DEFENSE THREAT REDUCTION AGENCY

NUCLEAR TEST PERSONNEL REVIEW PROGRAM

RADIATION DOSE ASSESSMENT

STANDARD METHOD

ED03 – Skin Dose from External Sources

Revision 2.0

Cleared for Release

Key to SOP ID Codes

RA (Radiation Assessment - SOP)
ED (External Dose - Standard Methods)
ID (Internal Dose - Standard Methods)
UA (Uncertainty Analysis - Standard Methods)

Revision Control

Revision	Revision Description	Revision Date	Authorization Official
1.0	Original	10/31/2007	Paul K. Blake
1.2	- New version. Revision 1.0 (considered a working draft) was completely rewritten to produce Rev. 1.2. - No Rev. 1.1 of this SM was produced.	10/31/2008	Paul K. Blake
1.3	- Minor editorial changes	01/31/2010	Paul K. Blake
2.0	- Explained the use of beta-gamma dose ratios for occupation troops at Hiroshima and Nagasaki in Section 5.2.1.2. -Updated the beta-gamma dose ratios for neutron-activated soil in Section 5.2.1.2 - Updated the immersion dose equations in Section 5.3 - Added "hand" as an anatomical location in Table 8 - Updated several references in Section 8 (References) - Made editorial changes and minor corrections as needed throughout document	04/30/2021	James D. Franks

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Standard Method

ED03 – Skin Dose from External Sources

1. Purpose/Summary

Standard Method (SM) ED03, *Skin Dose from External Sources*, provides general technical methods for assessing dose to the skin from surface-deposited fallout and activated sources to individuals in the Nuclear Test Personnel Review (NTPR) Program according to the procedures specified in SOP RA01. The skin dose from dermal contamination is addressed in SM ED04, *Skin Dose from Dermal Contamination*.

2. Scope

This standard method provides technical guidance for reconstructing skin doses due to beta particle and gamma-ray ionizing radiation from exposure to surface-deposited fallout and activated sources. This standard method should not be used to determine skin doses due to alpha radiation, internally deposited radioactive material exposures, or as the sole method for determining external radiation exposures (including skin contamination). This standard method is used in conjunction with other standard methods for assessing whole body radiation exposures in accordance with the requirements of Title 32, Code of Federal Regulations, Part 218, "*Guidance for the Determination and Reporting of Nuclear Radiation Dose for DoD Participants in the Atmospheric Nuclear Test Program"* (DoD, 2020).

3. Responsibilities

Qualified radiation dose analysis staff members use these methods and associated tools for assessing the radiation doses for exposed individuals. It is the responsibility of the analysts to understand and correctly apply the methods and techniques presented below. If situations arise where these methods and techniques are inadequate to address a specific exposure scenario, it is the responsibility of the analyst encountering this deficiency to bring it to the attention of appropriate staff personnel so that the methodology can be extended as required to provide adequate estimates of skin doses from external sources. It is the responsibility of the staff member executing and implementing this extension to document such in a revision to this standard method.

4. Definitions

Acute Exposure: Exposure to radiation from less than one to several hours, exemplified by a typical time period of a day's activity at a test site.

Beta Radiation: Electrons emitted in nuclear decay processes.

Beta-to-Gamma Dose Ratio: The ratio of skin dose from beta radiation to film badge (or film badge-equivalent) gamma dose.

Chronic Exposure: Exposure to radiation on a continuing basis over a time period greater than 1 day.

Film Badge: A device, frequently issued and worn during nuclear weapons testing, that records external gamma dose. A "properly worn" film badge is one that is assumed to be affixed to the external surface of clothing at a height of 137 cm on a standing individual.

Film Badge-Equivalent Dose: The reconstructed gamma dose that would have been recorded on a properly worn film badge.

Finite Plane Source: Fallout uniformly deposited over an area smaller than that used to define an infinite plane source constitutes a finite plane source. Shrinking a finite source to an infinitesimal diameter constitutes point source geometry.

Individual: Any member of the Armed Forces who participated in the atmospheric nuclear weapons testing program.

