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TECHNICAL REPORT

Expedited Processing of Radiation Dose Assessments for Military Personnel of the Enewetak Atoll Cleanup Project (1977–1980)

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Prepared by:

Leidos, Inc.

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14. ABSTRACT

This report serves as the technical basis document for performing expedited processing of radiation dose assessments (RDAs) for veterans who participated in the Enewetak Atoll Cleanup Project (ECUP) from 1977 to 1980. Approximately 6,000 Military Service members of the United States Department of Defense participated in the cleanup project. Expedited processing would result in the assignment of upper-bound, group-based radiation doses to ECUP veterans without the need for performing individualized RDAs. To create an expedited processing system for ECUP, Expedited Processing Groups (EPGs) are identified, and maximized upper-bound doses are estimated for each group. Eighty-five percent of the estimated EPG organ, skin, and lens of the eye doses meet the suitability criteria for dose assignment by expedited processing. Cases that do not satisfy the criteria for expedited processing are submitted for additional review by an RDA analyst.

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UNIT CONVERSION TABLE

U.S. customary units to and from international units of measurement*

U.S. Customary Units	Multiply by → / Divide by† ←		International Units
Length/Area/Volume			
inch (in)	2.54	$\times 10^{-2}$	meter (m)
foot (ft)	3.048	$\times 10^{-1}$	meter (m)
yard (yd)	9.144	$\times 10^{-1}$	meter (m)
mile (mi, international)	1.609 344	$\times 10^{3}$	meter (m)
mile (nmi, nautical, U.S.)	1.852	$\times 10^{3}$	meter (m)
barn (b)	1	$\times 10^{-28}$	square meter (m^2)
gallon (gal, U.S. liquid)	3.785 412	$\times 10^{-3}$	cubic meter (m^3)
cubic foot (ft^3)	2.831 685	$\times 10^{-2}$	cubic meter (m^3)
Mass/Density			
pound (lb)	4.535 924	$\times 10^{-1}$	kilogram (kg)
unified atomic mass unit (amu)	1.660 539	$\times 10^{-27}$	kilogram (kg)
pound-mass per cubic foot (lb ft^{-3})	1.601 846	$\times 10^{1}$	kilogram per cubic meter (kg m^{-3})
pound-force (lbf avoirdupois)	4.448 222		newton (N)
Energy/Work/Power			
electron volt (eV)	1.602 177	$\times 10^{-19}$	joule (J)
erg	1	$\times 10^{-7}$	joule (J)
kiloton (kt) (TNT equivalent)	4.184	$\times 10^{12}$	joule (J)
British thermal unit (Btu) (thermochemical)	1.054 350	$\times 10^{3}$	joule (J)
foot-pound-force (ft lbf)	1.355 818		joule (J)
calorie (cal) (thermochemical)	4.184		joule (J)
Pressure			
atmosphere (atm)	1.013 250	$\times 10^{5}$	pascal (Pa)
pound force per square inch (psi)	6.984 757	$\times 10^{3}$	pascal (Pa)
Temperature			
degree Fahrenheit (°F)	[T(°F) − 32]/1.8		degree Celsius (°C)
degree Fahrenheit (°F)	[T(°F) + 459.67]/1.8		kelvin (K)
Radiation			
curie (Ci) [activity of radionuclides]	3.7	$\times 10^{10}$	per second (s^{-1}) [becquerel (Bq)]
roentgen (R) [air exposure]	2.579 760	$\times 10^{-4}$	coulomb per kilogram (C kg^{-1})
rad [absorbed dose]	1	$\times 10^{-2}$	joule per kilogram (J kg^{-1}) [gray (Gy)]
rem [equivalent and effective dose]	1	$\times 10^{-2}$	joule per kilogram (J kg^{-1}) [sievert (Sv)]

*Specific details regarding the implementation of SI units may be viewed at http://www.bipm.org/en/si/.

†Multiply the U.S. customary unit by the factor to get the international unit. Divide the international unit by the factor to get the U.S. customary unit.

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Executive Summary

Expedited processing of radiation dose assessments (RDAs) by the Nuclear Test Personnel Review (NTPR) program is an option used by the Defense Threat Reduction Agency (DTRA) to assign doses in response to requests for dose information from the Department of Veterans Affairs (VA). The procedure was recommended by the Veterans' Advisory Board on Dose Reconstruction (VBDR) to allow for the timely processing of a veteran's claim while ensuring that the assigned doses are greater than the doses the veteran actually accrued during the performance of their duties. Procedures for expedited processing of claims for veterans potentially exposed during atmospheric nuclear tests have been used by DTRA since 2007. Expedited processing procedures were expanded in 2015 to include veterans who were World War II Prisoners of War (POW) in Japan and those veterans who participated in post-war occupation forces near Hiroshima and Nagasaki, Japan.

This technical report was prepared to further extend NTPR's expedited processing methodology to include veterans who participated in the Enewetak Atoll Cleanup Project (ECUP). The ECUP was conducted from 1977 to 1980 and involved the cleanup of radiological contamination remaining on Enewetak Atoll following the end of U.S. atmospheric nuclear testing. This report documents the technical basis for the estimation of radiation doses suitable for assignment using expedited processing of ECUP veteran RDAs by DTRA. Following approval and publication of this report, the implementation of expedited processing of ECUP RDAs will be documented in a DTRA standard operating procedure.

As in current DTRA expedited processing implementations, expedited processing of ECUP veteran RDAs involves the identification of coherent Expedited Processing Groups (EPGs) to include most of the approximately 6,000 Department of Defense (DoD) ECUP participants. To accomplish this requirement, four proposed EPGs were identified for individuals who share common aspects of radiation exposure scenarios and who can be grouped for purposes of upper-bound radiation dose assignments. The four ECUP EPGs are as follows:

- Soil Removal Workers: personnel who handled soil removed from one of the five northern islands that were identified for cleanup of transuranic (TRU) contamination by soil removal
- Northern Island Workers: personnel who worked on northern islands of the atoll other than the five soil-removal islands and were not support personnel who worked exclusively on Lojwa Island
- Lojwa Island Support Workers: personnel whose duties were on Lojwa Island and provided support services to the cleanup operations on the northern islands
- Southern Island Workers: personnel whose duties were primarily limited to the southern islands of the atoll.

Radiation dose estimates for the ECUP EPGs were developed in a manner similar to that used for EPGs previously developed by the NTPR program. The organ and skin doses estimated for each ECUP EPG and the bounding dose to the lens of the eye are based on high-sided and

maximizing parameter values and assumptions. These assumptions are designed to produce EPG doses that are higher than any upper-bound doses calculated in an individualized full RDA by detailed dose assessment for any member of the respective EPG. Consequently, the EPG doses estimated in this report are suitable for assignment in the expedited processing of RDAs for ECUP participants who can be included in one of the proposed EPGs, except in excluded cases as specified below.

To be suitable for assignment to a veteran, the EPG total organ, skin, or lens of the eye dose must not only bound a veteran's actual total dose but also must be well below the dose that would result in a service-connection determination. To assess whether EPG doses are well below this level, limiting doses (LDs) were estimated for all organ cancers/diseases and three skin cancer types. The LD value is the radiation dose that results in a probability of causation of 40 percent for an organ, tissue, or skin cancer. It was determined that the majority of the recommended ECUP EPG doses estimated for 24 internal organs and 17 skin sites for each EPG are less than the applicable LD and are therefore suitable for assignment by expedited processing.

For cases where the EPG total organ dose is higher than the applicable LD, expedited processing is not initially recommended and veteran doses should be estimated by alternate methods that may include a detailed RDA analysis. Such exceptions include EPG total organ doses for two out of 96 (about 2 percent) EPG/organ combinations and EPG total skin doses for 74 out of 408 (less than 20 percent) EPG/cancer/race category/skin site combinations that exceed their respective LDs. Veteran cases involving these combinations should be subjected to further detailed evaluation to determine suitability of expedited processing. The estimated upper-bound dose to the lens of the eye applicable to all EPGs is much lower than the minimum dose judged to induce posterior subcapsular cataracts and is therefore suitable for assignment in all ECUP EPG cases. Finally, claims involving cancers or diseases that do not have associated limiting doses identified in this report are not recommended for expedited processing unless appropriate surrogate organs and limiting doses are identified.

Additionally, exclusions from using expedited processing may be necessary when a veteran's scenario of participation and radiation exposure cannot be categorized to fit any of the characteristics described for the four ECUP EPGs. Unusual participation and exposure scenarios may involve sources of radiation or pathways that are not accounted for within dose components of one of the four ECUP EPGs. Unusual situations may involve veterans remaining aboard ships anchored in the lagoon or individuals who participated in the removal and disposal of a small number of bags containing plutonium fragments. Other examples are personnel who had radiological lab duties or contaminated laundry duties. All excluded cases require a more detailed case review and dose assessment.

1.

Introduction

This report serves as the technical basis document for use by the Defense Threat Reduction Agency (DTRA) in performing expedited processing of radiation dose assessments (RDAs) for veterans who participated in the Enewetak Atoll Cleanup Project (ECUP) from 1977 to 1980. Approximately 6,000 military service members of the United States Department of Defense (DoD) participated in the cleanup project. The DoD established a Joint Task Group (JTG) within the Defense Nuclear Agency (DNA) to conduct the cleanup project as authorized by Congress in Public Law 95-134 (Congress, 1977).

Enewetak Atoll was one of the primary locations in the Pacific Ocean where the United States conducted atmospheric tests of nuclear devices from the mid-1940s to 1962 (DNA, 1981). Radioactive contamination from atmospheric nuclear testing remained at Enewetak Atoll after testing ended. During the early 1970s, original inhabitants of the atoll, who had been relocated prior to the start of testing, expressed interest in returning to their homeland as they were promised. This created an urgent need to proceed to clean up contamination from the atoll.

The JTG performed the cleanup using 6,000 personnel mostly from the U.S. Military Services with an additional small number of individuals from Field Command Defense Nuclear Agency (FCDNA). The JTG was assisted by contractors, the United States Atomic Energy Commission (AEC) and other agencies (DNA, 1981). Major cleanup activities included:

- Clearance of vegetation and removal of contaminated soil and debris
- Transportation of contaminated soil and debris to disposal sites at the lagoon or Cactus crater on Runit Island
- Demolition and removal of uncontaminated buildings and debris
- Recovery and disposal of unexploded ordnance by explosive ordnance disposal teams
- Preparation of the atoll for resettlement.

1.1 Background

Since 2017, 16 ECUP VA requests for dose assessments have been fulfilled by DTRA. The dose estimations were completed based on early development of a methodology later published in DTRA (2018). Most of the veterans in these requests were involved in work on the residence islands of Enewetak[1] and Lojwa with occasional visits to northern islands with controlled access. Other veterans dealt with hauling contaminated soil and debris, repairing transport boats, performing radiological surveys in periods before and during cleanup operations, and Cactus dome construction. None of the total organ doses[2] reported for these 15 veterans

[1] This report uses traditional island names; a cross-reference between island and site names is given in Table 4.
[2] "Total organ dose" as used in this report means the sum of external and internal committed equivalent doses from all applicable exposure pathways.

exceeded 1 rem and most of them had upper-bound total organ doses in the 0.01 to 0.1 rem range. These doses are an order of magnitude or more below the U.S. federal occupational dose limits for radiation workers adopted by the ECUP (DNA, 1981).

In addition, the NTPR program developed standard operating procedure SOP RA06 (DTRA, 2021) to be used to prepare detailed RDAs for dose requests submitted by the Department of Veterans Affairs (VA) for ECUP veterans. The RDAs were based on participation scenarios found in the ECUP RDA technical report (DTRA, 2020) combined with statements in veteran-submitted questionnaires. In 2021, based on experience performing detailed RDAs, NTPR program analysts recommended that dose assessments for qualifying ECUP veteran claims could be expedited by assigning pre-estimated, group-based, upper-bound doses. As in other NTPR program components, the use of expedited processing procedures allows for timely processing of claims while ensuring that an individual veteran's assigned doses are greater than his actual doses.

Furthermore, since 2008, the NTPR program has used an approved procedure to expedite the processing of RDAs for dose requests submitted by the VA for atmospheric nuclear weapons testing veterans with qualifying participant exposure scenarios. Dose assessments for qualifying claims from such veterans may be expedited using NTPR procedure SOP RA02 (DTRA, 2021) by assigning pre-determined, group-based, upper-bound dose estimates to veteran claimants. In 2015, an approved procedure, SOP RA05 (DTRA, 2021), was implemented to help expedite dose assessments for post-war occupation of Hiroshima and Nagasaki veterans. The use of expedited processing procedures allowed for timely processing of large numbers of claims while ensuring that an individual veteran's assigned dose is greater than his actual dose.

1.2 Purpose of ECUP Expedited Processing

The expedited processing of RDAs is based on specific criteria provided in this technical report. The implementation of expedited processing of RDAs will be documented in a standard operating procedure (SOP RA07) to be developed after the completion of this technical report. The SOP will include detailed instructions and criteria for expedited processing of dose assessments for ECUP veterans. Expedited processing would result in the assignment of upper-bound, group-based radiation doses to ECUP veterans without the need for individualized RDAs. To create an expedited processing system for ECUP, Expedited Processing Groups (EPGs) are identified, and maximized upper-bound doses[3] are estimated for each group.

1.3 Scope of ECUP Expedited Processing

Claimant cases for ECUP veterans are initially evaluated for eligibility for expedited processing and processed according to a detailed methodology described in the SOP to be developed for ECUP veterans. The doses assigned under expedited processing would be significantly lower than the threshold for a disease to have been as likely as not caused by radiation exposure and result in service connection for a claim. Cases that do not pass the eligibility criteria for expedited processing would require further technical review of the veteran-specific dose estimates or may necessitate preparing an individualized RDA performed in

[3] A "maximized upper-bound dose" represents an estimated dose that is higher than a 95 percent upper confidence limit dose for an exposure scenario in which parameter values are selected to maximize external and internal doses.

accordance with SOP RA06 (DTRA, 2021). The methodology and dose estimates presented in this report apply to cases involving diseases covered under Title 38, Code of Federal Regulations, Part 3.311, *Claims based on exposure to ionizing radiation* (38 CFR 3.311).

1.4 Rationale for Developing an Expedited Processing Approach for ECUP RDAs

The benefits of creating and implementing expedited processing for ECUP participants' dose assessments include the following:

- De-emphasized focus of research on detailed participant activities which, if accounted for, does not yield doses high enough for service connection for claimed diseases
- Reduced processing costs for RDAs because most RDAs involve assignment of upper-bound doses based on veterans participating in broadly defined occupation/work groups versus individualized detailed activities and exposure scenario assessments
- More timely response to VA requests and more timely decision-making for veterans' claims than if veteran-specific, full RDAs were performed
- Options for conducting more detailed technical review and possibly an individualized RDA for ECUP cases that do not qualify for expedited processing under the exclusions specified in this report and related procedure.

2.

