	All concentrations ≥ 400 pCi/g and concentrations between 40 and 400 pCi/g as considerations warrant	All concentrations ≥ 400 pCi/g and concentrations between 40 and 400 pCi/g as considerations warrant
Thirty Year Dose to Average Individual (rem)					
Whole Body	6	Background	1	3 (6 on Enjebi)	Background
Bone	60	Background	5	10 (20 on Enjebi)	Background
Lung	0.1	Background	Background	[redacted] Background	Background
Number of Fatalities from Thirty Year Dose to Population of 1000	[redacted] ≤ 3	[redacted] Background	[redacted] ≤ 0.3	0.02-0.04 ≤ 0.8	[redacted] Background
Maximum Annual Dose to Average Individual (rem)					
Whole Body	0.3	Background	0.05	0.1 (0.3 on Enjebi)	Background
Bone	2	Background	0.2	0.5 (1 on Enjebi)	Background
Lung	0.004	Background	[redacted] Background	[redacted] Background	Background
Ratio of Maximum Annual Dose to AEC Criteria					
Whole Body	1.2	≤ Background	0.2	0.4 (1.2 on Enjebi)	≤ Background
Bone	[redacted] 2.7	≤ Background	0.3	0.7 (1.3 on Enjebi)	≤ Background
[redacted]	[redacted]		[redacted]	[redacted]	
Cleanup Cost (Millions of Dollars)	- 0	[redacted]	[redacted]	[redacted]	[redacted]
Disposal Cost (Millions of Dollars)	- 0	[redacted]	[redacted]	[redacted]	[redacted]

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TABLE 5-16: CLEANUP REQUIREMENTS BY CASE AND ISLAND[(a)]

Present Condition		Cleanup Actions	Case 2 Qty.	Case 2 Cost ($000)	Case 3 Qty.	Case 3 Cost ($000)	Case 4 Qty.	Case 4 Cost ($000)	Case 5 Qty.	Case 5 Cost ($000)
Bokoluo/22 Acres		Debrush							41.[illegible] A	[illegible]0.2
B+Y	130 μR/hr[(1)]	Scrape							54,706 cy	323.9
Pu	68 pCi/g[(2)]	Replace Soil							54,706 cy	610.8
Debris, Radioactive	10 cy	Debris-Radioactive				2.5		2.5		2.5
Total Debris N.C.	426 cy	Debris-Physical				13.9		13.9		20.[illegible]
Debris-Cosmetic	147 cy	Total				16.4		16.4		1,127.9
Bokombako/30 Acres		Debrush							33.15 A	191.0
B+Y	260 μR/hr	Scrape							24,495 cy	142.1
Pu	130 pCi/g	Replace Soil							24,495 cy	277.9
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	6 cy	Debris-Physical				4.0		4.0		5.4
Debris-Cosmetic	3 cy	Total				4.0		4.0		616.4
Kirunu/7 Acres		Debrush							5.73 A	141.9
B+Y	66 μR/hr	Scrape							3,051 cy	19.1
Pu	88 pCi/g	Replace Soil							3,051 cy	38.4
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	112 cy	Debris-Physical				5.3		5.3		10.8
Debris-Cosmetic	100 cy	Total				5.3		5.3		210.2
Louj/21 Acres		Debrush								
B+Y	66 μR/hr	Scrape								
Pu	98 pCi/g	Replace Soil								
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	0	Debris-Physical								
Debris-Cosmetic	0	Total								
Bokinwotme		Debrush								
B+Y	16 μR/hr	Scrape								
Pu	24 pCi/g	Replace Soil								
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	0	Debris-Physical								
Debris-Cosmetic	0	Total								
Boken/Bokaidrikdrik/ 60 Acres		Debrush			1.21 A	68.2	1.21 A	68.2	1.21 A	68.2
B+Y	260 μR/hr	Scrape			6403 cy	39.9	6403 cy	39.9	6403 cy	39.9
Pu	280 pCi/G	Replace Soil			6403 cy	73.8	6403 cy	73.8	6403 cy	73.8
Debris, Radioactive	0	Debris-Radioactive				3.2		3.2		3.2
Total Debris N.C.	1,312 cy	Debris-Physical				52.7		52.7		52.7
Debris-Cosmetic	717 cy	Total				237.8		237.9		237.8
Enjebi/291 Acres		Debrush					250 A	548.4	250 A	548.4
B+Y	130 μR/hr	Scrape					239,112 cy	991.3	239,112 cy	991.3
Pu	170 pCi/g	Replace Soil					239,112 cy	2,825.2	239,112 cy	2,825.2
Debris, Radioactive	568 cy	Debris-Radioactive				53.6		71.1		72.5
Total Debris N.C.	9,884 cy	Debris-Physical				316.1		313.7		338.3
Debris-Cosmetic	2,821 cy	Total				369.7		4,749.7		4,775.7