Infinite Plane Source: Fallout uniformly deposited over a flat surface constitutes an infinite plane source if the lateral dimensions of the contaminated surface are large compared to the mean free path (mfp) of the emitted gamma rays. (The field size criterion is referenced to gamma ray mfp because gammas propagate much farther in air than do beta particles/electrons.) Such a surface is generally represented by land (e.g., Pacific islands and Nevada Test Site) where the radiation can originate 200 m or more in all directions from an individual standing on the ground.

Source Size Modification Factor (*SSMF*): A parameter that corrects the infinite geometry beta-to-gamma dose ratio for finite geometry applications. Without such correction, beta dose may be significantly underestimated when applying infinite-geometry ratios to finite-geometry exposures.

5. Method Description

Surface-deposited fallout and neutron-activated materials provided sources for skin exposure of external origin. Individuals present during the nuclear weapons testing were potentially exposed to initial gamma and neutron emissions from the detonation, and to gamma and beta emissions from mixed fission products and actinides in fallout and from neutron activation products in the soil and surrounding environment. Monitoring devices (film badges) were worn by individuals, or by representative members of groups of individuals, during most weapon testing activities. These film badges measured the amount of gamma radiation individuals received during testing activities. If a specific individual did not wear a film badge, it is generally possible to reconstruct the individual's gamma dose based upon film badges worn by other individuals in the nearby vicinity or from gamma intensity measurements. Utilizing film badge data or gamma dose reconstruction, it is also possible to estimate the dose the individual received due to beta radiation from the surrounding environment (fallout and soil).

5.1 Gamma Radiation Skin Dose

Given the nature of gamma interaction with human tissue, skin dose due to gamma radiation is assumed to equal the film badge or reconstructed film badge-equivalent dose.

5.2 Beta Radiation Skin Dose

Beta radiation can have sufficient energy to penetrate the epidermal skin layer. Thus, beta radiation can be considered an external radiation source contributing to skin dose along with gamma radiation (Turner, 1995). Beta skin dose from external sources is accrued concurrently with the gamma dose from mixed fission products, actinides and neutron-activated material. For an infinite plane source, the relationship between the beta dose and the gamma dose can be expressed by a beta-to-gamma dose ratio. This ratio is dependent on time (because the spectrum of the emitted radiation changes with time) and on the geometrical relationship between an individual and the source (e.g., distance from or height above the source) (Barss and Weitz, 2006).

Due to beta particle range and attenuation characteristics, beta dose depends more critically than gamma dose on geometry and the shielding material between the radiation source and the individual. Thus, the nature of specific jobs or task-related activities and their associated protective measures must be considered when reconstructing beta skin dose (Barss and Weitz, 2006).

Understanding radiation injury of the skin is enhanced by a basic understanding of the anatomy of the organ. Skin consists of a keratinized stratified squamous cell tissue termed the *epidermis*, a juxtaposed supporting *dermis* of connective tissue fibers, nerves and vessels, and a deeper supporting fat pad, the *hypodermis,* shown in Figure 1. Beta doses to the skin are evaluated at the anatomic location where a skin cancer has been diagnosed. The skin dose estimation methodology considers the basal cell layer between the epidermis and the dermis, shown in Figure 2, to be the target organ for the induction of skin cancer (ICRU, 1997). Although the depth of the basal cell layer can vary from 20 to 100 μm (ICRU, 1997), the depth for the evaluation is generally taken as 70 μm. This depth is consistent with ICRP (2002) and ICRU (1997) as the reference epidermal thickness. Basal cells consist of a single layer of cells and, as they divide, produce upward migrating cells that eventually become the keratinized outer layer of skin, the horny layer or *stratum corneum*. Keratin is the component of nails, hair and the dry outer layer of skin that is strong and impermeable to water. The basal cells, comprising the *stratum basale* or *stratum germinativum*, are very active metabolically and their active DNA is very sensitive to ionizing and ultraviolet (UV) radiation, thus the low energy threshold for skin injury.