Methodology for the Development of an Expedited Processing Approach for ECUP Participants

The general approach for EPG dose assessments was established previously by the process used to develop EPG scenarios and doses for atmospheric testing veterans and veterans of Hiroshima and Nagasaki (Case et al., 2011; McKenzie-Carter and Egbert, 2015). In this approach, maximized upper-bound doses are estimated for each EPG using dose-maximizing exposure scenarios that are applicable to large groups of participants. Dose-maximizing exposure scenarios, parameter values, and assumptions represent exposure conditions such as exposure duration and radiation source characterization that are well above what typical ECUP personnel experienced. This approach is intended to result in estimated maximized upper-bound doses that exceed the 95th percentile of any dose distribution actually received by ECUP participants.

For ECUP expedited processing, EPGs are formed based on the types and locations of activities, related sources of exposure, and exposure pathways. For the ECUP EPGs, specific cohorts, units, or teams cannot be distinctly defined. This is in contrast with previous expedited processing assessments where each EPG was identified to include specific cohorts, such as crewmembers aboard specific ships in a test series or troops that participated in observing test detonations and maneuvering in forward test areas.

2.1 Expedited Processing Concept

In the NTPR program, DTRA developed an expedited processing system for atmospheric testing veterans by which most veteran dose assessments are handled. In that system, doses are assigned for a veteran claim from pre-calculated doses that apply to various EPGs. Each EPG is defined by the cohorts or units that make it up so that any claimant can be uniquely placed in his applicable EPG. In most cases, the doses estimated for the applicable EPG are assigned to the veteran.

Participants in ECUP did not perform activities that allows for defining EPGs based on specific cohorts or units. However, an expedited processing concept can be created that relies on a broad definition of the types of participant's activities and their locations, sources of radiation, and exposure pathways. Using this concept, four ECUP EPGs are identified, and their characteristics are defined in a distinct manner as discussed in Section 3.

To ensure that doses assigned to a veteran through expedited processing are higher than the veteran's actual doses, EPG doses must satisfy the following major conditions:

- The EPG doses are upper bounds of dose-maximizing exposure scenarios with respect to dose input parameter values and assumptions, not all of which the veteran may have actually encountered.
- The EPG doses are broadly applicable to large groups of veterans rather than doses estimated for individualized RDAs.

- The dose-maximizing assumptions are designed to produce maximized upper-bound doses that are higher than 95th percentile doses that would be estimated in individualized ECUP RDAs for any member of an EPG.
- The EPG doses, although not necessarily the absolute maximum possible, are high enough to ensure that the assigned doses exceed a veteran's true upper-bound (95th percentile) dose.

With these criteria, individual veteran claimants whose doses are assigned by expedited processing can be assured that the assigned doses are higher than their actual doses including all known uncertainties. In addition, if more than one EPG applies to a veteran, the one that results in higher assigned doses should be selected. This approach should always prevail in expedited processing to provide the utmost benefit to a veteran.

2.2 Confidence in Assigned EPG Doses

As discussed above, when using expedited processing for assigning doses to individual veterans, the process must clearly show that the assigned doses are greater than the actual doses that any member of the group could have received. Achieving this goal requires the use of many dose-estimating factors that reflect worst-case scenarios, such as the veteran's specific activities that could have resulted in exposure to radiation, the characteristics of the radiation environment, and the uncertainties in the parameters used in the EPG dose calculations.

The doses produced for expedited processing are adequate for submission to VA when they are maximized and are well below the doses that result in a probability of causation (PC) for a specific cancer of 50 percent, called screening doses. As has been done in previous DTRA expedited processing assessments developed for other veteran populations, it is recommended that ECUP EPG total organ doses correspond to an estimated probability of causation that is no higher than 40 percent. This recommendation is intended to provide an additional margin of confidence and to ensure suitability of the doses for use in ECUP expedited processing. Doses corresponding to a 40 percent probability of causation are referred to as Limiting Doses (LD); these doses are discussed further in Section 2.6.1. (DTRA, 2021, SOP RA02; McKenzie-Carter and Egbert, 2015)

2.3 Suitability of EPG Doses

During the development of the EPG approach, it was recognized that some EPG doses, which are maximized using the methodology described in this section, could be near or above the doses that would result in a service-connection determination by the VA. Such doses would not be suitable for use in support of VA's claim decisions. Therefore, a review of EPG doses to determine their suitability for assignment to individual participants must be accomplished to identify organs associated with those doses. Further discussion on EPG doses that are not suitable for assignment is provided in Section 2.6.1.

2.3.1. Internal Organ and Skin Doses

EPG doses for specific organs or skin cancer sites are suitable for assignment in veteran cases when the total organ or skin dose for an EPG is well below the screening dose, which is the

dose corresponding to a probability of causation of an organ or skin cancer of 50 percent. To identify doses that may not be suitable, total organ and skin doses for all EPGs are compared to the applicable limiting doses, which produce an estimated probability of causation of about 40 percent using the NIOSH-IREP software application (NIOSH, 2020).

If an EPG total organ dose, which is the sum of the maximized upper-bound external and internal doses, is higher than the limiting dose of the corresponding NIOSH-IREP cancer model, the external and internal upper-bound doses estimated for the EPG/organ combination are deemed not suitable for assignment by expedited processing. If an EPG total organ dose is lower than the corresponding limiting dose, then the external and internal doses for the EPG/organ combination are suitable and are proposed for use in expedited processing of ECUP veteran cases.

The same approach is used for determining the suitability of assigning skin doses by expedited processing for the selected EPGs. Results of the EPG dose estimates and comparison with the limiting doses are discussed in Section 5.

2.3.2. Lens of the Eye Doses

Unlike EPG doses for internal organs and skin that are generally estimated for assignment in cases involving cancers, doses to the lens of the eye are estimated for use in cases involving posterior subcapsular cataracts (PSCs, or "cataracts"). Because cataracts are not a cancer, the concept of an LD discussed above is not applicable. However, cataracts are a deterministic effect for which a "threshold dose" can be estimated. For cataracts, the threshold dose is the lowest radiation dose that is expected to result in cataracts.

A threshold dose for cataracts can be used to determine the suitability of assigning a dose to the lens of the eye through expedited processing. A threshold dose of 35 rad has been cited by the VA as the "maximum likelihood dose" for Stage I PSCs with an associated 95 percent confidence interval of 19–66 rad (VA, 2011). For ECUP expedited processing, the lower limit of this confidence interval is proposed as a threshold dose for comparison with an estimated maximized upper-bound dose to the lens of the eye. Therefore, if the total dose to the lens of the eye is lower than 19 rad, it is suitable and is proposed for use in expedited processing of ECUP veteran cases. Results of the ECUP EPG lens of the eye dose estimation and comparison with the threshold dose are discussed in Section 5.

2.4 Criteria for Selecting ECUP Expedited Processing Groups

Each EPG, discussed in Section 3, includes ECUP participants whose actual activities would have resulted in total doses that are lower than the EPG total organ doses. The aim is to set EPG selection criteria so that all possible exposure pathways and radiation sources are used to estimate the EPG's external and internal doses. In addition, it is important that each EPG and corresponding doses can be applied to a relatively large number of participants. Therefore, to identify coherent EPGs, the following criteria should apply to all members of an EPG:

- Commonality of activities and radiation environments
- Similarity of exposure pathways that contribute the most significant doses

- Comparability of types of radiation, e.g., external gamma, internal alpha, and internal beta/gamma radiation
- Similarity of durations of participation and exposure
- Likelihood that total organ doses, i.e., external plus internal doses, are well below the screening doses for all or most applicable cancers.

In general, use of the above criteria along with the conditions specified in Section 2.1 results in EPGs and corresponding doses that can be assigned to most ECUP participants. To accomplish this goal, four EPGs were identified and are described in Section 3.

2.5 Experience Performing ECUP Radiation Dose Assessments

In late 2017, the first ECUP veteran case RDA that was performed by the NTPR Program was used as one of several sample cases assessed as part of the development of the ECUP RDA technical basis document published in April 2018 (DTRA, 2018). Subsequently, cases were assessed using the methods, data, and results reported in the ECUP RDA draft and final technical report (DTRA, 2018). Based on the findings published in the ECUP RDA technical report, the NTPR team developed a standard operating procedure (SOP RA06) that was published on DTRA's NTPR website in December 2019. It included approved instructions on conducting ECUP RDAs and the dose default parameter values to be used in estimating veteran doses requested by the VA.

In total, since 2017, 16 ECUP VA requests for dose assessment have been fulfilled by DTRA's NTPR Program team. Most of these cases involved veterans who worked on the residence islands of Enewetak and Lojwa with occasional visits to northern islands with restricted access. These participants were involved in activities such as operational administration, supply management, air transportation, central communications, analytical laboratory testing, and mobilization/demobilization support. Other veterans conducted activities including hauling contaminated soil and debris, repairing transport boats, surveys in periods before and during cleanup operations, and encapsulation of contaminated soil and debris in Cactus crater on Runit Island.

Some of the cases completed are for veterans who were at Enewetak Atoll during the ECUP for a short period, from a few days to a couple of weeks. These cases involved support by transient ships that visited Enewetak Atoll to perform maintenance and repair of small boats, deliver supplies and equipment, pick up retrograde cargo, etc. Crewmembers of transient ships typically remained on their ships in the lagoon and spent little or no time on the islands and their estimated total organ doses were much lower than those estimated for other participants.

Visitors to the northern islands of Enewetak Atoll, where access was often controlled, were issued one or more film badges (FB) or thermoluminescent dosimeters (TLD). Because the low doses recorded by FBs were at or below the minimum detectible level of 0.020 rem, dose reconstruction in all such cases was performed (DTRA, 2020).

In general, scenarios of exposure were characterized by similar types of radiation sources and pathways as follows:

- External radiation exposure to the whole body
- Inhalation of contaminated soil and dust generally suspended from ground surfaces
- Incidental ingestion of soil and dust from inadvertent intake by mouth of small quantities of soil and dust particles that adhered to food, beverages, cigarettes, or hands
- Ingestion by consumption of potentially contaminated local foods.

Overall, none of the total organ doses estimated for the 16 veterans exceeded 1 rem and most of them had upper-bound total organ doses in the 0.01 to 0.1 rem range. These doses are an order of magnitude, or more, lower than the U.S. Nuclear Regulatory Commission (USNRC) occupational dose limits for radiation workers that were adopted by the ECUP (DNA, 1981).

2.6 Exclusion from Expedited Processing

2.6.1. Exclusion Based on Exceedance of Limiting Doses

It is possible that organ or skin doses calculated for ECUP EPGs using the conservative methodology described above could be near or above the level that could lead to service-connection determinations, if used by the VA. To be suitable for assignment, upper-bound total organ doses that result from the expedited processing approach described in this section must be well below the dose that could result in service-connection. Consistent with previous expedited processing assessments (Case et al., 2011; McKenzie-Carter and Egbert, 2015), the dose defined as "well below the dose that could result in compensation" is the dose that produces a probability of causation for cancers of 40 percent at the upper 99 percent credibility limit for an acute exposure at age 18 years, and diagnosis of cancer at either age 50 years or after an appropriate elapsed time following exposure. This dose is defined as the "Limiting Dose" (LD) for each organ or skin cancer model and is compared with the corresponding total organ or skin dose estimated for each ECUP EPG and reported in Section 5.

Values of LDs for cancers of internal organs assuming all (external and internal) doses are acute doses from photons with energy greater than 250 keV (LDγ) were previously estimated using the NIOSH-IREP application (NIOSH, 2020). These LDγ values are reported in SOP RA02 (DTRA, 2021), and are also shown in Table 1. However, for some ECUP EPG and organ combinations, the dose from alpha radiation is the major contributor to the total dose. To account for these occurrences, LD values calculated by assuming that the total dose is from alpha radiation (LDα) were estimated using the NIOSH-IREP application and are shown in Table 1. Acute exposures to alpha radiation were assumed in estimating LDα values to produce conservative (lower) LDα values for most organs/diseases. In Section 5, these limiting doses (LDα) are those used to determine exclusions from expedited processing.

Like internal organ doses, LDγ for three types of skin cancers were previously determined using input to NIOSH-IREP that assumed that doses were acute doses from photons with energy greater than 250 keV. In addition, skin cancer LDγ were estimated assuming exposure at age 18 years and attained age of 50 years at the time of cancer diagnosis. However, like internal organ doses, some of the estimated EPG skin doses include a large contribution from alpha radiation, which is due to the highly conservative exposure model used for estimating

dermal contamination skin doses. To account for these occurrences, LDα values based on the assumption that the total skin dose is due to alpha radiation were estimated. Furthermore, LDs for the three types of skin cancers vary according to the race of an individual. The LD values in this report were estimated for the five race categories included in NIOSH-IREP: "American Indian or Alaska Native," "Asian, Native Hawaiian, or other Pacific Islander," "Black," "White, Hispanic," and "White, Non-Hispanic." All LD values for the three types of skin cancers are shown in Table 2.

As reported in Section 5, the EPG total organ doses (TODs) were calculated by adding the maximized upper-bound external dose and the maximized upper-bound internal doses (alpha and beta+gamma doses) for 24 organs for which ICRP 68 dose coefficients are available. Also, maximized upper-bound external doses (alpha+beta+gamma) were calculated for 17 representative skin sites and the lens of the eye (beta+gamma). When the EPG TOD or the total maximized upper-bound skin dose exceeds the applicable LDα, expedited processing is not recommended for the specific veteran's claim. Cases involving an EPG/organ combination or an EPG/skin cancer combination that is found to be unsuitable for expedited processing should be referred for further evaluation by an RDA analyst; guidance will be included in a standard operating procedure to specify how these cases are processed.

In addition, any organs or skin cancers that do not have associated LDα values listed in this report are not recommended for expedited processing unless surrogate organs or skin sites are identified. The TODs and total upper-bound skin doses that exceed the applicable LDα are presented in Table 15 to Table 17.

Some ECUP standard organs are used for more than one tissue or organ, some of which have different LDα values. For example, liver is the surrogate organ for gallbladder (LDα = 6.5 rem) but the LDα for liver cancer is 3.6 rem. Similarly, ET Region is the surrogate organ for larynx (LDα = 48 rem), and several tissues and organs in the oral cavity such as tongue, parotid gland, and pharynx (LDα = 36 rem). In these cases, the lowest of these multiple LDα values for any standard organ is the LDα that is compared to the ECUP EPG dose for each organ in subsequent sections. For example, the LDα used for liver is 3.6 rem (the lower of 6.5 and 3.6 rem), and the LDα used for ET Region is 36 rem (the lower of 36 and 48 rem).