(a) Case 1 is not listed as no cleanup would be performed and requirements and costs would be zero.

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TABLE 5-19 (continued)

Present Condition		Cleanup Actions	Case 2 Qty.	Case 2 Cost ($000)	Case 3 Qty.	Case 3 Cost ($000)	Case 4 Qty.	Case 4 Cost ($000)	Case 5 Qty.	Case 5 Cost ($000)
		Debrush								
Mijikadrek/16 Acres		Scrape								
B+Y	33 μR/hr									
Pu	50 pCi/g	Replace Soil								
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	1,049 cy	Debris-Physical				23.1		23.1		42.9
Debris-Cosmetic	691 cy	Total				23.1		23.1		42.9
		Debrush								
Kidrinen/20 Acres		Scrape								
B+Y	33 μR/hr									
Pu	22 pCi/g	Replace Soil								
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	61 cy	Debris-Physical				2.5		2.5		4.[illegible]
Debris-Cosmetic	57 cy	Total				2.5		2.5		4.[illegible]
		Debrush								
Bokenelab/12 Acres		Scrape								
B+Y	16 μR/hr									
Pu	35 pCi/g	Replace Soil								
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	272 cy	Debris-Physical				15.4		15.4		24.3
Debris-Cosmetic		Total				15.4		15.4		24.3
		Debrush								
Elle/11 Acres		Scrape								
B+Y	16 μR/hr									
Pu	28 pCi/g	Replace Soil								
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	0	Debris-Physical								
Debris-Cosmetic	0	Total								
		Debrush							28 A	123.5
Aej/41 Acres		Scrape							26,621 cy	158.1
B+Y	33 μR/hr									
Pu	30 pCi/g	Replace Soil							26,621 cy	303.3
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	1 cy	Debris-Physical								1.9
Debris-Cosmetic	1 cy	Total								591.8
		Debrush			1.1 A	3.2	1.1 A	3.2	50.75 A	91.6
Lujor/54 Acres		Scrape			600 cy	6.7	600 cy	6.7	41,135 cy	244.2
B+Y	260 μR/hr									
Pu	330 pCi/g	Replace Soil			600 cy	12.4	600 cy	12.4	41,135 cy	464.6
Debris, Radioactive	317 cy	Debris-Radioactive				20.8		20.8		20.8
Total Debris N.C.	29 cy	Debris-Physical				.4		.4		3.5
Debris-Cosmetic	27 cy	Total				43.5		43.5		824.7
		Debrush								
Eleleron/4 Acres		Scrape								
B+Y	33 μR/hr									
Pu	24 pCi/g	Replace Soil								
Debris, Radioactive	196 cy	Debris-Radioactive				12.1		12.1		33.1
Total Debris N.C.	0	Debris-Physical				.1		.1		.4
Debris-Cosmetic	0	Total				12.2		12.2		33.5

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TABLE 5-19 (continued)