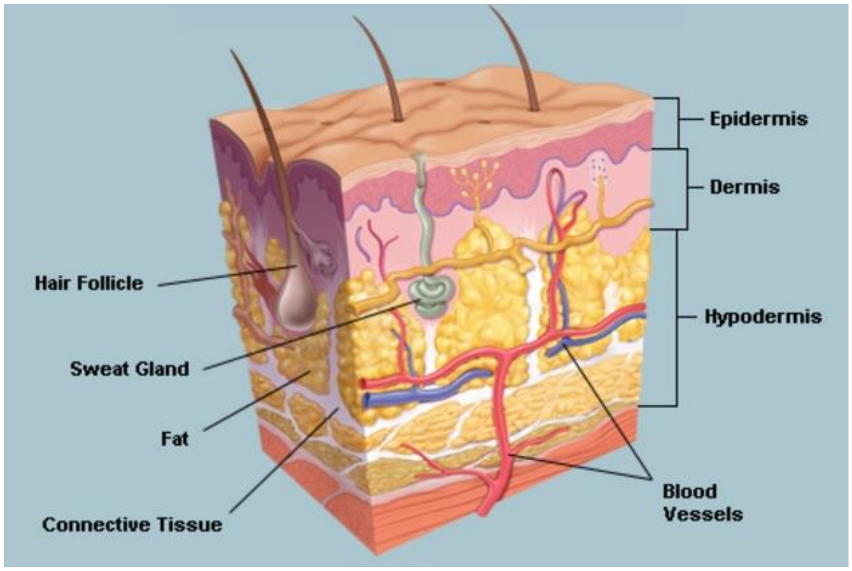

Figure 1. Cross Section of Skin (WebMD, 2019)

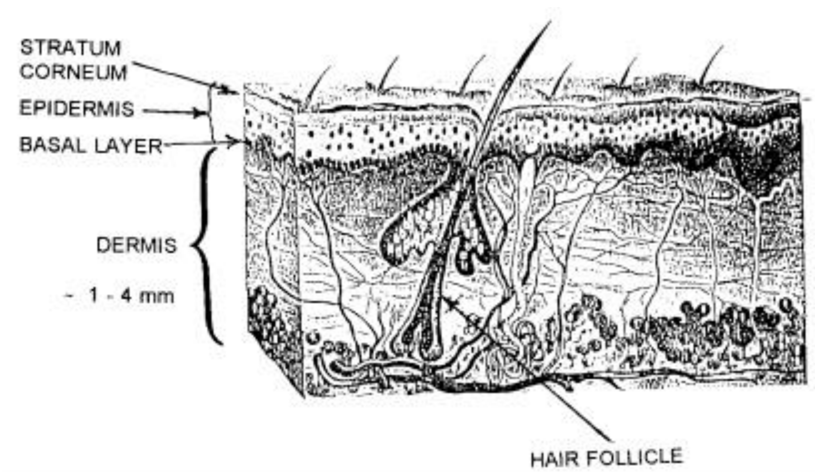

Figure 2. Location of Basal Cell Layer (ICRU, 1997)

Skin doses from external sources may result from four source configurations: infinite plane, finite plane, point, and volumetric. Examples of sources that can usually be treated as infinite planes are fallout deposited on land and neutron-activated materials in soil. Finite plane sources include the fallout-contaminated topside of a ship and contaminated equipment, aircraft, and engines. Point sources are isolated “hot spots” whose spatial dimension is small compared to the source-target distance; examples include contaminated tools, encapsulated radioactive sources used for calibration, and cloud sampling filters. The most commonly encountered volumetric source is contaminated lagoon water. When reconstructing an individual’s skin dose, it will generally be necessary to consider multiple source configurations relevant to the exposure scenario. Consider, for example, an individual who served on a contaminated ship during a Pacific test series, and was exposed to a finite fallout source when topside on the ship, to an infinite fallout source when taking liberty on a contaminated island, and to a volumetric source while swimming in contaminated water.

The internal contamination of a ship's saltwater system and the contaminants on the exterior hull generally did not constitute sources of beta exposure (because of the intrinsic shielding of these structures) unless the individual was involved in intrusive inspection/maintenance of the saltwater system or was directly exposed to the external hull (e.g., while inspecting, scraping, and/or painting it). In addition, it is assumed that no beta doses were accrued by individuals while inside buildings or aircraft that were not internally contaminated.