Table 1. Limiting doses for cancers based on all alpha or all photon radiation

Cancer of Organ/Disease	LDα* (rem)	LDγ† (rem)
Acute Lymphocytic Leukemia (ALL)	20‡	14‡
Acute Myeloid Leukemia (AML)	15‡	20‡
All digestive, other than excluding esophagus, stomach, colon, rectum/anus	17	44
Bone	15	32
Breast (male)	10	36
Breast (female)	15	39
Chronic Lymphocytic Leukemia (CLL)	34‡	45‡
Chronic Myeloid Leukemia (CML)	89‡	41‡
Colon	11	26
Connective tissue	17	34
Endocrine glands, other than thyroid	12	30
Esophagus	11	22
Eye	16	32
Female genitalia	1400	1000
Gallbladder	6.5	11
Leukemia, other than ALL, AML, CML, and CLL	27‡	29‡
Liver	3.6	7.7
Lung (never smokers)	13	30
Lymphoma and multiple myeloma	28	41
Male genitalia	30	41
Nervous system	37	64
Oral cavity and Pharynx	36	66
Other and ill-defined sites	17	34
Ovary	14	25
Pancreas	34	61
Rectum	43	72
Respiratory tract, other than lung	48	67
Stomach	10	18
Thyroid	3.2§	5.1§
Urinary Bladder	16	33
Urinary organs, other than bladder)	13	31

* LDα = Limiting dose (PC of 40 percent) assuming the total organ dose is due entirely to alpha radiation. LDα values were estimated with the NIOSH-IREP online software. Assumptions include acute exposure at age 18 years and attained age of 50 years (elapsed time of 32 years) unless noted otherwise. Values are for males except values for three female-specific organs listed.

† LDγ = Limiting dose (PC of 40 percent) assuming the total organ dose is due entirely to photon radiation > 250 keV. LDγ values are from DTRA (2021, SOP RA02) except values for three female-specific organs listed. All LDγ values were calculated using the NIOSH-IREP software as described in the footnote above.

‡ LDα and LDγ values for leukemia are calculated for an elapsed time of 30 years.

§ LDα and LDγ values for thyroid cancer are calculated for an elapsed time of ≥10 years.

Table 2. Limiting doses for skin cancers assuming all alpha or all photon radiation

	LDα* (rem)			LDγ* (rem)		
NIOSH-IREP Race Category	**MM†**	**BCC†**	**SCC†**	**MM†**	**BCC†**	**SCC†**
American Indian or Alaska Native	1.0	0.85	63	2.1	1.7	89
Asian, Native Hawaiian, or other Pacific Islander	1.8	0.85	63	3.6	1.7	89
Black	1.7	0.85	63	3.5	1.7	89
White - Hispanic	2.1	2.4	165	3.9	4.0	188
White - Non-Hispanic	2.4	2.5	175	4.1	4.1	190

* – LD values correspond to a PC of 40 percent. LD values are estimated with the on-line NIOSH-IREP software (NIOSH, 2020), using an acute exposure at age 18 and cancer diagnosis at age 50.
– LDα is estimated by assuming the total skin dose is due entirely to alpha radiation.
– LDγ is estimated by assuming the total skin dose is due entirely to photons with energies > 250 keV.

† MM = malignant melanoma; BCC = basal cell carcinoma; SCC = squamous cell carcinoma.

2.6.2. Exclusion Based on Unusual Participation or Exposure Scenario

In the previous subsection, the exclusion of EPG/organ combinations from expedited processing that are driven by the EPG total organ dose exceeding the applicable LD were discussed. In addition to those exclusions, exclusion from expedited processing when a veteran's scenario of participation and radiation exposure cannot be categorized to fit any of the ECUP EPG characteristics discussed in Section 3. Excluded cases require a more detailed case review and dose assessment

Unusual participation and exposure scenarios may involve sources of radiation or pathways that are not included or only partially covered by any of the four ECUP EPGs dose components. By "not covered", it is meant that any dose resulting from the unusual scenario cannot be accounted for within any of the exposure pathways considered for any of the four EPGs.

Situations that could be considered unusual may involve veterans who only spent short periods at the atoll and were not stationed on any of the islands, e.g., Navy crews that remained aboard their ships that were anchored in the lagoon and personnel who flew in supplies and personnel and were at the atoll for only a limited time away from contaminated areas. Specific examples of exclusions based on unusual participation and exposure scenarios are given in Section 3.

Although, these unusual types of participation would result in actual doses that are likely lower than any EPG doses, any relevant cases should be processed differently from those that can be assigned to one of the four EPGs. Guidance on the treatment of such cases will be included in the standard operating procedure on ECUP expedited processing of veteran RDAs.

3.

Identification and Selection of Expedited Processing Groups

This section describes the basis for sorting the ECUP participant population into groups appropriate for expedited processing. The radiation exposure scenarios of members of the population are broken out by radiation sources and exposure pathways. Together, the applicable populations are allocated to four EPGs based on the application of selection criteria in Section 2. Each EPG is fully described by common activities in which selected subpopulations were involved. Finally, ECUP activities that may not fit into the EPG scenarios are identified.

3.1 Participant Population and General Radiation Exposure Scenarios

3.1.1. Potentially Exposed Population

The management of the ECUP operations was assigned to a Joint Task Group (JTG) that was responsible for all aspects of the cleanup operations on Enewetak. The JTG was staffed by nearly 6,000 individuals from the U.S. Army, U.S. Navy, and U.S. Air Force in five divisions that reported to the Commander of JTG (CJTG). The CJTG was also given supervisory authority for direction and control over the Military Service components of the JTG. The total number of participants and units composing the Military Service elements and the FCDNA JTG that make up the ECUP participation population are shown in Table 3. (DNA, 1981)

Table 3. Military Service element and DNA/JTG staffing of the Enewetak Cleanup Project

U.S. Army Element	U.S. Navy Element	U.S. Air Force Element	FCDNA/JTG
2,670	2,207	740	246
• Engineer Units • Helicopter Team • LARCs and amphibious vehicle operations • Chaplain Team • Finance Team • General Laundry Team • Decontamination Laundry	• Harbor Clearance Units and Water-Beach Cleanup Teams • Intra-atoll Transportation • Radiological and laboratory technicians	• Field Radiation Support Team • Medical Team • Radiological and lab technicians • Communications-electronics Team • Petroleum-oil-lubricants Team • Airfield Team • Postal Team	• Commander, JTG • Administration • Engineering • Radiological Control • Logistics • Security

3.1.2. Radiation Sources and Exposure Pathways

Sources of radiation that may have resulted in exposure of ECUP participants to radiation include:

- Fallout mixed in the top layer of soil of contaminated islands
- Stockpiles of contaminated soil and debris
- Contaminated soils and debris during transport by trucks and boats
- Contaminated concrete slabs and building debris
- Slurry of mixed contaminated soil and cement, during preparation, transport and disposal in the Cactus crater
- Soil-cement mix produced and contained in the Cactus dome
- Lagoon and ocean waters, while retrieving debris and during recreational diving or swimming
- Contaminated equipment and decontamination laundry.

In general, an exposure pathway is the route followed by radiation or contaminants from a source, via air, soil, water, or food to a human receptor. Participants in the ECUP were potentially exposed to external gamma and beta radiation and internal radiation from the intake of radioactive materials by inhalation and ingestion, or through wounds. In the context of the ECUP and potential exposure to radiation, pathways involve exposure of the whole body to gamma radiation from external sources, inhalation of airborne contaminants, ingestion of contaminated foods, and exposure of the skin and lens of the eye to external sources of gamma and beta and alpha radiation. The radionuclides of concern in these pathways are Sr-90, Cs-137, Co-60, Pu-239/240, and Am-241. (DTRA, 2020)

Exposure from contaminated ground surfaces or debris was the most likely potential external radiation exposure pathway for ECUP participants. This external exposure pathway applies to participants who were working or residing on islands, whether involved in cleanup activities or not. The potential inhalation of soil that was excised, windrowed, stockpiled, and transported for ultimate containment in Cactus crater on Runit Island represents an internal exposure pathway for individuals who were involved in soil cleanup activities. Inhalation of suspended contaminated soil during other activities was the most likely internal radiation exposure pathway for other ECUP participants. A more detailed discussion of sources of radioactive contaminants and exposure pathways during the ECUP can be found in Section 5 of DTRA (2020).

Exposure of the skin to external sources of gamma and beta and alpha radiation could have occurred from the same sources listed above. In addition, exposure of the skin could have occurred if contaminated soil and dust were deposited directly on the skin or clothing.

3.2 Expedited Processing Groups and Applicable Exposure Scenarios

Four EPGs were selected based on the criteria presented in Section 2. For each EPG, potential exposure pathways, radiation environments, and participant activities were based on

specific assumptions and parameter values allowing the development of maximized doses. Each EPG was defined to represent a sizeable population of ECUP participants that were engaged in common activities and experiencing similar radiation exposure environments at worksites. The selected EPGs are discussed below.

3.2.1. Soil Removal Workers EPG

Members of this EPG are ECUP participants who performed activities involving disrupting and handling contaminated soil that required removal from the five northern islands of Boken, Enjebi, Lujor, Aomon, and Runit. These islands were identified by DNA as requiring cleanup by soil removal, transport to Runit Island, and disposal in Cactus crater (DNA, 1981). These islands are located in the north rim and in the northeast quadrant of the atoll as shown in Figure 1.

Personnel included in this EPG are assumed to have resided on Lojwa Island while performing cleanup work on the northern islands for their entire assignment. These personnel performed several activities involving disrupting and handling contaminated soil. Sample activities that could have been performed by individuals that would be members of this EPG include, but are not limited to, the following:

- Digging, excavating, moving, stockpiling soil
- Loading soil into dump trucks, boats, and vehicles of any kind using heavy machinery
- Transporting soil to Runit
- Unloading soil
- Gathering and reforming the soil into other media for disposal, such as soil-cement slurry by-products from the tremie system
- Moving soil or reformed soil to the disposal site for containment.

3.2.2. Northern Island Workers EPG

This EPG includes personnel whose primary work assignment involved work on one or more of the northern islands (except Lojwa) for their entire assignment. These workers may have been involved in earthmoving activities on a limited or occasional basis but they were not involved in directly disrupting and handling contaminated soil that required excision, transportation, and disposal, such as in the Soil Removal Workers EPG. Refer to Section 4 for discussions on accounting for these activities. The 21 northern islands included in this EPG are listed in Table 4, and consist of the line of islands starting with Bokoluo in the northwest clockwise along the northern and northeast rim of the atoll to Runit, excluding Lojwa (see Figure 1). These personnel typically resided on Lojwa Island. Sample work activities that would have been performed by members of this EPG include, but are not limited to, the following:

- Handling contaminated and uncontaminated debris
- Preparing debris for transport
- Accompanying debris during transport

- Unloading, moving, and disposing of yellow debris at lagoon disposal sites and red debris in the crater
- Performing radiological monitoring, sampling, and inspections
- Removing brush.

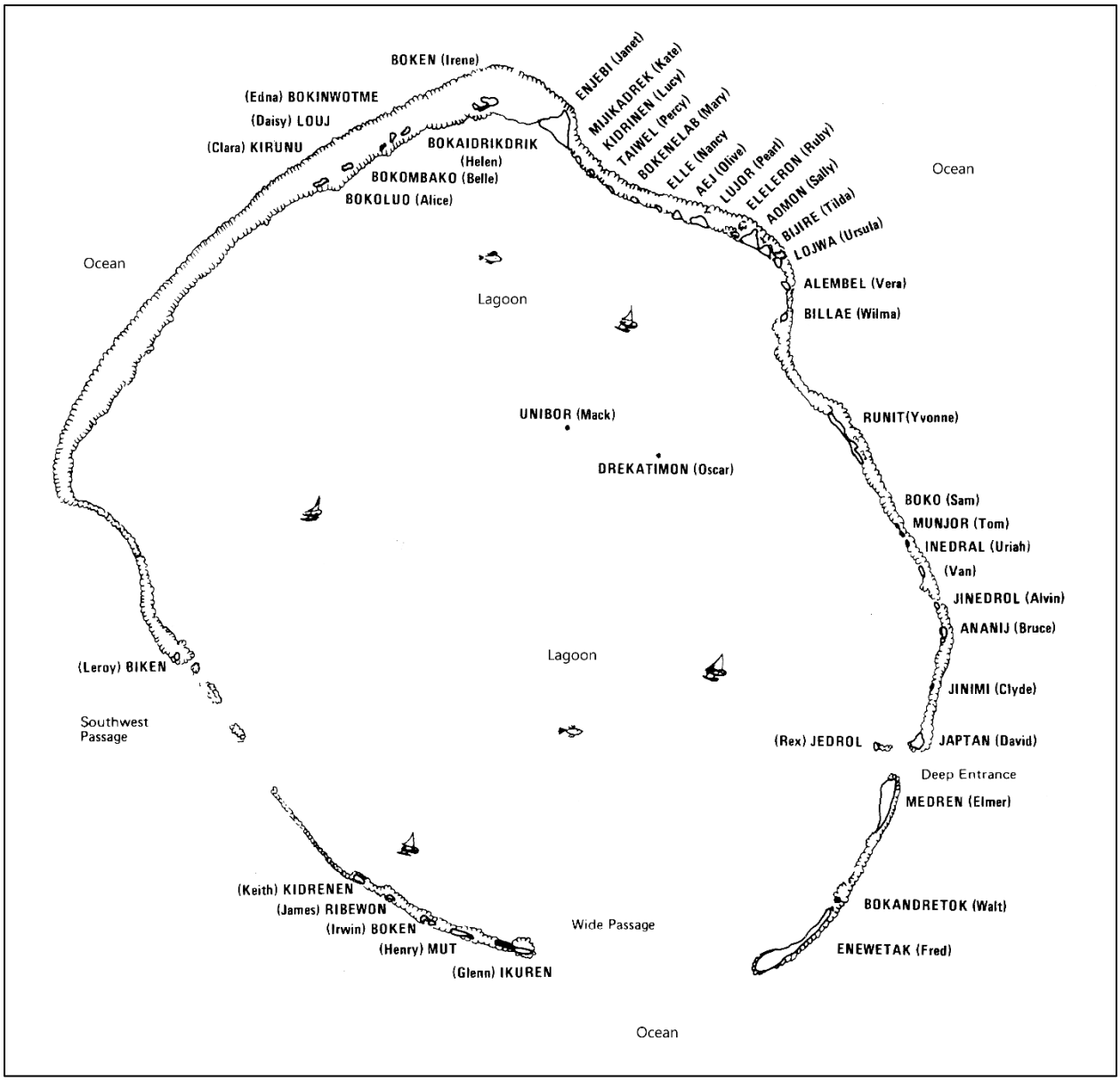

Figure 1. Islands of Enewetak Atoll (Adapted from DNA (1981))

Table 4. Enewetak Atoll islands

Island Code*	Site Name	Island Name†
Northern Islands		
FA	Alice	Bokoluo
FB	Belle	Bokombako
FC	Clara	Kirunu
FD	Daisy	Louj
FE	Edna	Bocinwotme
FH	Helen	Bokaidrik
FI	Irene	Boken
FJ	Janet	Enjebi
FK	Kate	Mijikadrek
FL	Lucy	Kidrinen
MP	Percy	Taiwel
FM	Mary	Bokenelab
FN	Nancy	Elle
FO	Olive	Aej
FP	Pearl	Lujor
FR	Ruby	Eleleron
FS	Sally	Aomon
FT	Tilda	Bijile‡
FU	Ursula	Lojwa
FV	Vera	Alembel
FW	Wilma	Billae
FY	Yvonne	Runit
Southern Islands		
MS	Sam	Boko
MT	Tom	Munjor
MU	Uriah	Inedral
MV	Van	—§
MA	Alvin	Jinedrol
MB	Bruce	Ananij
MC	Clyde	Jinimi
MC	David	Japtan
MR	Rex	Jedrol
ME	Elmer	Medren (aka Parry)
MW	Walt	Bokandretok
MF	Fred	Enewetak
MG	Glenn	Ikuren
MH	Henry	Mut
MI	Irwin	Boken
MJ	James	Ribewon
MK	Keith	Kidrenen
ML	Leroy	Biken
MO	Oscar (coral head)	Drekatimon
MM	Mack (coral head)	Unibor

* Island codes were assigned by the JTG.