Present Condition		Cleanup Actions	Case 2 Qty.	Case 2 Cost ($000)	Case 3 Qty.	Case 3 Cost ($000)	Case 4 Qty.	Case 4 Cost ($000)	Case 5 Qty.	Case 5 Cost ($000)
Aomon/99 Acres		Debrush			7.6 A	5.7	[illegible] A	5.7	[illegible] A	[illegible]
B+Y	33 μR/hr	Scrape			6800 cy	45.3	6800 cy	45.3	72,140 cy	435.5
Pu	130 pCi/g	Replace Soil*			140,200 cy	1,617.3	140,200 cy	1,617.4	204,140 cy	2,316.0
Debris, Radioactive	2106 cy	Debris-Radioactive				95.6		95.6		95.6
Total Debris N.C.	1054 cy	Debris-Physical				7.3		7.3		40.4
Debris-Cosmetic	954 cy	Total				1,771.3		1,771.3		2,923.4
Bijire/52 Acres		Debrush							34 A	61.4
B+Y	16 μR/hr	Scrape							31,461 cy	187.4
Pu	34 pCi/g	Replace Soil							31,461 cy	355.2
Debris, Radioactive	45 cy	Debris-Radioactive								
Total Debris N.C.	200 cy	Debris-Physical				13.4		13.4		29.9
Debris-Cosmetic	196 cy	Total				13.4		13.4		633.8
Lojwa/40 Acres		Debrush							25 A	45.3
B+Y	8 μR/hr	Scrape							24,201 cy	144.1
Pu	7.3 pCi/g	Replace Soil							24,201 cy	275.4
Debris, Radioactive	4 cy	Debris-Radioactive								
Total Debris N.C.	170 cy	Debris-Physical				2.5		2.5		21.2
Debris-Cosmetic	156 cy	Total				2.5		2.5		486.0
Alembel/38 Acres		Debrush							23 A	41.[illegible]
B+Y	8 μR/hr	Scrape							22,587 cy	135.2
Pu	25 pCi/g	Replace Soil							22,587 cy	256.0
Debris, Radioactive	0	Debris-Radioactive								
Total Debris N.C.	25 cy	Debris-Physical								5.4
Debris-Cosmetic	18 cy	Total								438.1
Runit/94 Acres		Debrush			57 A	95.6	57 A	95.6	61 A	[illegible]
B+Y	520 μR/hr	Scrape			63,725 cy	40.3	63,725 cy	40.3	100,832 cy	60.3
Pu	840 pCi/g	Replace Soil			63,725 cy	714.0	63,725 cy	714.0	100,832 cy	1,130.3
Debris, Radioactive	4,064 cy	Debris-Radioactive				473.1		473.2		457.4
Total Debris N.C.	6,155 cy	Debris-Physical				107.2		107.2		965.4
Debris-Cosmetic	3,748 cy	Total				1,430.2		1,430.2		2,715.5
		Subtotal				[illegible]		[illegible]		[illegible]

(1) Gross count exposure rate, typical all Islands (EG&G Aerial Survey, 1972).

(2) pCi/g in top 15 cm of soil, except Runit where high concentration is at a greater depth (Enewetak Radiological Survey, NVO-140, October 1973).

*Cost includes 132,000 cy of fill for PACE excavation.

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TABLE 5-19 (continued)