5.2.1 Infinite Plane Source

Spectral Characterization of Radiation Emitted from Fallout

Fast fissioning of U-235 is generally representative of the fission process that took place during the detonations of nuclear test devices. The gamma and beta emissions from fission products produced in such detonations are characterized by their energy spectra (Finn et al., 1979). The Finn spectra for the fast fission of U-235, given in the cited reference for 32 times from 0 to 70 years post-detonation, were used in the following analysis. Although the spectra differ somewhat from device to device, these variations usually have little effect on the beta-to-gamma dose ratios and can generally be ignored. An exception is the un-fissioned safety shots where isotopes of uranium and plutonium are the predominant radionuclides. The impact of actinide content in the fallout, potentially significant for thermonuclear detonations, is assessed below.

5.2.1.1 Beta-to-Gamma Dose Ratios for Infinite Geometries

The methods and assumptions for using the Finn spectra to calculate the infinite plane source beta-to-gamma dose ratios, $R_{\beta/\gamma}$, are presented in Barss and Weitz (2006). These ratios apply to bare skin exposure of an individual standing upright in a planar fallout field of infinite spatial extent. It was assumed in the derivation that body self-shielding (1) reduced the beta dose at any target site on the body by a factor of 0.5 from its free-field value, and (2) reduced the gamma dose recorded on a properly worn film badge to a value of 0.7 times its free-field value. Tables of $R_{\beta/\gamma}(h,t)$ as functions of distance (h) from the contaminated surface to the target site on an individual's body and time (t) after the detonation are presented below (Barss and Weitz, 2006). Table 1 and Table 2 are generally applicable to fission detonations at Pacific Proving Ground (PPG) and the Nevada Test Site (NTS), respectively. The values in Table 1 are also used for occupation troops at Hiroshima or Nagasaki and for POWs that passed near either ground zero (GZ).

Table 1. Beta-to-Gamma Dose Ratios for Bare Skin Exposures to Mixed Fission Products at Pacific Proving Ground

Time *t* after Detonation	Distance *h* from source plane (cm)							
	1	20	40	80	100	120	160	200
0.5 h	36.4	24.2	17.7	11.9	10.4	9.1	7.0	5.4
1 h	32.5	21.4	15.5	10.3	8.9	7.8	5.9	4.5
2 h	32.0	20.8	15.0	9.9	8.5	7.4	5.5	4.2
4 h	40.3	25.9	18.5	12.0	10.3	8.9	6.7	5.0
6 h	51.1	32.6	23.1	14.9	12.7	11.0	8.2	6.2
12 h	65.6	41.0	28.6	17.8	15.0	12.8	9.3	6.8
1 d	65.1	38.7	25.8	14.9	12.2	10.0	6.8	4.7
2 d	64.4	35.2	22.1	11.8	9.3	7.4	4.7	2.9
3 d	62.8	32.2	19.3	9.8	7.6	6.0	3.6	2.1
1 wk	62.3	29.0	16.3	7.7	5.8	4.5	2.5	1.4
2 wk	65.5	30.5	17.1	8.1	6.2	4.7	2.7	1.6
1 mo	72.4	34.7	19.9	9.8	7.6	6.0	3.7	2.2
2 mo	85.7	39.8	22.8	11.8	9.5	7.8	5.1	3.3
4 mo	90.7	40.4	23.0	12.5	10.5	9.0	6.4	4.4
6 mo	94.6	42.5	24.5	13.9	11.9	10.4	7.7	5.5
9 mo	116.7	54.5	32.5	19.6	17.2	15.4	11.8	8.8
1 y	166.1	81.2	50.3	31.7	28.2	25.6	20.1	15.2
2 y	494.2	251.9	160.5	104.2	93.6	85.3	68.0	52.3

Table 2. Beta-to-Gamma Dose Ratios for Bare Skin Exposures to Mixed Fission Products at the Nevada Test Site