† For further reference, refer to Section 2 of DTRA (2020).

‡ Shown as Bijire in DNA (1981).

§ The Enewetak people had no name for this island.

3.2.3. Lojwa Island Support Workers EPG

Members of this EPG include personnel whose primary work assignment and residence was on the island of Lojwa. These are generally identified as support personnel maintaining the Lojwa island infrastructure and services that supported cleanup operations. Sample work activities associated with this EPG include, but are not limited to, the following:

- Maintaining instrumentation, analyzing samples, and decontaminating clothing at on-site facilities
- Maintaining the facilities and structures
- Installing and maintaining telecommunication systems
- Supporting petroleum, oil, and lubrication stores to supply other northern islands
- Operating postal, food, and welfare and recreation services
- Transporting workers to and from cleanup sites
- Producing potable and drinking water and operating desalination systems
- Running laundry services
- Providing medical and dental care.

3.2.4. Southern Island Workers EPG

Individuals that can be assigned to this EPG include personnel whose primary work assignment involved work on one or more of southern islands. The southern islands included in this EPG are listed in Table 4 and are shown in Figure 1. The southern islands comprise the line of islands starting with Boko in the eastern rim of the atoll south of Runit, continuing clockwise along the southern rim of the atoll and ending with the island of Biken. Personnel included in this EPG resided for the most part on Enewetak Island. Sample activities associated with work performed on the southern islands by members of this EPG include, but are not limited to, the following:

- Performing command, control, and communication functions
- Providing central logistical support to the cleanup
- Performing project management and administration
- Constructing and maintaining buildings and structures
- Preserving petroleum, oil, and lubrication stores
- Providing medical and dental care
- Installing and maintaining telecommunication systems
- Operating the postal, food, and welfare and recreation services
- Transporting other personnel and materials during MEDEVAC and SAR missions
- Performing gross radiological islands surveys

- Supplying/resupplying the northern residence island of Lojwa
- Removing contaminated soil from Medren
- Removing uncontaminated debris
- Removing unexploded ordnance
- Conducting mobilization and demobilization activities.

3.3 Potential Exclusion from Expedited Processing Consideration

Several activities may have resulted in exposure scenarios that may not fit within the EPG definitions given above. They may include:

- Removing plutonium fragments removal from burial crypts on Aomon
- Disposing soil bags with plutonium fragments from Fig-Quince on Runit
- Removing concentrated contaminated material from outside of the bunkers on Boken
- Repairing or maintaining contaminated equipment removed from controlled areas
- Participating in duties at the Decontamination Laundry Facility on Lojwa Island
- Participating in RSAIT inspection activities
- Consuming local foods in excess of what is assumed for estimating EPG doses
- Being involved in or near accidents or abnormal events involving contaminated soil or debris
- Being present at Enewetak Atoll for only a short time, e.g., DoD VIP visitors, or military personnel on transient ships or transport aircraft
- Having an ECUP assignment at Enewetak Atoll for greater than one year.

4.

Maximizing Exposure Scenarios and Dose Parameter Assumptions

To estimate expedited processing doses for ECUP military participants, four generic groups of personnel were defined based on similarity of work location and activity (see Section 3). These four expedited processing groups (EPGs) encompass the majority of ECUP participants. For each EPG, maximizing exposure scenarios were developed based on activities and work locations that would result in TODs for the EPG that are clearly greater than any actual veteran TOD. Radiation doses estimated for the maximizing scenarios are calculated to be higher than any member of the EPG actually received. Exposure scenarios discussed in this section include sources of exposure, associated exposure pathways, and exposure times for external and internal radiation dose estimates.

The following subsection describes the exposure scenarios to maximize the doses for each EPG. This is followed by descriptions of the parameters and the values used to estimate expedited processing doses for external, internal, skin, and lens of the eye for each EPG.

4.1 Exposure Scenarios

This section describes potential exposure sources and exposure pathways for each EPG. A scenario is then described for each EPG that is based on a subset of these sources and pathways and maximizing parameter assumptions.

4.1.1. Soil Removal Workers EPG

This EPG includes personnel whose primary duties involved working directly with or near soil removal activities on one or more of the five northern islands of Boken, Enjebi, Lujor, Aomon, and Runit, where soil was excised and taken to Runit for containment in the Cactus crater. As described in Section 3, soil removal activities involved excising, windrowing, stockpiling, loading/unloading, transporting, and mixing soil for containment in the Cactus dome or containment cap. Typical members of this EPG would include, but are not limited to, U.S. Army Engineer heavy equipment operators, soil transport truck drivers, crew of boats that transported soil, tremie workers and soil-cement mix teams on Runit.

The primary potential sources of external whole-body exposure for members of this EPG are as follows:

- Fallout mixed in the soil on contaminated islands
- Stockpiled and windrowed contaminated soil
- Contaminated soil, during loading, transport, or unloading
- Slurry of mixed contaminated soil and cement
- Contaminated concrete slabs and debris, during handling, transport, or disposal
- For skin and lens of the eye, contaminated soil deposited directly on the skin or clothing.

The primary potential sources and intake routes of internal exposure for members of this EPG are as follows:

- Inhalation of contaminated and excised soil suspended during soil removal activities
- Inhalation of contaminated and excised soil suspended during soil-handling and transport
- Inhalation of suspended soil on residence islands
- Ingestion of locally sourced foods
- Incidental ingestion of contaminated soil and dust.

The exposure scenario used to maximize doses for this EPG is represented by workers who performed soil removal activities for an entire assignment on one or more of the five northern soil-cleanup islands of Boken, Enjebi, Lujor, Aomon, and Runit, where soil was excised because of its transuranic (TRU) element content. This scenario includes the assumption of excised and subsequently suspended soil contaminated with elevated levels of TRU. Full workday exposures for an entire 12-month ECUP assignment are also assumed.

The maximized external exposures to the whole-body, skin, and lens of the eye for this EPG scenario involve exposure to contaminants in the top layer of soil on one of the five contaminated islands on all workdays. Continuous exposure to this source bounds potential exposures to other sources, such as contaminated debris (DTRA, 2020). Maximized daily exposure of skin to dermal contamination consisting of excised soil is also included.

The maximizing internal exposure pathways include inhalation of airborne excised soil during the workday, with an assumed constant airborne mass loading approximately 15 times greater than the estimated ambient dust loading of 40 $\mu g\ m^{-3}$ for the atoll (AEC, 1973). In addition, inhalation of suspended soil during all outdoor off-duty hours on Lojwa, consumption of local food, and incidental ingestion of contaminated soil and dust while on Lojwa are included.

Parameter values used for estimation of external whole body doses, internal organ doses, external skin doses, and external doses to the lens of the eye resulting from the sources and pathways described above for the maximizing scenario of the Soil Removal Workers EPG are presented in Sections 4.2 and 4.3.

4.1.2. Northern Island Workers EPG

This EPG includes personnel whose primary duties involved working on northern islands of the atoll other than the five soil removal islands. These islands comprise the islands from Bokoluo clockwise around the northern portion of the atoll to Runit. The residence island of Lojwa where members of this EPG were billeted is not considered a work island for this EPG. Because more fallout occurred on the northern islands during the atmospheric testing period, the external dose rates and soil radionuclide concentrations were generally significantly higher on the northern islands than on the southern islands. As described in Section 3, activities of members of this EPG involved removing, handling, and transporting debris, regular performance of radiological safety monitoring or sampling, and brush removal work. These personnel may

have also occasionally handled contaminated soil. Typical members of this EPG would include, but are not limited to, members of U.S. Army Engineer Units, U.S. Navy Harbor Clearance Units and Water-Beach Cleanup Teams, and U.S. Air Force Field Radiation Support Teams.

The primary potential sources of external whole-body exposure for members of this EPG are as follows:

- Fallout mixed in the top layer of soil on contaminated islands
- Contaminated concrete slabs and debris during handling, transport, or disposal
- Stockpiled and windrowed contaminated vegetation and debris
- Samples of contaminated soil during sampling and handling
- Lagoon and ocean waters, while retrieving or disposing debris
- Contaminated equipment
- For skin and the lens of the eye, contaminated soil deposited directly on the skin or clothing.

The primary potential sources and intake routes of internal exposure for members of this EPG are as follows:

- Inhalation of contaminated soil suspended during work activities on one or more of the northern islands
- Inhalation of suspended soil on residence islands
- Ingestion of locally-sourced foods
- Incidental ingestion of contaminated soil and dust
- Inadvertent ingestion of lagoon or ocean water while extracting offshore debris or swimming.

The exposure scenario used to maximize doses for this EPG is represented by workers who performed cleanup or support work on one or more of the northern islands other than the five soil removal islands and Lojwa for their entire assignment. This involved activities such as debris and brush removal including the use of heavy equipment that suspended contaminated soil. Full workday exposure for an entire 12-month ECUP assignment is also assumed.

The maximized external exposures to the whole-body and skin for this EPG scenario involve exposure to contaminants in the top layer of soil on one or more of the northern islands on all workdays. Continuous exposure to this source bounds potential exposures to other sources, such as contaminated debris (DTRA, 2020). Maximized daily exposure of skin to dermal contamination from northern island soils is also included.

The maximizing internal exposure pathways include inhalation of airborne contaminated soil on one or more of the northern islands on all workdays, with an assumed constant airborne mass loading approximately 7.5 times greater than the estimated ambient dust loading of 40 $\mu g\ m^{-3}$ for the atoll (AEC, 1973). In addition, inhalation of suspended soil during all outdoor

off-duty hours on Lojwa, consumption of local food, and incidental ingestion of contaminated soil and dust while on Lojwa are included.

Parameter values used for estimation of external whole body doses, internal organ doses, external skin doses, and doses to the lens of the eye resulting from the sources and pathways described above for the maximizing scenario of the Northern Island Workers EPG are presented in Sections 4.2 and 4.3.

4.1.3. Lojwa Support Workers EPG

This EPG includes personnel whose primary job during the ECUP involved working on Lojwa Island. As described in Section 3, activities of members of this EPG generally involved maintaining the island's infrastructure that supported the cleanup operations. Typical members of this EPG would include, but is not limited to, members of U.S. Army Engineer Units, U.S. Army, U.S. Navy, and U.S. Air Force providers of support services such as laundry, finance, laboratory technician, medical, postal, and communication services.

The primary potential sources of external whole-body exposure for members of this EPG are as follows:

- Fallout mixed in the top layer of soil on Lojwa
- Contaminated equipment and laundry
- Samples of contaminated soil
- For skin and the lens of the eye, contaminated soil deposited directly on the skin or clothing.

The primary potential sources of internal exposure and intake routes for members of this EPG are as follows:

- Inhalation of contaminated soil suspended by routine activities such as vehicle traffic
- Ingestion of locally-sourced foods
- Incidental ingestion of contaminated soil and dust
- Inadvertent ingestion of lagoon or ocean water while swimming.

The exposure scenario used to maximize doses for this EPG is represented by workers whose regular duty was performed primarily on Lojwa for an entire assignment. Full workday outdoor exposures on Lojwa for an entire 12-month ECUP assignment is assumed.

The maximized external exposures to the whole-body and skin for this EPG involve exposure to contaminants in the top layer of soil on Lojwa on all work and non-workdays. Continuous exposure to this source bounds potential exposures to other sources, such as contaminated debris (DTRA, 2020). Maximized daily exposure of skin to dermal contamination from Lojwa soil is also included.

The maximizing internal exposure pathways include inhalation of suspended soil during all duty and outdoor off-duty hours on Lojwa, consumption of local food, and incidental ingestion of contaminated soil and dust on Lojwa.

Parameter values used for estimation of external whole body doses, internal organ doses, external skin doses, and lens of the eye doses resulting from the sources and pathways described above for the maximizing scenario of the Lojwa support Workers EPG are described in Sections 4.2 and 4.3.

4.1.4. Southern Island Workers EPG

This EPG includes personnel whose primary job involved working on one or more of the southern islands of the atoll. As described in Section 3, activities of members of this EPG included removal, transport, and disposal of uncontaminated debris; building and maintaining facilities and structures; and providing support services. In addition, a small volume (110 yd^3) of soil contaminated with Co-60 was removed from Medren and transported to Runit over a period of four days (DNA, 1981). Due to the small soil volume, absence of TRU contamination, and short duration, this activity was not a significant potential source of exposure. Typical members of this EPG would include, but are not limited to, members of all of the service elements and FCDNA that provided support services such as laundry, finance, medical, postal, communication, security, airfield, and administrative services. The members of this EPG were billeted at the residence facilities on Enewetak Island.

The primary potential sources of external whole-body exposure for members of this EPG are as follows:

- Fallout mixed in the top layer of soil on the southern islands
- Contaminated equipment
- For skin and the lens of the eye, contaminated soil deposited directly on the skin or clothing.

The primary potential sources of internal exposure and intake routes for members of this EPG are as follows:

- Inhalation of contaminated soil suspended by routine activities such as vehicle traffic
- Ingestion of locally-sourced foods
- Incidental ingestion of contaminated soil and dust
- Inadvertent ingestion of lagoon or ocean water while extracting offshore debris or swimming.

The exposure scenario used to maximize doses for this EPG is represented by workers who participated in construction of houses and other buildings on Medren as part of the Enewetak Rehabilitation Program for their entire assignment. This is used as the exposure scenario for this EPG because of the higher doses potentially accrued while routinely working on Medren as compared to other southern islands. Full workday outdoor exposures on Medren for an entire 12-month ECUP assignment is assumed.

The maximized external exposures to the whole-body and skin dose for this EPG involve exposure to contaminants in the top layer of soil on Medren (work) and Enewetak (residence) islands on all work and non-workdays. Maximized daily exposure of skin to dermal contamination from Medren soil is also included.

The maximizing internal exposure pathways include inhalation of suspended soil on Medren on all workdays, inhalation of suspended soil on Enewetak during all outdoor off-duty hours, routine consumption of local food, and incidental ingestion of contaminated soil and dust on Enewetak.

Parameter values used for estimation of external whole-body doses, internal organ doses, external skin doses resulting from the sources and pathways described above for the maximizing scenario of the Southern Island Workers EPG are described in Sections 4.2 and 4.3.