Present Condition		Cleanup Actions	Case 2 Qty.	Case 2 Cost ($000)	Case 3 Qty.	Case 3 Cost ($000)	Case 4 Qty.	Case 4 Cost ($000)	Case 5 Qty.	Case 5 Cost ($000)
Talwel/5 Acres B+Y Pu	 5 µR/hr 23 pCi/g	Debris-Physical				1.3		1.3		1.3
		Total				1.3		1.3		1.3
Billae/16 Acres B+Y Pu	 4 µR/hr 5.3 pCi/g	Debris-Physical				10.3		10.3		18.3
		Total				10.3		10.3		18.3
Inedral/4 Acres B+Y Pu	 1.5 µR/hr 1.1 pCi/g	Debris-Physical				0.4		0.4		1.3
		Total				0.4		0.4		1.3
Van/7 Acres B+Y Pu	 1.5 µR/hr 1.1 pCi/g	Debris-Physical								1.3
		Total								1.3
Ananij/25 Acres B+Y Pu	 2 µR/hr 1.1 pCi/g	Debris-Physical		11.9		11.9		11.9		17.7
		Total		11.9		11.9		11.9		17.7
Japtan/79 Acres B+Y Pu	 1.5 µR/hr .31 pCi/g	Debris-Physical		28.9		28.9		28.9		1,266.6
		Total		28.9		28.9		28.9		1,266.6
Jedrol/5 Acres B+Y Pu	 1.5 µR/hr 1.1 pCi/g	Debris-Physical		3.2		3.2		3.2		8.0
		Total		3.2		3.2		3.2		8.0
Medren/220 Acres B+Y Pu	 8 µR/hr .31 pCi/g	Debris-Physical		1,138.2		1,136.2		1,138.2		2,169.2
		Total		1,138.2		1,138.2		1,138.2		2,169.2
Bokandretok/2 Acres B+Y Pu	 3 µR/hr 1.1 pCi/g	Debris-Physical		1.5		1.5		1.5		3.8
		Total		1.5		1.5		1.5		3.8
Enewetak/322 Acres B+Y Pu	 4 µR/hr .31 pCi/g	Debris-Physical		249.7		249.7		249.7		1,015.3
		Total		249.7		249.7		249.7		1,015.3
Ikuren/41 Acres B+Y Pu	 2 µR/hr 1.1 pCi/g	Debris-Physical		28.5		28.5		28.5		138.5
		Total		28.5		28.5		28.5		138.5
Mut/40 Acres B+Y Pu	 2 µR/hr 1.1 pCi/g	Debris-Physical		14.6		14.6		14.6		28.6
		Total		14.6		14.6		14.6		28.6
Boken/29 Acres B+Y Pu	 1.5 µR/hr 1.1 pCi/g	Debris-Physical		3.2		3.2		3.2		28.6
		Total		3.2		3.2		3.2		28.6
Rigewon/19 Acres B+Y Pu	 2 µR/hr 1.1 pCi/g	Debris-Physical		11.6		11.6		11.6		43.0
		Total		11.6		11.6		11.6		43.0
Kidrenen/19 Acres B+Y Pu	 2 µR/hr 1.1 pCi/g	Debris-Physical		10.7		10.7		10.7		19.6
		Total		10.7		10.7		10.7		19.6
Biken/14 Acres B+Y Pu	 8 µR/hr 2 pCi/g	Debris-Physical				11.7		11.7		14.3
		Total				11.7		11.7		14.3
Western Reef		Debris-Physical								1.6
		Total								1.6
		~~Subtotal~~		~~1,502.0~~		[illegible]		[illegible]		[illegible]
		Total		1,502.0		5,473.0		9,853.0		20,464.0

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5.7 SUMMARY OF AEC TASK GROUP RECOMMENDATIONS

INTRODUCTION

The Atomic Energy Commission agreed to provide radiological criteria for cleanup and rehabilitation of Enewetak Atoll to the Department of Defense (DOD) and to the Department of the Interior (DOI). A comprehensive survey of the radiological environment of Enewetak was made to serve as a basis for judgement and recommendations. The survey data show that the northern islands have the greater amount of radioactive contamination and there are plutonium problems.

The Director, Division of Operational Safety, appointed a Task Group and through it staff liaison representatives of DNA, DOI and EPA were kept informed of progress toward completion of recommendations. Current radiation protection guidance containing numerical standards and radiation protection philosophy of national and international standards bodies was used to develop recommended criteria:

- Population dose to the Enewetak people should be as low as practicable.
- The Federal Radiation Council (FRC) Radiation Protection Guides (RPG) for individual and gonadal exposures will be used to evaluate exposure options. The values should be reduced by 50 percent for individual exposure and 20 percent for gonadal exposure to allow for uncertainties in dose predictions. The guides for cleanup planning become:

	Exposure
Whole body and bone marrow	0.25 Rem/yr
Thyroid	0.75 Rem/yr
Bone	0.75 Rem/yr
Gonads	4 Rem in 30 yr

Cleanup of soil containing Pu can be handled on a case-by-case basis using the following:

a. <40 pCi/gm of soil - corrective action not required.

b. 40 to 400 pCi/gm of soil - corrective action determined on a case-by-case basis considering all radiological conditions.

c. >400 pCi/gm of soil - corrective action required.