Time *t* after Detonation	Distance *h* from source plane (cm)							
	1	20	40	80	100	120	160	200
0.5 h	36.0	24.6	18.3	12.4	10.8	9.6	7.6	5.9
1 h	32.2	21.8	16.1	10.8	9.4	8.2	6.4	4.9
2 h	31.6	21.2	15.5	10.3	8.9	7.8	6.1	4.6
4 h	40.1	26.6	19.3	12.7	10.9	9.5	7.3	5.6
6 h	50.5	33.3	24.0	15.7	13.4	11.7	9.0	6.9
12 h	64.7	41.8	29.7	18.7	15.9	13.7	10.2	7.6
1 d	64.2	39.6	26.9	15.9	13.0	10.9	7.7	5.4
2 d	63.4	36.3	23.3	12.7	10.1	8.2	5.4	3.5
3 d	62.0	33.4	20.5	10.7	8.4	6.7	4.2	2.6
1 wk	61.6	30.3	17.5	8.4	6.4	5.0	3.1	1.8
2 wk	64.7	31.9	18.4	8.9	6.8	5.3	3.3	2.0
1 mo	71.6	36.2	21.3	10.7	8.3	6.7	4.3	2.7
2 mo	84.6	41.5	24.3	12.6	10.2	8.5	5.9	3.9
4 mo	89.4	42.2	24.4	13.3	11.1	9.6	7.1	5.0
6 mo	93.4	44.3	26.0	14.6	12.5	11.0	8.5	6.2
9 mo	114.7	56.5	34.3	20.3	17.8	16.0	12.8	9.7
1 y	164.0	84.3	52.9	32.8	29.1	26.5	21.7	16.8
2 y	487.7	260.5	168.1	107.5	96.1	88.1	72.9	57.3

In addition to fission products, fallout contains “unburned” fissile materials (e.g., U-235 and Pu-239) and other radionuclides of the actinium series of elements, which constitute additional sources of beta and gamma radiation. The external contribution of actinides to skin dose is expected to be small for most detonations and exposure scenarios. However, for fallout from thermonuclear devices, the beta-to-gamma dose ratios for times less than a few weeks and distances within a few centimeters of a contaminated surface can increase significantly from those listed in Table 1 due to the additional presence of actinides. The predominant actinide contributors to a thermonuclear fallout radiation field are U-237, U-240, Np-239, and Np-240m (i.e., isomeric state of Np-240) (Barss and Weitz, 2006). The beta-to-gamma dose ratios for thermonuclear fallout with significant actinide content (Operation CASTLE Shot BRAVO being prototypical of this class) are given in Table 3.

Table 3. Beta-to-Gamma Dose Ratios for Bare Skin Exposures to Mixed Fission Products and Actinides at Pacific Test Sites

Time *t* after Detonation	**Distance *h* from source plane (cm)**							
	1	**20**	**40**	**80**	**100**	**120**	**160**	**200**
1 h	33.8	21.6	15.6	10.3	8.9	7.7	5.8	4.4
2 h	35.6	22.0	15.4	10.0	8.6	7.5	5.6	4.2
6 h	65.9	37.0	24.3	15.0	12.8	11.1	8.1	6.0
12 h	76.4	39.9	24.9	14.6	12.3	10.5	7.5	5.4
1 d	102.8	46.8	26.3	13.8	11.3	9.4	6.4	4.3
2 d	103.2	44.2	23.8	11.7	9.4	7.7	5.1	3.3
1 wk	105.3	33.3	14.3	5.2	3.8	2.8	1.6	0.9
2 wk	84.1	32.0	15.6	6.6	4.9	3.8	2.2	1.2
1 mo	77.5	35.0	19.5	9.4	7.3	5.7	3.5	2.1
2 mo	85.7	39.8	22.8	11.8	9.5	7.8	5.1	3.3
6 mo	94.6	42.5	24.5	13.9	11.9	10.4	7.7	5.5
1 y	166.1	81.2	50.3	31.7	28.2	25.6	20.1	15.2
2 y	494.2	251.9	160.5	104.2	93.6	85.3	68.0	52.3

Activated soil at NTS test locations was another infinite plane source (neutron-activated soil is generally not a source of exposure for PPG participants). Activation products are produced by neutron absorption in materials. The radioisotopes Na-24, Mn-56, Si-31, Cl-38, and K-42 are the primary contributors to the gamma and beta radiation in the vicinity of activated NTS soil for the first few weeks after detonation, with Cs-134, Sc-46, , and Ca-45 dominant at later times (e.g., months to years after the detonation). Aluminum activation products (e.g., Al-28) decayed to immeasurable levels within minutes after a detonation and, therefore, did not contribute to skin dose by the time test participants entered contaminated areas.