4.2 External Dose Parameter Values

This section describes the assumptions and parameter values that are used to estimate maximized upper-bound external radiation doses for the ECUP EPGs. Common and EPG-specific parameter values are described in the following subsections. Some parameter values are defaults, and some are indicated as maximizing values. The equations used for the dose estimation are presented in Appendix C of DTRA (2020).

4.2.1. External Dose Parameter Values Common to all ECUP EPGs

Values for several parameters used for calculating the ECUP EPG external doses are the same for all four EPGs. These common parameters are shown in Table 5, with a discussion of the parameters below.

- **Duration of duty tour**: The typical ECUP temporary duty assignment was 4–6 months (DNA, 1981). The assignment of some participants was extended to as long as 1 year.
- **Work schedule**: The maximum work schedule for all participants was 10 hours for 6 days a week. ECUP workers typically did not work on Sundays (DNA, 1981).
- **Travel time**: For many workers, the 10-hour workday included up to 2 h of travel time between the residence island and the work location. There was no potential for exposure during this travel time. Assumption of no travel time is a dose-maximizing assumption.
- **Time spent outdoors and indoors**: It is assumed that all of a participant's time during his assignment was spent on either a work island or the residence island. To maximize the estimated dose, it is assumed that all time on the work island was outdoors. Outdoor time on the residence island is assumed to be all time spent on the island except for 8 h d^{-1} spent sleeping indoors every day.
- **Building protection factor**: This parameter accounts for the degree of protection from radiation afforded by the walls and floor of a tent or building. The value assumed for the EPGs is a value applicable to a soft-sided tent rather than the metal buildings that were typically used for sleeping (DTRA, 2021, SM ED02).

Table 5. External dose parameter values common to all ECUP EPGs

Parameter	Value	Comment
Duration of duty tour	1 y (52 wk)	Maximizing value is used instead of typical duration of 26 wk
Work schedule on work island	10 h d^{-1} for 6 d wk^{-1}	Maximizing values are used assuming entire workday for all workdays spent on work island
Travel time to work island	0 h d^{-1}	Maximizing value is used instead of typical 1-2 h d^{-1} travel time
Time spent outdoors		Maximizing values are used that assume all work and non-work time is outside except time for 8 h d^{-1} sleeping indoors
(1) Workdays: Work Island	10 h d^{-1}	
Residence Island	6 h d^{-1}	
(2) Non-workdays: Work Island	0	
Residence Island	16 h d^{-1}	
Time spent indoors (all days)	8 h d^{-1}	See discussion in text
Building protection factor		Maximizing value for tent is used instead of value of 2.0 applicable to metal buildings
Work Island	1.0	
Residence Island	1.5	
Film badge conversion factor	0.7 rem R^{-1}	SM ED02 (DTRA, 2021)
Fraction of time exposed to source	1.0	Maximizing value is used that assumes continuous exposure to external source during work hours
Uncertainty factor	3	SM UA01 (DTRA, 2021)

- **Film badge conversion factor**: The film badge conversion factor is the ratio of dose recorded on a properly worn film badge to free-in-air integrated exposure and is used to convert an exposure to a dose. The factor accounts for body shielding of the film badge to gamma radiation and is assigned the values of 0.7 for the standing position on a planar surface (DTRA, 2021, SM ED02).
- **Fraction of time exposed to source**: This factor accounts for the fraction of time that an ECUP worker is actually exposed to a specific external source of radiation. Examples of scenario characteristics that could be accounted for include fraction of a workday that an individual is on a specific island, or is near a specific source (e.g., debris piles). The value of 1.0 is a maximum value.
- **Uncertainty factor**: This factor represents the ratio of an upper-bound dose to the best estimate dose. The uncertainty factor is typically used to ensure that an upper-bound dose is estimated that has a 95 percent probability of being higher than the actual dose. The use of an uncertainty factor with the EPG doses that are already maximized results in a dose above a 95^{th} percentile dose.

4.2.2. External Dose Parameter Values Specific to each EPG

For all four EPGs, the only external source assumed for estimating whole body external doses is undisturbed contaminated soil. This source has been determined to bound doses from

exposures to other sources of external radiation that ECUP participants in a specific EPG may have encountered such as contaminated debris (DTRA, 2020). The specific external exposure rates used for each EPG are shown in Table 6, and brief discussions of the exposure rate for each EPG follow the table.

Table 6. External exposure rates for ECUP EPGs

Parameter	Soil Removal Workers	Northern Island Workers	Lojwa Support Workers	Southern Island Workers
External exposure rate[*] (μR h^{-1})				
Work Island	39[†]	36[†]	5	0.31
Residence Island	5	5	5	0.26

[*] The exposure rates used in the EPG dose assessments are not decay-corrected for the elapsed time from the AEC 1972-1973 surveys to the time of the ECUP exposure scenarios.

[†] These exposure rates are weighted averages and are used to account for the assumed amount of time on each of the islands relevant to the EPG. See Sections 4.2.2.1 and 4.2.2.2 for additional information.

4.2.2.1 Soil Removal Workers EPG

The external exposure rate on the work island used for this EPG consists of the weighted average of the island-average exposure rates on the five soil removal islands, i.e., Boken, Enjebi, Lujor, Aomon, and Runit. The weighted average is calculated by weighting each of the five island exposure rates by the fraction of the total volume of excised soil that is removed from the island and assumes that the volume of soil removed is directly related to time spent on the island. The residence island external exposure rate used for this EPG is the island-average exposure rate for Lojwa. Although the residence facilities on Lojwa were not available for the entire 1977–1980 period, they were used for greater than a 1-y period. (DTRA, 2020)

4.2.2.2 Northern Island Workers EPG

The external exposure rate on the work island used for this EPG consists of the weighted average of the island-average exposure rates on the northern islands. The weighted average is calculated by weighting each island exposure rate by the fraction of the total volume of debris that was removed from the island and assumes that the volume of debris removed is directly related to time spent on the island by workers in this EPG. The residence island external exposure rate used for this EPG is the island-average exposure rate on Lojwa. Although the residence facilities on Lojwa were not available for the entire 1977–1980 period, they were used for more than one year. (DTRA, 2020)

4.2.2.3 Lojwa Support Workers EPG

The work and residence island external exposure rate used for this EPG is the island-average exposure rate on Lojwa (DTRA, 2020).

4.2.2.4 Southern Island Workers EPG

The external exposure rate on the work island for this EPG consists of the island-average exposure rate on Medren. Although the island-average external exposure rate on Medren was lower than several other southern islands, this work location is used because there was a considerable amount of work accomplished on the island such as debris removal and rehabilitation work. Furthermore, the soil TRU concentrations were higher on Medren than on all other southern islands except Biken, a small, isolated island with a small volume of non-contaminated debris that was removed. The residence island external exposure rate used for this EPG is the island-average exposure rate of Enewetak Island. (DNA, 1981; DTRA, 2020)

4.3 Internal Dose Parameter Values

This section describes the assumptions and parameter values that are used to estimate maximized upper-bound internal radiation doses for the ECUP EPGs. Common and EPG-specific are described in the following subsections. Some parameter values are defaults, and some are indicated as maximizing values. The equations used for the dose estimation are presented in Appendix C of DTRA (2020).

4.3.1. Internal Dose Parameter Values Common to all ECUP EPGs

Values for several parameters used for calculating the ECUP EPG internal doses are the same for all four EPGs. These common parameter values are shown in Table 7. Parameters for duration of duty tour, Work schedule, Travel time to Work Island, Time spent outdoors, and Time spent indoors are discussed in Section 4.2.1 and are not repeated here. The remaining parameters are discussed below.

- **Soil density**: A default value of 1.5 g cm^{-3} is used based on the recommendation in DTRA (2020) and SM ID01 (DTRA, 2021).
- **Depth of soil available for suspension**: A default value of 1 cm is used based on the recommendation in DTRA (2020) and SM ID01 (DTRA, 2021).
- **Breathing rate**: A default breathing rate of 1.2 m^3 h^{-1} is based on an adult male performing light activities, comparable to walking at a rate of 3 mph on a flat firm surface (DTRA, 2021, SM ID01). This rate is used as an average, constant breathing rate for all periods and activities where inhalation exposure is applied.
- **Respiratory protection factor**: This factor represents the degree of protection afforded by a respirator, and it is equal to the ratio of the concentration of contaminants outside the respirator to the concentration inhaled. Although respiratory protection with protection factors up to 1,000 was required during certain activities, some ECUP veterans have stated that they did not wear respiratory protection at any time. Therefore, a value of 1 is assumed in order to maximize the inhalation dose estimates.
- **Fraction of time exposed to source**: This factor is intended to account for the fraction of a workday or workweek that an ECUP worker is actually exposed to suspended soil. Examples of scenario characteristics that could be accounted for include fraction of a workday that disruption of soil is actually occurring, and the locations of personnel with respect to the prevailing wind. A value of 1.0 for this parameter is a maximum value.

Table 7. Internal dose parameter values common to all ECUP EPGs

Parameter	Value	Comment
Duration of duty tour	52 wk	Maximizing value is used instead of typical duration of 26 wk
Work schedule	10 h d^{-1} for 6 d wk^{-1}	Maximizing values are used assuming entire workday for all workdays spent on work island
Travel time to work island	0 h	Maximizing value is used instead of typical 1-2 h d^{-1} travel time
Time spent outdoors Workdays: Work Island Residence Island Non-workdays: Work Island Residence Island	 10 h d^{-1} 6 h d^{-1} 0 16 h/d	Maximizing values are used that assume all work and non-work time is outside except 8 h d^{-1} sleeping indoors
Time spent indoors (all days)	8 h d^{-1}	See discussion in text
Soil density	1.5 g cm^{-3}	See discussion in text
Suspended soil thickness	1 cm	See discussion in text
Inhalation rate	1.2 m^3 h^{-1}	SM ID01 (DTRA, 2021)
Respiratory protection factor Work Island Residence Island	 1 1	Maximizing values are used that assume no respiratory protection used at any time, instead of factor of 50–1,000 for respirators required during soil handling operations
Fraction of outdoor time exposed to airborne source	1.0	Maximizing value is used that assumes continuous exposure to suspended soil during work hours
Consumption of local food Fish Clam Coconut Meat Coconut Crab	 4 servings mo^{-1} 1 serving mo^{-1} 1 serving mo^{-1} 1 serving mo^{-1}	Maximizing values assume that a veteran consumed all four foods at the indicated rates
Incidental ingestion of contaminated soil and dust	0.002 rem (all organs)	Maximized dose is assigned instead of calculated organ doses less than 0.002 rem for most organs
Inhalation Dose Coefficients	Organ-specific (Table A-1)	See discussion in text
Ingestion Dose Coefficients	Organ-specific (Table A-2)	See discussion in text
Uncertainty factor	10	SM UA01 (DTRA, 2021)

- **Consumption of local food**: The default assumption for most ECUP dose assessments is that local foods were not consumed. However, some ECUP veterans have stated that they occasionally ate certain local foods. Fish is the most likely local food that might have been

consumed by ECUP participants, and other accessible foods may also have been collected and eaten. In order to reasonably maximize this potential exposure pathway, very high-sided consumption rates of four local foods are used. Organ doses per serving for each type of local food have been estimated (DTRA, 2020).

- **Incidental ingestion of soil and dust**: This exposure pathway is normally assessed for ECUP participants using a default incidental soil and dust ingestion rate of 0.05 g d^{-1} to calculate an upper-bound dose in SM ID01 (DTRA, 2021). However, previous ECUP dose estimates have demonstrated that the highest organ dose for this pathway for a 1-year exposure is approximately 0.002 rem for bone surface. Therefore, in order to simplify this exposure pathway, a dose of 0.002 rem is assigned for all organs and all EPGs and the internal dose uncertainty factor of 10 is applied.
- **Inhalation dose coefficients**: To high side the dose estimates for most internal organs, it was assumed that all suspended soil particles were respirable with an average activity median aerodynamic diameter (AMAD) of 1 μm. This conservative assumption results in dose coefficients that are higher than those of AMADs in the 3–10 μm range by factors of up to about 4 for most organs.
  In addition to particle size, the chemical form of a radionuclide affects the doses delivered to internal organs. The five radionuclides of most importance for inhalation doses to ECUP participants are the fission products Sr-90 and Cs-137, the TRU radionuclides Pu-239 and Am-241, and the neutron activation product Co-60 (DTRA, 2020). Although Cs-137 and Am-241 each has only one set of dose coefficients available for all chemical forms, dose coefficients are available for multiple chemical forms for Sr-90, Pu-239, and Co-60. However, a definitive understanding of the chemical forms of these radionuclides in the environment at Enewetak Atoll during the ECUP is not available. Therefore, the ICRP 68 category "unspecified compounds" with the corresponding material type absorption rate was assumed for Sr-90, Pu-239, and Co-60. Material types assumed for all five radionuclides are given in Appendix A.
  The choice of "unspecified compounds" results in higher dose coefficients by factors of up to 20 for Sr-90 and Pu-239 for most organs. Lungs are an exception to this generalization, as the Pu-239 dose coefficient for lung corresponding to insoluble oxides is higher than the unspecified compounds dose coefficient by a factor of about 2.5 due to a lower lung clearance value. In addition, Co-60 dose coefficients for "unspecified compounds" are generally lower than those for specific compounds by a factor of up to 4. However, for the most important radionuclides of concern for estimated internal doses, e.g., Pu-239 and Am-241, these assumptions high side the organ doses by at least a factor of 8. (ICRP, 2011)
- **Ingestion dose coefficients**: Like the inhalation dose coefficients discussed above, when a choice was available in determining the dose coefficients (for Sr-90, Pu-239, and Co-60), "Unspecified compounds" was assumed. For all organs, this assumption results in the use of very similar or higher dose coefficients than those for alternative choices by factors of up to 30 for Sr-90 and up to 50 for Pu-239. Ingestion dose coefficients for Co-60 do not vary much for different chemical forms. (ICRP, 2011)

4.3.2. Internal Dose Parameter Values Specific to each EPG

The only EPG-specific internal exposure pathway is inhalation of suspended soil. The specific parameter values used for each EPG for estimation of soil inhalation doses from this pathway are shown in Table 8, and brief discussions of the parameter values for each EPG are in the following subsections.