DOSE ASSESSMENT AND CORRECTIVE ACTION ALTERNATIVES

For comparison with population dose guidelines, evaluations were made for the following conditions:

- Dose without cleanup.
- Dose reductions obtained by diet modification.
- Dose reductions achieved by removal of contaminated soil.

In addition, estimates were made for representative living patterns plus corrective actions:

- Plow the village island, and gravel the village area for radiation shielding.
- Import pandanus and breadfruit from the southern islands (ALVIN-KEITH) for inhabitants of the northern islands to control ingestion of radionuclides.
- Import pandanus, breadfruit, coconut and tacca from the southern islands.
- Import pandanus, breadfruit, coconut, tacca, and domestic meat from the southern islands.

DISPOSAL OF CONTAMINATED MATERIAL

Contaminated material is composed of soil, debris and scrap. At some places there is Pu including pieces of Pu metal. Contamination is distributed on and below the surface; some is in rad waste burial sites.

Fission products and induced radioactivity found on such scrap and debris, particularly scrap metal, should be made unavailable to the returning people. Possible approaches are:

1. Disposal in water-filled and underwater craters.

2. Land burial where the radiation level of the scrap is not significantly above that on land.

3. Disposal in deep water.

Pu excepted, the Task Group has not made recommendations for removal of contaminated soil. For any disposal there should be no pathway to people; periodic followup surveys are necessary. Disposal of Pu in any form is a greater problem, and disposal must protect against exposure for the future.

OBSERVATIONS AND CONCLUSIONS

The consensus of the Task group reflects consideration of a range of options and the benefits of reviews and comments.

Choice of the method which will optimize reduction of exposures is a matter of judgement. Action such as use of imported foods could be effective but is not recommended. Although engineering actions, e.g., soil removal and replacements may appear to be preferable to restricting use of land for living and agriculture, these actions can otherwise adversely affect the environment and for some the effectiveness is uncertain. The extent of compliance by the people with restrictions has been considered, and an acceptable level of cooperation is expected so that they may use land where the radiation environment is or can be made acceptable.

Return of people to live on the southern islands, ALVIN through KEITH, is expected to result in radiation doses within the recommended criteria. JANET (Enjebi), which the people desire for a residence island is a special case of the category of islands having radiation and radioactivity levels which preclude living and agriculture. Steps to make this island completely or partially available in the near term are important from the social as well as scientific viewpoint. Predicted radiation doses associated with the Task Groups recommendation are given in the following table. The Bikini Atoll estimates and natural background estimates of typical levels in the U.S. are given for comparison.

RECOMMENDATIONS

The Task Group reached the following conclusions:

1. Observing precautions, the people may safely return after certain actions are taken. Exposures will be somewhat above current levels in the U.S., but the small risk seems permissible in relation to the desire of the people to return.

2. To assure exposures that will be as low as practicable:

   a. Villages and residences to be located on ELMER, FRED, DAVID, or other southern islands (ALVIN-KEITH).

   b. Travel and visits may be unrestricted to all islands except YVONNE. When Pu contamination on YVONNE is removed, the restriction of travel to that island may be lifted.

   c. Coconut excepted, growth of animal and vegetable subsistence crops to be limited to southern islands ALVIN-KEITH.

   d. Subsistence and commercial coconut may be grown without remedial measures except on ALICE, BELLE, CLARA, DAISY, IRENE, JANET, and YVONNE.

   e. Fishing permitted anywhere.

   f. Wild birds and eggs may be collected anywhere.

   g. Coconut crabs may be collected only on the southern islands (ALVIN-KEITH).

   h. Wells to provide lens water for human consumption or for agricultural use to be drilled only on the southern islands (ALVIN-KEITH). Water from any well to be assayed for bacterial, salinity, and radioactivity content before approved for use.