Beta-to-gamma dose ratios for neutron activation products in soil were calculated from their respective parent elemental abundances and neutron capture cross sections by calculating an activity depth profile for 12 radionuclides to a depth of 30 cm (51 g cm^{-2}). Dose ratios were calculated out to 10,000 h post-detonation for four stay times (designated Δt) in areas of NTS activated soil at Area 7 and Frenchman Flat. The four stay times include the limiting case of Δt approaching zero (very short stay times) to $\Delta t = 100$ h. The calculated dose ratios for the limiting case are shown in Table 4, and ratios for additional stay times of 1 h, 10 h, and 100 h are available in Weitz and Egbert (2017). The limiting values shown in Table 4 are generally slightly higher (i.e., a few percent) than the more typical stay time of 1 h. (Weitz and Egbert, 2017)

The beta-gamma ratios for neutron-activated soil shown above are not used for participants that were present in the soil activation areas near GZ following the Hiroshima and Nagasaki detonations in Japan. For these participants, single high-sided values are used to bound the exposures for all body locations (heights) and times of possible entry of the occupation troops or prisoners of war (POWs). Constant beta-gamma ratios of 0.03 and 0.02 are used for occupation troops who were in the vicinity of the Hiroshima or Nagasaki GZ, respectively. For all POWs that passed near either GZ, a beta-gamma ratio of 0.2 is used.

5.2.1.2 Modification Factor

The beta-to-gamma dose ratios reported in Table 1, Table 2 and Table 3 apply to exposures of *bare* skin to infinite fallout fields. Frequently the target site on the body was covered by an article of clothing during the period of exposure. Clothing strongly attenuates beta particles but does not affect the gamma dose recorded on a properly worn film badge. Thus, if the skin site of interest was covered by even a relatively thin layer of clothing during the exposure, the beta-to-gamma dose ratios can be significantly reduced. A modification factor (M) is used to adjust the dose ratios to account for the additional beta shielding provided by clothing. Values of M applicable for exposures to mixed fission products when wearing a layer of clothing 28 mg cm^{-2} in density-thickness, representative of “coverall” material, are provided in Table 5 (Barss and Weitz, 2006). Except for locations close to the source plane, the presence of this clothing reduces the beta dose by 10 to 30 percent.

Table 4. Beta-to-Gamma Dose Ratios for Bare Skin Exposures to Neutron-Activated Soil at NTS for Very Short Stay Times (Δt → 0)