4.3.2.1 Soil Removal Workers EPG

The soil radionuclide concentrations on the work island used for this EPG for all radionuclides except TRU radionuclides consist of the weighted averages of the island-average concentrations on the five soil removal islands of Boken, Enjebi, Lujor, Aomon, and Runit. The weighted average is calculated by weighting each of the island concentrations by the fraction of the total volume of excised soil that is removed from the island and assumes that the volume of soil removed is directly related to time spent on the island. To maximize the potential internal dose, the value listed for Pu-239 in Table 8 is the weighted average of TRU radioactivity concentration in soil removed from the soil removal islands. The TRU value is weighted in the same manner as the other radionuclides. Small quantities of TRU radionuclides other than Pu-239 were also present in excised soil and elsewhere on the atoll (e.g., Pu-238 and Pu-241) as well as other fission products (e.g., Sb-125 and Eu-155). However, because of their low concentrations and/or radiological decay characteristics, these additional radionuclides are not important from an ECUP radiological dose perspective. The residence island soil concentrations used for this EPG are the island-average concentrations on Lojwa. (DTRA, 2020)

The resuspension factor used for the work island for this EPG is based on airborne soil concentrations near an operating bulldozer and is applicable to soil excision and windrowing activities. The selected value for the resuspension factor for this EPG is 1.2×10^{-7} m^{-1}, which corresponds to a mass loading of 600 μg m^{-3} (DTRA, 2020). An additional maximizing assumption is that dust suppression during soil disruption activities via water spraying is not considered. The resuspension factor used for the residence island of Lojwa for this EPG is based on the default mass loading value reported in DTRA (2020) and is representative of airborne mass loading due to truck traffic. The selected value for the resuspension factor for this EPG residence island is 2×10^{-8} m^{-1}, which corresponds to a mass loading of 100 μg m^{-3} (DTRA, 2020). This high-sided value is approximately 2.5 times greater than the estimated ambient dust loading of 40 μg m^{-3} for the Atoll (AEC, 1973). A discussion of ECUP mass loading values and conversions between mass loading values and resuspension factors is provided in DTRA (2020).

Table 8. EPG-specific inhalation dose parameter values

Parameter	Soil Removal Workers*	Northern Island Workers*	Lojwa Support Workers	Southern Island Workers
Soil radionuclide concentrations on work island(s) (pCi g^{-1}) †				
Sr-90	47.2	39.4	8.2	0.76
Cs-137	17.1	13.9	2.6	0.32
Pu-239	123‡	12.8	1.8	0.21
Am-241	-§	3.28	1.2	0.14
Co-60	3.1	1.70	0.31	0.06
Soil radionuclide concentrations on residence island (pCi g^{-1}) †				
Sr-90	8.2	8.2	8.2	0.61
Cs-137	2.6	2.6	2.6	0.25
Pu-239	1.8	1.8	1.8	0.08
Am-241	1.2	1.2	1.2	0.05
Co-60	0.31	0.31	0.31	0.04
Resuspension factor (m^{-1})				
Work Island(s)	1.2×10^{-7}	6.0×10^{-8}	2.0×10^{-8}	2.0×10^{-8}
Residence Island	2.0×10^{-8}	2.0×10^{-8}	2.0×10^{-8}	2.0×10^{-8}

* The soil radionuclide concentrations on the work islands for these EPGs are weighted averages and are used to account for the assumed amount of time on each of the islands relevant to the EPG. See Sections 4.3.2.1 and 4.3.2.2 for additional information.

† These soil radionuclide concentrations are not decay-corrected for the elapsed time between the AEC 1972-1973 surveys and the start of the ECUP.

‡ This is the estimated average TRU concentration of the soil removed from the five soil removal islands (DTRA, 2020).

§ Am-241 is included in the value shown for Pu-239.

4.3.2.2 Northern Island Workers EPG

The soil radionuclide concentrations on the work island used for this EPG consists of the weighted average of the island-average exposure rates on the northern islands. The weighted average is calculated by weighting each of the island concentrations by the fraction of the total volume of debris removed from the island and assumes that the volume of debris removed is directly related to time spent on the island by workers in this EPG. The residence island soil concentrations used for this EPG are the island-average concentrations on Lojwa. (DTRA, 2020)

The resuspension factor used for the work island for this EPG is based on airborne soil concentrations near activities such as agricultural tilling. It is considered to be applicable to vegetation clearing, buried debris removal, and similar ECUP activities. The selected value for the resuspension factor for work islands for this EPG is 6×10^{-8} m^{-1}, which corresponds to a mass loading of 300 μg m^{-3} (DTRA, 2020). An additional maximizing assumption is that dust suppression during any soil disruption activities via water spraying is not considered. The resuspension factor used for the residence island of Lojwa for this EPG is based on the default mass loading value reported in DTRA (2020) and is representative of airborne mass loadings due

to truck traffic. The selected value for the resuspension factor for this EPG residence island is 2×10^{-8} m^{-1}, which corresponds to a mass loading of 100 μg m^{-3} (DTRA, 2020). Like the Soil Removal Workers EPG described in Section 4.3.2.1, the high-sided default value is approximately 2.5 times greater than the estimated ambient dust loading for the Atoll. (AEC, 1973; DTRA, 2020)

4.3.2.3 Lojwa Support Workers EPG

The soil radionuclide concentrations on the work and residence island used for this EPG (Lojwa) are the island-average concentrations on Lojwa (DTRA, 2020).

The resuspension factor used for the work and residence island of Lojwa for this EPG is based on the default mass soil loading value reported in DTRA (2020) and is representative of airborne mass loadings due to truck traffic. The selected value for this resuspension factor is 2×10^{-8} m^{-1}, which corresponds to a mass loading of 100 μg m^{-3} (DTRA, 2020). Like the Soil Removal Workers EPG described in Section 4.3.2.1, the high-sided default value is approximately 2.5 times greater than the estimated ambient dust loading for the Atoll. (AEC, 1973; DTRA, 2020)

4.3.2.4 Southern Island Workers EPG

The soil radionuclide concentrations on the work island used for this EPG consist of the island-average concentrations on Medren. This work location is used because there was a considerable amount of work accomplished on the island (debris removal and rehabilitation work) and the soil TRU concentration is higher than on all other southern islands except Biken, a small, isolated island with a small volume of non-contaminated debris that was removed. The residence island soil radionuclide concentrations used for this EPG is the island-average concentrations on Enewetak, which was the primary residence island for ECUP. (DTRA, 2020)

The resuspension factor on the work and residence islands used for this EPG, Medren and Enewetak, respectively, is based on the default mass loading value reported in DTRA (2020) and is representative of airborne mass loadings due to truck traffic. The selected value for this resuspension factor is 2×10^{-8} m^{-1}, which corresponds to a mass loading of 100 μg m^{-3} (DTRA, 2020). Like the other EPGs, this high-sided default value is approximately 2.5 times greater than the estimated ambient dust loading for the Atoll. (AEC, 1973; DTRA, 2020)

4.4 Skin Dose Parameter Values

This section describes the assumptions and parameter values that are used to estimate maximized upper-bound skin doses for the ECUP EPGs. The skin dose estimation consists of an external non-contact dose from contaminated soil, and an external dose due to contamination deposited on the skin. Dose parameters used for these two exposure pathways are discussed in the following subsections. The equations used for the dose estimation are presented in Appendix C of DTRA (2020).

4.4.1. Parameter Values for Non-contact Skin Doses

Non-contact skin doses consist of external exposure of the skin to gamma and beta radiation emanating from a contaminated source. For the ECUP EPG skin dose assessments, the contaminated source consists of undisturbed soil on the work and residence island(s). Because this is an external exposure dose that would be accrued simultaneously with the external whole-body dose discussed in Section 4.2, the parameters and maximizing parameter values are largely the same as discussed in that section. Specifically, the parameters in Table 5 and Table 6 are used for the estimation of non-contact skin doses. In addition to these parameters, other assumptions include a veteran height of 68 inches, and a modifying factor of 1 to estimate exposure of bare skin. The final parameter used in the estimation of non-contact skin doses is the beta-gamma dose ratio. The beta-gamma dose ratios used for 17 skin sites on an individual of height 173 cm (68 in) are shown in Table 9 (DTRA, 2020). These parameters are briefly discussed below.

- **Veteran height**: A veteran height of 68 inches is assumed. This value is typically assumed as a default value in NTPR, and it is similar to the ICRP reference value of 176 cm (69.3 in) for adult males (ICRP, 2002). An assumed height that is less than the reference height results in slightly higher non-contact skin doses for most skin sites.
- **Modifying factor:** A value of 1 is used, which indicates no modifications to the dose estimates to account for factors such as a skin site covered by clothing. A factor of 1.0 represents exposure to bare, dry skin, and is used for all veteran skin sites in order to maximize the estimated non-contact skin doses.
- **Beta-gamma dose ratio**: The beta-gamma dose ratio relates the beta skin dose to the gamma skin dose from exposure to a contaminated infinite plane source. Values of this ratio for ECUP scenarios have been estimated (DTRA, 2020). Median values of these ratios are used for all ECUP EPGs.

Table 9. Skin site-specific parameter values

Skin Site	Skin Site Height Above Ground (standing) (cm)*	Beta-Gamma Dose Ratio*	Skin Dose Modification Factor†	Effective Retention Fraction†
Scalp	173	0.177	1.3	0.23
Face	160	0.194	1.3	0.015
Forehead	160	0.194	1.3	0.015
Behind ear	160	0.194	1.3	1.5
Neck	150	0.207	1.3	0.015
Back of neck	150	0.207	0.9	1.5
Shoulder	140	0.222	1.3	0.015
Chest	140	0.222	1.3	0.03
Torso (back, side)	140	0.222	1.3	0.015
Under belt	119	0.256	1.3	1.5
Forearm	99	0.295	0.9	0.06
Upper leg	71	0.366	1.3	0.06
Palm	71	0.366	0.3	0.015
Back of hand	71	0.366	1.3	0.06
Lower leg	20	0.631	0.9	0.06
Sole of foot	1	1.270	0.3	0.06
Under boot edge	1	1.270	0.9	1.5

* Skin site heights and beta-gamma dose ratios are for an individual with a height of 173 cm (68 in).

† The Skin Dose Modification Factor and the Effective Retention Fraction are used in the dermal contamination skin dose estimation (DTRA, 2021, SM ED04).

4.4.2. Parameter Values for Dermal Contamination Skin Doses

Dermal contamination skin doses consist of external exposure of the skin to gamma, beta, and alpha radiation emanating from a contaminated source deposited on the skin or clothing. For the ECUP EPG skin dose assessments, the contaminated source consists of contaminated soil on the work and residence island(s) that has been suspended and then deposited on the skin. Because this is an external exposure dose that would be accrued simultaneously with the internal doses from suspended soil discussed in Section 4.3, there are many parameters and parameter values in common with those discussed in that section. Specifically, the parameters in Table 7 and Table 8 regarding maximizing assignment duration and work schedule, time spent indoors and outdoors, as well as resuspension factors, soil density, suspended soil thickness, and radionuclide concentrations, are used for the estimation of dermal contamination skin doses. Skin-site specific parameters used to estimate dermal contamination skin doses are shown in Table 9 (skin dose modification factors and effective retention fractions). Additional parameters include an airborne soil deposition velocity of 1 m s^{-1}, an additional post-work exposure time of 2 h, and a maximizing value of 1.0 for the fraction of a workday a worker is exposed to suspended soil. Finally, radionuclide- and skin site-specific dose coefficients for dermal contamination are shown in Table 10. (DTRA, 2020)

Table 10. Dermal contamination skin dose coefficients

	Dose Coefficient (rem h^{-1} per pCi cm^{-2})*				
Skin site	**Sr/Y-90**	**Cs-137**	**Pu-239/240**	**Am-241**	**Co-60**
Scalp	1.20×10^{-5}	5.69×10^{-6}	6.40×10^{-3}	7.40×10^{-3}	3.83×10^{-6}
Face	(all sites)	(all sites)	6.40×10^{-3}	7.40×10^{-3}	(all sites)
Forehead	↓	↓	6.40×10^{-3}	7.40×10^{-3}	↓
Behind ear			6.40×10^{-3}	7.40×10^{-3}	
Neck			6.40×10^{-3}	7.40×10^{-3}	
Back of neck			6.40×10^{-3}	7.40×10^{-3}	
Shoulder			6.40×10^{-3}	7.40×10^{-3}	
Chest			6.70×10^{-3}	8.20×10^{-3}	
Torso (back, side)			6.40×10^{-3}	7.40×10^{-3}	
Under belt			6.70×10^{-3}	8.20×10^{-3}	
Forearm			7.40×10^{-4}	1.30×10^{-3}	
Upper leg			7.40×10^{-4}	1.30×10^{-3}	
Palm			0	0	
Back of hand			0	0	
Lower leg			7.40×10^{-4}	1.30×10^{-3}	
Sole of foot			0	0	
Under boot edge	↓	↓	7.40×10^{-4}	1.30×10^{-3}	↓

* Dermal contamination dose coefficients are documented in DTRA (2020). If a value is not included in that report for a specific skin site, an estimated value is used.

Maximized skin doses from dermal contamination are estimated over a total period of 12 h d^{-1} for all EPGs. This is based on the maximizing assumption that the total amount of contaminated soil that could have gradually accumulated on bare skin over a 10-hour workday is assumed to be deposited at the beginning of the workday. Furthermore, accumulated soil is assumed to remain on the skin until completely removed by washing an average of 2 h after the end of the workday. Daily soil accumulation on the skin is limited to 2 mg cm^{-2} because it is likely that a worker would brush off accumulated soil before such an amount is deposited (DTRA, 2020). The assumption that the entire amount of soil that would have accumulated during the workday is deposited at the beginning of the day overestimates the skin dermal contamination dose by a factor of about two. The assumptions of a 10-hour accumulation period and 12-hour dose period for workdays are also used for non-workdays. Ignoring the small skin dermal contamination doses from any accumulation while outdoor on the residence island following the workday is largely compensated by the assumption of deposition of the daily soil loading at the beginning of the day. In addition, the radionuclide soil concentrations on the residence islands were lower than on work islands and there were fewer activities conducted during non-work hours that would disrupt soil.

4.5 Lens of Eye Dose Parameter Values

A dose to the lens of the eye is estimated for the ECUP EPGs for use in veteran claims involving posterior subcapsular cataracts ("cataracts"). In order to simplify the EPG assessments, a single, maximized upper bound is estimated that bounds the potential dose for ECUP participants in all ECUP EPGs. The dose estimation for the lens of the eye consists of a maximized upper-bound external non-contact dose from contaminated soil, and a maximized upper-bound external dose due to contamination deposited on the eyelid. Dose parameters used for these two exposure pathways are discussed in the following subsections.

4.5.1. Parameter Values for Non-contact Lens of Eye Dose

Similar to the ECUP EPG skin dose, the source and exposure pathway for the non-contact dose to the lens of the eye consists of external exposure to gamma and beta radiation emanating from undisturbed soil on the work and residence island(s). Because this is an external exposure dose that would be accrued simultaneously with the external whole body dose and the skin doses discussed in Sections 4.2 and 4.4, some of the parameters and parameter values are the same as discussed in those sections. Specifically, the parameter values in Table 5 and the external exposure rate for the Soil Removal Workers EPG in Table 6 are used for the estimation of the gamma portion of the non-contact skin doses. As a maximizing assumption, this dose is estimated for a height corresponding to an individual that is sitting on the ground for an entire ECUP assignment. Additional parameters used to estimate the beta portion of the non-contact dose are shown in Table 11.