3. Enjebi (JANET) is a special case, and the people have a strong desire to live there. Three ground zeroes were on Enjebi and high yield events were fired nearby, with the result that this was the most heavily contaminated of the larger islands. The Task Group has been unable to determine a reliable, feasible way to bring exposures within the acceptable criteria and permit resettlement of Enjebi on the same schedule as southern islands. The island can be resettled sometime in the future when

radionuclide ingestion is no longer a problem. To develop the facts, test plantings with and without soil removal may be made. Construction and agriculture would be deferred until produce from test plantings showed acceptably low levels of radioactivity. Test plantings without soil removal would have least adverse impact on the island environment.

4. Concurrent with the Enjebi work, radioactivity levels should be measured in coconut and other food crops grown on PEARL, CLARA, ALICE, and BELLE. Produce from YVONNE should be included after removal of plutonium contamination.

5. All radioactive scrap metal and contaminated debris now or later identified should be removed. This includes three locations on SALLY and one on ELMER where buried contaminated debris should be exhumed and removed.

6. YVONNE, quarantined by the USAF in 1972, should remain quarantined until plutonium contamination on that island has been cleaned up. An authority responsible for enforcement of the quarantine should be identified and in residence in the atoll if people return to the atoll before cleanup is completed.

7. Only general recommendations for cleanup of Pu on YVONNE can be presented at this time. An accurate picture of this contamination should develop as the decontamination proceeds. The area observed to have small pieces of plutonium and the highest soil concentrations is about 30% of the island. A background for plans for the recovery of Pu will require:

   a. Assembly of a team of experts to interpret field radiation and radioactivity measurements, advise on cleanup actions and provide necessary health physics support. A Public Health Service group, now part of EPA, provided radiological assistance for cleanup of Bikini Atoll. Similar support should be sought from EPA for Enewetak.

   b. Decontamination of YVONNE is seen as an iterative process. This amounts to a search for and removal of the higher plutonium levels in soil.

   c. The objectives of the cleanup are two:

      (1) Recovery of the pieces of plutonium that have been observed on or near the island surface.

      (2) Recovery of plutonium contaminated soil.

d. Recovery of plutonium in soil at concentrations greater than 400 pCi/g $^{239, 240}Pu$ at any depth these levels are found. Also, recovery of contaminated soil sufficient to reduce surface levels to a value well below 40 pCi/g $^{239, 240}Pu$. After soil removal, all areas should be resurveyed to ensure no pieces or hot spots of plutonium remain.

8. Plutonium contaminated soil on IRENE should be handled as on YVONNE. Pieces of Pu metal are not expected to be found.

9. Test plantings of food crops may be conducted on each of the "no crops" islands as designated by the Enewetak people. As edible parts of these plants become available, concentrations of significant radionuclides should be measured and compared with the radiological survey predictions. These studies will indicate times at which planting of subsistence and commercial crops can be safely resumed.

10. Lens water sampling and analysis should be conducted, samples to be taken over a period of at least 12 calendar months. Bacterial content, salinity, and radionuclide content should be measured. Radioactivity information will contribute to an understanding of processes operating - or which can be made to operate - to reduce the ecological half-life of ^{90}Sr and ^{137}Cs below the radioactive half-life on the northern islands, especially JANET.

11. A comprehensive air sampling program should be conducted over a period of 12 consecutive months under conditions closely approximating human habitation and expected soil disturbance to provide information on radioactivity levels in air. This program could be conducted coincident with and support cleanup.

12. Base-line surveys of body burdens and urine content of ^{137}Cs and ^{90}Sr should be made for the Enewetak people prior to return to Enewetak Atoll, and periodically thereafter. Resurveys of the environmental radiation and radioactivity should be made in the first year of return and repeated, for example, every other year.

13. Methods of disposal of plutonium contaminated soil and scrap will have to be decided. Pending a decision, it is recommended that cleanup should accomplish the recovery of plutonium contaminated soil and scrap with storage on YVONNE. If disposal is deferred for further study, such study should be initiated promptly.

14. The cleanup, with particular attention to removal and disposal of contaminated scrap, debris, and soil, should be documented in detail in a final report by those responsible in the field.

15. Advantage would be taken of experience gained during cleanup of Bikini Atoll. No objection should be made to employment of Enewetak people during cleanup.