Table 11. Parameter values used to estimate the non-contact lens of the eye dose

Parameter	Value	Comment
Height of eye while sitting on the ground	75 cm	Maximizing assumption used instead of standing eye height of 160 cm
Ratio of lens of the eye beta-gamma dose ratio to eyelid beta-gamma dose ratio	0.25	Estimated value based on available ratios for NTPR (see text discussion)
Beta-gamma dose ratio for skin of eyelid while sitting on the ground	0.354	Median value estimated using method in DTRA (2020)
Beta-gamma dose ratio for lens of the eye while sitting on the ground	0.089	Calculated using parameter values listed above

- **Height of eye:** This maximizing assumption assumes that a participant is sitting on the ground rather than standing upright. This orientation places the lens of the eye at 75 cm above the contaminated ground source rather than the default height of 160 cm. This increases the estimated beta radiation dose.
- **Ratio of lens of the eye beta-gamma dose ratio to eyelid beta-gamma dose ratio**: Beta-gamma dose ratios for the lens of the eye are not available for ECUP scenarios. Therefore, a value is estimated for ECUP based on the NTPR lens of the eye beta-gamma dose ratios in

SM ED05 (DTRA, 2021), and the beta-gamma dose ratios for bare skin exposures in SM ED03 (DTRA, 2021).

- **Beta-gamma dose ratio for skin of eyelid**: The beta-gamma dose ratio for the eyelid is based on the ratio for the skin of the face. This ratio relates the beta skin dose to the gamma skin dose from exposure to a contaminated infinite plane source. A median value of this ratio for a height of 75 cm was estimated using the equation provided in DTRA (2020).

4.5.2. Parameter Values for Lens of the Eye Dose from Dermal Contamination of Eyelid

The lens of the eye dose from dermal contamination of the eyelid consists of external exposure of the lens of the eye to gamma and beta radiation emanating from contaminated soil deposited on the eyelid. For this dose assessment, the contaminated soil is assumed to be suspended and then deposited on the eyelid while on the work and residence islands. The dose is based on the dermal contamination beta dose to the eyelid, and application of a ratio of the lens of the eye dose to the eyelid dose. Because this is an external exposure dose that would be accrued simultaneously with the external and skin dermal contamination doses from suspended soil, there are many parameters and parameter values in common with those discussed in Sections 4.2 and 4.4.2. Specifically, the maximizing parameter values in Table 7 and Table 8 regarding assignment duration and work schedule, time spent indoors and outdoors, as well as the resuspension factors, soil density, suspended soil thickness, and radionuclide concentrations for the Soil Removal Workers EPG are used for the estimation of dermal contamination skin doses. Additional parameters used to estimate the lens of the eye dose are shown in Table 12.

Table 12. Parameter values used to estimate the lens of the eye dose from dermal contamination of the eyelid

Parameter	Value	Comment
Upper-bound dermal contamination beta+gamma eyelid dose (rem)	0.003	See Section 4.4.2. (dose to face is used as a surrogate)
Ratio of 95th percentile to default values of Effective Retention Fraction for face	8	Maximizing value based on the NTPR 95th percentile upper limit of this parameter rather than the NTPR default value in SM ED04 (DTRA, 2021)
Ratio of lens of the eye dose to eyelid dose	0.2	NTPR methodology in SM ED05 (DTRA, 2021)

5.

Results and Discussion of the ECUP Expedited Processing Doses

Four EPGs with distinct exposure scenarios are identified in Section 3 that collectively cover the majority of the ECUP participants. The details of the dose assessments for the four EPGs are presented in Section 4. This section presents the external and internal organ doses, and external skin doses estimated for each EPG. A bounding dose to the lens of the eye applicable to all EPGs is also discussed. Recommendations for use of the dose results in expedited processing, including EPG/organ combinations not recommended for expedited processing, are also discussed.

5.1 Dose Assessment Results

Scenario-based external, internal, skin, and lens of the eye doses are calculated for each EPG based on the methodology described in Section 4. These doses and their corresponding upper bounds are recommended for use in expedited processing of most ECUP cases except as noted in this section.

5.1.1. External and Internal Organ Doses

The EPG doses consist of estimates calculated using maximizing exposure scenarios and input parameter values that clearly high side each dose component. The EPG doses are estimated for external gamma radiation, internal alpha radiation, and internal beta+gamma radiation for 24 organs, for which ICRP 68 dose coefficients are available. The 24 EPG TODs are calculated for each EPG by adding the upper-bound external dose and the upper-bound internal alpha and beta+gamma organ doses.

For each EPG, upper-bound doses are generated from the maximized doses by applying DTRA-approved uncertainty factors, which are detailed in SM UA01 (DTRA, 2021). Across all EPGs, the maximized upper-bound external doses range from less than 0.1 to 0.3 rem. A wider range is observed for maximized upper-bound internal organ doses. The maximized external doses, the maximized upper-bound external and internal doses (upper-bound alpha and beta+gamma doses presented separately), and the EPG TODs for four ECUP EPGs are provided in Table 13.

5.1.2. Skin Doses

Maximized upper-bound skin doses (alpha, beta+gamma, and total) are calculated for 17 representative skin sites for members of the four EPGs using the assumptions and parameter values described in Section 4. A summary of these skin doses is shown in Table 14.

Table 13. Estimated organ doses for ECUP EPGs (rem) *

EPG Name		Internal Radiation Type and EPG TOD*	ECUP Standard Organs																						
			Adrenals	Bladder Wall	Bone Surface	Brain	Breast	Esophagus	Stomach Wall	SI Wall*	ULI Wall*	LLI Wall*	Colon	Kidneys	Liver	Muscle	Ovaries	Pancreas	Red Marrow	ET Airways*	Lungs	Spleen	Testes	Thymus	Thyroid	Uterus
Soil Removal Workers		UB α	0.08	0.08	47	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.2	10	0.08	0.6	0.08	3	0.3	1	0.08	0.6	0.08	0.08	0.08
External Dose	Upper Bound	UB β+γ	0.02	0.02	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02
0.1	0.3	EPG TOD	0.4	0.4	48	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.4	0.5	10	0.4	1	0.4	3	0.7	2	0.4	1	0.4	0.4	0.4
Northern Island Workers		UB α	0.009	0.009	4	0.009	0.009	0.009	0.009	0.009	0.01	0.02	0.01	0.02	0.7	0.009	0.06	0.009	0.2	0.03	0.07	0.009	0.06	0.009	0.009	0.009
External Dose	Upper Bound	UB β+γ	0.02	0.02	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02
0.1	0.3	EPG TOD	0.4	0.4	5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1	0.4	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Lojwa Support Workers		UB α	0.004	0.004	1	0.004	0.004	0.004	0.004	0.004	0.005	0.008	0.006	0.006	0.2	0.004	0.02	0.004	0.05	0.006	0.01	0.004	0.02	0.004	0.004	0.004
External Dose	Upper Bound	UB β+γ	0.02	0.02	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02
0.03	0.09	EPG TOD	0.1	0.1	1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Southern Island Workers		UB α	0.003	0.003	0.6	0.003	0.003	0.003	0.003	0.004	0.005	0.007	0.006	0.005	0.1	0.003	0.01	0.003	0.03	0.004	0.004	0.003	0.01	0.003	0.003	0.003
External Dose	Upper Bound	UB β+γ	0.02	0.02	0.07	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02
0.002	0.005	EPG TOD	0.03	0.03	0.7	0.02	0.02	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.2	0.02	0.04	0.03	0.07	0.03	0.03	0.03	0.03	0.03	0.03	0.03

* The upper-bound external, UB α, and UB β+γ doses in this table are recommended for assignment in expediting ECUP cases except as noted in Table 15. For each standard organ, the doses are recommended for all organs, diseases, and tissues for which the standard organ is applicable.

† ECUP standard organs are the organs for which internal dose coefficients are available in ICRP 68 (ICRP, 2011).

‡ EPG TOD is the sum of the External Upper Bound, UBα, and UB β+γ doses.

SI = small intestine; ULI = upper large intestine; LLI = lower large intestine; ET Airways = extra-thoracic airways.

Table 14. Upper-bound external lens of the eye and skin doses for ECUP EPGs

Dose location	Total Upper-Bound External (beta+gamma) Eye Lens Dose (rem)*											
	Soil Removal			Northern Islands			Lojwa Support			Southern Islands		
Lens of the eye	0.4											
Skin Site	Upper-Bound External Skin Doses (rem)											
	Soil Removal			Northern Islands			Lojwa Support			Southern Islands		
	UB α	UB β+γ	UB Tot†	UB α	UB β+γ	UB Tot	UB α	UB β+γ	UB Tot	UB α	UB β+γ	UB Tot
Scalp	45	0.4	45	3	0.4	4	0.3	0.1	0.4	0.02	0.006	0.02
Face	3	0.4	4	0.2	0.4	0.6	0.02	0.1	0.1	0.001	0.006	0.007
Forehead	3	0.4	4	0.2	0.4	0.6	0.02	0.1	0.1	0.001	0.006	0.007
Behind ear	60.	0.5	60.	9	0.4	9	2	0.2	2	0.1	0.007	0.1
Neck	3	0.4	4	0.2	0.4	0.6	0.02	0.1	0.1	0.001	0.006	0.007
Back of neck	60	0.5	60	9	0.4	9	2	0.1	2	0.1	0.006	0.1
Shoulder	3	0.4	4	0.2	0.4	0.6	0.02	0.1	0.1	0.001	0.006	0.007
Chest	6	0.4	7	0.5	0.4	0.8	0.04	0.1	0.2	0.002	0.006	0.008
Torso (backside)	3	0.4	4	0.2	0.4	0.6	0.02	0.1	0.1	0.001	0.006	0.007
Under belt	63	0.5	63	9	0.4	9	2	0.2	2	0.1	0.007	0.1
Forearm	2	0.4	2	0.1	0.4	0.5	0.009	0.1	0.1	<0.001	0.006	0.007
Upper leg	2	0.5	2	0.1	0.4	0.5	0.009	0.1	0.2	<0.001	0.006	0.007
Palm	0	0.4	0.4	0	0.4	0.4	0	0.1	0.1	0	0.006	0.006
Back of hand	0	0.5	0.5	0	0.4	0.4	0	0.1	0.1	0	0.006	0.006
Lower leg	2	0.5	2	0.1	0.5	0.6	0.009	0.2	0.2	<0.001	0.007	0.008
Sole of foot	0	0.7	0.7	0	0.7	0.7	0	0.2	0.2	0	0.009	0.009
Under boot edge	7	0.8	8	1	0.7	2	0.2	0.2	0.4	0.02	0.01	0.03

* A maximized upper-bound lens of the eye dose was estimated for the Soil Removal Workers EPG and is recommended as a bounding dose for all EPGs.

† "UB Tot" is the total upper-bound skin site dose. This dose may not equal the sum of UB α and UB β+γ because the doses shown are rounded up.

5.1.3. Lens of the Eye Dose

A maximized external dose for the lens of the eye is estimated for the Soil Removal Workers EPG using the assumptions and parameter values described in Section 4. The resulting total upper-bound external dose (beta plus gamma) to the lens of the eye is 0.4 rem. The total upper-bound skin dose for face for the Soil Removal Workers EPG bounds the upper-bound face skin doses for the other three EPGs (Table 14). Therefore, the total maximized upper-bound dose to the lens of the eye calculated based on this EPG will bound the lens of the eye doses for the other EPGs. This maximized upper-bound dose is much lower than the dose of 19 rad that is the lower limit of the 95 percent confidence interval for a threshold dose for Stage I posterior subcapsular cataracts quoted by the VA (2011). Therefore, the maximized upper-bound dose to the lens of the eye estimated here can be assigned during ECUP expedited processing of cataract cases for all ECUP veterans.

5.2 Organ and Skin Site Exclusions from Expedited Processing

To determine exclusions of EPG/organ combinations from automatic expedited processing based on exceeding applicable limiting doses, the EPG TODs of the 24 standard organs for each EPG shown in Table 13 are compared with the applicable organ cancer/disease LDα values listed in Table 1. This evaluation process is discussed in detail in Section 2. If an EPG TOD is equal to or higher than its applicable limiting dose, it is recommended that the EPG/organ combination be excluded from automatic expedited processing. Only the EPG/organ combinations for which the NIOSH-IREP estimated probability of causation is lower than 40 percent are deemed eligible for automatic expedited processing.

Of these EPG/organ dose comparisons to LDα values, EPG TODs for only two EPG/organ combinations, or approximately 2 percent of all EPG/organ combinations, are equal to or higher than the respective LDα; these are shown in Table 15. Cases involving all other organs and cancer models in all ECUP EPGs may be expedited by assigning the upper-bound external, internal alpha, and internal beta+gamma doses in Table 13. As discussed earlier, the limiting doses based on acute alpha radiation (LDα) were assumed to be appropriate for comparison with ECUP EPG organ doses because the TODs for several organs are dominated by alpha radiation, and LDα values are generally lower than LDγ values (Table 1). For the few organs and cancer models that have lower LDγ values than LDα values, the EPG TODs are well below both the LDγ and LDα values and comparison with either value results in the same conclusion. Finally, the EPG TODs for the two EPG/organ combinations that are higher than the respective LDα are both dominated by alpha radiation.

Table 15. EPG and organ combinations not recommended for expedited processing

ECUP EPG	ECUP Standard Organ	NIOSH-IREP Cancer Model
Soil Removal Workers	Bone Surface	Bone
	Liver	Liver, Gallbladder
Northern Island Workers	None	n/a
Lojwa Support Workers	None	n/a
Southern Island Workers	None	n/a

To determine exclusions of EPG/cancer/race category/skin site combinations from automatic expedited processing based on exceeding applicable limiting doses, the total upper-bound skin doses for 17 skin sites are compared with LDα values for three types of skin cancers and two combined groups of races. Three races are merged into the first grouping (Table 16), and two races are combined into the second grouping (Table 17), based on similarity of LDα values. Decisions on expediting skin dose cases should be based on the recommendations and doses shown in Table 16 and Table 17. Total doses for 74 of the 408 EPG/cancer/race category/skin site combination doses (approximately 18 percent) exceed the applicable LDα values. These are limited to skin sites with malignant melanoma and basal cell carcinoma in three of the four ECUP EPGs, as shown in Table 16 and Table 17. Similar to internal organ dose comparisons, the limiting doses based on acute alpha radiation (LDα) were assumed to be appropriate for comparison with ECUP EPG skin doses because the estimated upper-bound skin doses for many of the skin sites are dominated by alpha radiation from dermal contamination. The comparison to LDα values to determine exclusions is acceptable for the skin sites that are not dominated by alpha radiation because the upper-bound doses for these sites are less than the LDα values for all three skin cancer types in all races.

Table 16. Recommendations for EPG dose assignments for skin cancer cases for "American Indian or Alaska Native", "Asian, Native Hawaiian, or other Pacific Islander", and "Black" participants

	EPG/Cancer/Skin Site Combinations that are Recommended (green) and Not Recommended (red) for ECUP Expedited Processing [*,†,‡]											
	Soil Removal			Northern Islands			Lojwa Support			Southern Islands		
Skin Site	MM	BCC	SCC	MM	BCC	SCC	MM	BCC	SCC	MM	BCC	SCC
Scalp												
Face												
Forehead												
Behind ear												
Neck												
Back of neck												
Shoulder												
Chest												
Torso (backside)												
Under belt												
Forearm												
Upper leg												
Palm												
Back of hand												
Lower leg												
Sole of foot												
Under boot edge												

* MM = malignant melanoma. LDα values for MM are 1.0–1.8 rem for the participants represented in this table; an LDα of 1.0 rem is used for expedited processing recommendations.
BCC = basal cell carcinoma. The BCC LDα value for all participants represented in this table is 0.85 rem.
SCC = squamous cell carcinoma cases. The SCC LDα value for all participants represented in this table is 63 rem.

† Red-shaded table cells indicate EPG/Skin cancer/Skin site combinations that are not recommended for expedited processing for the participants represented in this table (see Table caption).

‡ Green-shaded table cells shaded green indicate EPG/Skin cancer/Skin site combinations that are recommended for expedited processing for the participants represented in this table (see Table caption), with assignment of the applicable dose from Table 14.

Table 17. Recommendations for EPG dose assignments for skin cancer cases for "White (Hispanic)" and "White (Non-Hispanic)" participants

Skin Site	EPG/Cancer/Skin Site Combinations that are Recommended (green) and Not Recommended (red) for ECUP Expedited Processing*,†,‡											
	Soil Removal			Northern Islands			Lojwa Support			Southern Islands		
	MM	BCC	SCC	MM	BCC	SCC	MM	BCC	SCC	MM	BCC	SCC
Scalp												
Face												
Forehead												
Behind ear												
Neck												
Back of neck												
Shoulder												
Chest												
Torso (backside)												
Under belt												
Forearm												
Upper leg												
Palm												
Back of hand												
Lower leg												
Sole of foot												
Under boot edge												

* MM = malignant melanoma. LDα values for MM are 2.1–2.4 rem for the participants represented in this table; an LDα of 2.1 rem is used for expedited processing recommendations.
BCC = basal cell carcinoma. LDα values for BCC are 2.4–2.5 rem for the participants represented in this table; an LDα of 2.4 rem is used for expedited processing recommendations.
SCC = squamous cell carcinoma cases. LDα values for SCC are 165–175 rem for the participants represented in this table; an LDα of 165 rem is used for expedited processing recommendations.

† Red-shaded table cells indicate EPG/Skin cancer/Skin site combinations that are not recommended for expedited processing for the participants represented in this table (see Table caption).

‡ Green-shaded table cells indicate EPG/Skin cancer/Skin site combinations that are recommended for expedited processing for the participants represented in this table (see Table caption), with assignment of the applicable dose from Table 14.

6.

References

AEC (United States Atomic Energy Commission, Nevada Operations Office), 1973. *Enewetak Radiological Survey, Vol I.* NVO-140, United States Atomic Energy Commission, Nevada Operations Office, Las Vegas, NV. October.

Case, D. R., Chehata, M., Dunavant, J. D., Egbert, S. D., Mason, C. L., McKenzie-Carter, M. A., Singer, H. A., and Weitz, R. L., 2011. *A Technical Approach to Expedited Processing of NTPR Radiation Dose Assessments*. DTRA-TR-10-29, Defense Threat Reduction Agency. Fort Belvoir, VA. October 17.

Congress (United States Congress), 1977. *An Act to authorize certain appropriations for the territories of the United States, to amend certain acts relating thereto, and for other purposes.* House of Representative Bill 6550, 95th Congress (Second Session). Washington, DC. September 30.

DNA (Defense Nuclear Agency), 1981. *The Radiological Cleanup of Enewetak Atoll*. Defense Nuclear Agency, Washington, D.C.

DTRA (Defense Threat Reduction Agency), 2018. *Radiation Dose Assessment for Military Personnel of the Enewetak Atoll Cleanup Project (1977-1980).* DTRA-TR-17-003. Defense Threat Reduction Agency, Fort Belvoir, VA, April 13.

DTRA (Defense Threat Reduction Agency), 2020. *Radiation Dose Assessment for Military Personnel of the Enewetak Atoll Cleanup Project (1977-1980), Revision 1.* DTRA-TR-17-003(R1). Defense Threat Reduction Agency, Fort Belvoir, VA, April 30.

DTRA (Defense Threat Reduction Agency), 2021. *Nuclear Test Personnel Review, Standard Operating Procedures for Radiation Dose Assessments – List and Overview (Revision 1). Update: April 2021*. DTRA-SOP-17-01(R1), Defense Threat Reduction Agency, Fort Belvoir, VA. April 30.

ICRP (International Commission on Radiological Protection), 2011. *ICRP Database of Dose Coefficients: Workers and Members of the Public, Version 3.0*. The International Commission on Radiological Protection, Ottawa, Ontario.

ICRP (International Commission on Radiological Protection), 2002. *Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values*. ICRP Publication 89. Ann. ICRP 32 (3-4). International Commission on Radiological Protection, Ottawa, Ontario.

McKenzie-Carter, M. and Egbert, S. 2015. *Technical Basis for Expedited Processing of Radiation Dose Assessments for NTPR Hiroshima and Nagasaki Participants.* DTRA-TR-15-044, Defense Threat Reduction Agency, Fort Belvoir, VA. November 16.

NIOSH (National Institute for Occupational Safety and Health), 2020. *Interactive RadioEpidemiological Program, NIOSH-IREP ver. 5.9.* National Institute for

Occupational Safety and Health, Washington, DC. December. Available at: https://irep.oraucoc.org/, accessed August 25, 2021.

VA (U.S. Department of Veterans Affairs), 2011. *Instructions for VBA Staff for Screening "Worst Case" Posterior Subcapsular Cataract (PSC) Compensation Claims from "Radiation-Exposed Veterans."* Memo from Walters, T., Director of Environmental Agents Service (10P3A) to Director, Compensation Service (211B). April 25.

Appendix A.

Inhalation and Ingestion Dose Coefficients

The tables in this Appendix contain the ICRP 68 dose coefficients used for the estimation of ECUP EPG internal organ doses for inhalation (Table A-1) and ingestion (Table A-2).

Table A-1. ICRP 68 Organ Inhalation Dose Coefficients (rem pCi^{-1}) *

Organ/Tissue†	Co-60 (Type M)	Sr-90 (Type F)	Cs-137 (Type F)	Pu-239 (Type M)	Am-241 (Type M)
Adrenals	2.41×10^{-8}	2.22×10^{-9}	1.81×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Bladder Wall	8.88×10^{-9}	4.81×10^{-9}	1.85×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Bone Surface	1.37×10^{-8}	1.37×10^{-6}	1.78×10^{-8}	5.55×10^{-3}	5.92×10^{-3}
Brain	7.03×10^{-9}	2.22×10^{-9}	1.52×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Breast	2.15×10^{-8}	2.22×10^{-9}	1.44×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Esophagus	2.52×10^{-8}	2.22×10^{-9}	1.67×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Stomach Wall	1.59×10^{-8}	2.29×10^{-9}	1.70×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
SI Wall	1.22×10^{-8}	2.41×10^{-9}	1.81×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
ULI Wall	1.44×10^{-8}	7.03×10^{-9}	1.85×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
LLI Wall	1.81×10^{-8}	1.92×10^{-8}	2.15×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Colon	1.59×10^{-8}	1.22×10^{-8}	1.96×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Kidneys	1.41×10^{-8}	2.22×10^{-9}	1.74×10^{-8}	2.18×10^{-5}	3.00×10^{-5}
Liver	3.00×10^{-8}	2.22×10^{-9}	1.74×10^{-8}	1.11×10^{-3}	3.59×10^{-4}
Muscle	1.33×10^{-8}	2.22×10^{-9}	1.63×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Ovaries	1.15×10^{-8}	2.22×10^{-9}	1.85×10^{-8}	7.03×10^{-5}	1.15×10^{-4}
Pancreas	2.00×10^{-8}	2.22×10^{-9}	1.85×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Red Marrow	1.52×10^{-8}	5.92×10^{-7}	1.67×10^{-8}	2.59×10^{-4}	2.04×10^{-4}
ET Airways	6.29×10^{-8}	6.66×10^{-9}	2.89×10^{-8}	3.52×10^{-5}	3.66×10^{-5}
Lungs	1.81×10^{-7}	2.29×10^{-9}	1.63×10^{-8}	1.11×10^{-4}	1.26×10^{-4}
Skin	8.51×10^{-9}	2.22×10^{-9}	1.37×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Spleen	1.85×10^{-8}	2.22×10^{-9}	1.74×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Testes	7.03×10^{-9}	2.22×10^{-9}	1.63×10^{-8}	7.03×10^{-5}	1.15×10^{-4}
Thymus	2.52×10^{-8}	2.22×10^{-9}	1.67×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Thyroid	1.33×10^{-8}	2.22×10^{-9}	1.67×10^{-8}	9.25×10^{-6}	9.99×10^{-6}
Uterus	9.99×10^{-9}	2.22×10^{-9}	1.85×10^{-8}	9.25×10^{-6}	9.99×10^{-6}

* ICRP 68 dose coefficients for a particle size of 1 μm AMAD were obtained from ICRP (2011). The dose coefficients for each radionuclide correspond to the absorption type indicated.

† Abbreviations used in this table: SI = Small Intestine; ULI = Upper Large Intestine; LLI = Lower Large Intestine; ET = Extra-thoracic

Table A-2. ICRP 68 Organ Ingestion Dose Coefficients (rem pCi^{-1}) *

Organ/Tissue†	Co-60 (f1=0.1)	Sr-90 (f1=0.3)	Cs-137 (f1=1.0)	Pu-239 (f1=0.0005)	Am-241 (f1=0.0005)
Adrenals	9.25×10^{-9}	2.44×10^{-9}	5.18×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Bladder Wall	9.62×10^{-9}	5.55×10^{-9}	5.18×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Bone Surface	7.40×10^{-9}	1.52×10^{-6}	5.18×10^{-8}	3.03×10^{-5}	3.33×10^{-5}
Brain	5.18×10^{-9}	2.44×10^{-9}	4.44×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Breast	4.81×10^{-9}	2.44×10^{-9}	4.07×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Esophagus	6.29×10^{-9}	2.44×10^{-9}	4.81×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Stomach Wall	9.25×10^{-9}	3.33×10^{-9}	4.81×10^{-8}	5.55×10^{-8}	5.92×10^{-8}
SI Wall	1.55×10^{-8}	4.07×10^{-9}	5.18×10^{-8}	6.29×10^{-8}	6.66×10^{-8}
ULI Wall	2.41×10^{-8}	2.15×10^{-8}	5.18×10^{-8}	1.18×10^{-7}	1.30×10^{-7}
LLI Wall	4.44×10^{-8}	8.14×10^{-8}	6.29×10^{-8}	2.48×10^{-7}	2.74×10^{-7}
Colon	3.22×10^{-8}	4.81×10^{-8}	5.55×10^{-8}	1.74×10^{-7}	1.92×10^{-7}
Kidneys	8.88×10^{-9}	2.44×10^{-9}	4.81×10^{-8}	1.22×10^{-7}	1.70×10^{-7}
Liver	1.63×10^{-8}	2.44×10^{-9}	4.81×10^{-8}	6.29×10^{-6}	2.00×10^{-6}
Muscle	7.03×10^{-9}	2.44×10^{-9}	4.44×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Ovaries	1.59×10^{-8}	2.44×10^{-9}	5.18×10^{-8}	4.07×10^{-7}	6.29×10^{-7}
Pancreas	9.62×10^{-9}	2.44×10^{-9}	5.18×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Red Marrow	7.77×10^{-9}	6.66×10^{-7}	4.81×10^{-8}	1.44×10^{-6}	1.15×10^{-6}
ET Airways	6.29×10^{-9}	2.44×10^{-9}	4.81×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Lungs	6.66×10^{-9}	2.44×10^{-9}	4.81×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Skin	4.81×10^{-9}	2.44×10^{-9}	4.07×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Spleen	7.77×10^{-9}	2.44×10^{-9}	4.81×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Testes	6.66×10^{-9}	2.44×10^{-9}	4.44×10^{-8}	4.07×10^{-7}	6.29×10^{-7}
Thymus	6.29×10^{-9}	2.44×10^{-9}	4.81×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Thyroid	6.29×10^{-9}	2.44×10^{-9}	4.81×10^{-8}	5.18×10^{-8}	5.55×10^{-8}
Uterus	1.11×10^{-8}	2.44×10^{-9}	5.18×10^{-8}	5.18×10^{-8}	5.55×10^{-8}

* ICRP 68 dose coefficients were obtained from ICRP (2011). The dose coefficients for each radionuclide correspond to the elemental fractional uptake from the GI tract (f1 value) as indicated.

† Abbreviations used in this table: SI = Small Intestine; ULI = Upper Large Intestine; LLI = Lower Large Intestine; ET = Extra-thoracic

Abbreviations, Acronyms, and Symbols

AEC	Atomic Energy Commission
aka	also known as
ALL	acute lymphocytic leukemia
Am	americium
AMAD	activity median aerodynamic diameter
AML	acute myeloid leukemia
BCC	basal cell carcinoma
CFR	Code of Federal Regulations
Ci	curie
CJTG	Commander, Joint Task Group
CLL	chronic lymphocytic leukemia
cm	centimeter
CML	chronic myeloid leukemia
Co	cobalt
Cs	cesium
d	day
DNA	Defense Nuclear Agency
DNA/JTG	Defense Nuclear Agency/Joint Task Group
DoD	Department of Defense
DTRA	Defense Threat Reduction Agency
ECUP	Enewetak Atoll Cleanup Project
EPG	expedited processing group
ET	extra-thoracic
Eu	europium
FB	film badge
FCDNA	Field Command, Defense Nuclear Agency
g	gram
h	hour
in	inch
ICRP	International Commission on Radiological Protection
IREP	Interactive RadioEpidemiological Program
JTG	Joint Task Group
keV	kiloelectron volt
LD	limiting dose
kg	kilogram
LD_{α}	limiting dose based on alpha radiation
LD_{γ}	limiting dose based on gamma radiation
LLI	lower large intestine
m	meter
MEDEVAC	medical evacuation
MM	malignant melanoma
μR	microroentgen
mo	month

mph	mile per hour
NIOSH	National Institute for Occupational Safety and Health
NTPR	Nuclear Test Personnel Review
PC	probability of causation
pCi	picocurie
POW	prisoner of war
PSC	posterior subcapsular cataract
Pu	plutonium
R	roentgen
rad	radiation absorbed dose
RDA	radiation dose assessment
rem	roentgen equivalent man
RSAIT	Radiation Safety Audit and Inspection Team
s	second
SAR	search and rescue
Sb	antimony
SCC	squamous cell carcinoma
SI	small intestine
SM	standard method
SOP	standard operating procedure
Sr	strontium
TLD	thermoluminescent dosimeter
TOD	total organ dose
TRU	transuranic
UB α	upper-bound alpha dose
UB β+γ	upper-bound beta+gamma dose
ULI	upper large intestine
U.S.	United States
USNRC	United States Nuclear Regulatory Commission
VA	Department of Veterans Affairs
VBDR	Veterans' Board on Dose Reconstruction
VIP	very important person
wk	week
y	year
yd	yard