Entry Time *t* after Detonation (h)	NTS Area 7 at Height =			NTS Frenchman Flat at Height =		
	1 cm	100 cm	160 cm	1 cm	100 cm	160 cm
0.1	6.12×10^{-1}	3.52×10^{-1}	2.57×10^{-1}	6.15×10^{-1}	3.55×10^{-1}	2.59×10^{-1}
0.2	5.86×10^{-1}	3.31×10^{-1}	2.41×10^{-1}	6.01×10^{-1}	3.42×10^{-1}	2.49×10^{-1}
0.5	4.35×10^{-1}	2.09×10^{-1}	1.46×10^{-1}	4.59×10^{-1}	2.22×10^{-1}	1.56×10^{-1}
1	4.20×10^{-1}	1.99×10^{-1}	1.38×10^{-1}	4.32×10^{-1}	2.03×10^{-1}	1.41×10^{-1}
2	4.00×10^{-1}	1.88×10^{-1}	1.30×10^{-1}	3.99×10^{-1}	1.82×10^{-1}	1.24×10^{-1}
3	3.83×10^{-1}	1.79×10^{-1}	1.23×10^{-1}	3.73×10^{-1}	1.67×10^{-1}	1.13×10^{-1}
4	3.66×10^{-1}	1.70×10^{-1}	1.17×10^{-1}	3.49×10^{-1}	1.55×10^{-1}	1.04×10^{-1}
5	3.49×10^{-1}	1.62×10^{-1}	1.11×10^{-1}	3.28×10^{-1}	1.44×10^{-1}	9.58×10^{-2}
6	3.33×10^{-1}	1.54×10^{-1}	1.05×10^{-1}	3.07×10^{-1}	1.34×10^{-1}	8.84×10^{-2}
7	3.18×10^{-1}	1.46×10^{-1}	9.97×10^{-2}	2.88×10^{-1}	1.24×10^{-1}	8.16×10^{-2}
8	3.03×10^{-1}	1.39×10^{-1}	9.45×10^{-2}	2.70×10^{-1}	1.15×10^{-1}	7.52×10^{-2}
9	2.90×10^{-1}	1.32×10^{-1}	8.97×10^{-2}	2.54×10^{-1}	1.07×10^{-1}	6.95×10^{-2}
10	2.78×10^{-1}	1.26×10^{-1}	8.54×10^{-2}	2.39×10^{-1}	9.96×10^{-2}	6.43×10^{-2}
12	2.57×10^{-1}	1.16×10^{-1}	7.80×10^{-2}	2.15×10^{-1}	8.75×10^{-2}	5.57×10^{-2}
15	2.35×10^{-1}	1.04×10^{-1}	7.00×10^{-2}	1.90×10^{-1}	7.51×10^{-2}	4.69×10^{-2}
20	2.15×10^{-1}	9.37×10^{-2}	6.23×10^{-2}	1.69×10^{-1}	6.43×10^{-2}	3.92×10^{-2}
24	2.06×10^{-1}	8.90×10^{-2}	5.88×10^{-2}	1.61×10^{-1}	6.03×10^{-2}	3.63×10^{-2}
36	1.94×10^{-1}	8.14×10^{-2}	5.29×10^{-2}	1.53×10^{-1}	5.54×10^{-2}	3.26×10^{-2}
48	1.85×10^{-1}	7.59×10^{-2}	4.87×10^{-2}	1.49×10^{-1}	5.27×10^{-2}	3.05×10^{-2}
72	1.71×10^{-1}	6.70×10^{-2}	4.16×10^{-2}	1.42×10^{-1}	4.84×10^{-2}	2.71×10^{-2}
120	1.56×10^{-1}	5.56×10^{-2}	3.23×10^{-2}	1.36×10^{-1}	4.29×10^{-2}	2.27×10^{-2}
168	1.79×10^{-1}	5.83×10^{-2}	3.19×10^{-2}	1.49×10^{-1}	4.27×10^{-2}	2.21×10^{-2}
200	2.34×10^{-1}	7.32×10^{-2}	3.96×10^{-2}	1.70×10^{-1}	4.55×10^{-2}	2.41×10^{-2}
250	2.86×10^{-1}	8.79×10^{-2}	4.78×10^{-2}	1.82×10^{-1}	4.59×10^{-2}	2.49×10^{-2}
300	2.78×10^{-1}	8.45×10^{-2}	4.61×10^{-2}	1.75×10^{-1}	4.28×10^{-2}	2.33×10^{-2}
400	2.45×10^{-1}	7.20×10^{-2}	3.93×10^{-2}	1.58×10^{-1}	3.64×10^{-2}	1.99×10^{-2}
500	2.15×10^{-1}	6.11×10^{-2}	3.33×10^{-2}	1.44×10^{-1}	3.09×10^{-2}	1.69×10^{-2}
700	1.68×10^{-1}	4.38×10^{-2}	2.39×10^{-2}	1.22×10^{-1}	2.23×10^{-2}	1.22×10^{-2}
1,000	1.22×10^{-1}	2.66×10^{-2}	1.45×10^{-2}	9.99×10^{-2}	1.37×10^{-2}	7.46×10^{-3}
1,400	8.30×10^{-2}	1.16×10^{-2}	6.30×10^{-3}	8.24×10^{-2}	6.05×10^{-3}	3.29×10^{-3}
2,000	6.72×10^{-2}	5.05×10^{-3}	2.73×10^{-3}	7.68×10^{-2}	2.71×10^{-3}	1.46×10^{-3}
3,000	6.07×10^{-2}	1.06×10^{-3}	5.37×10^{-4}	7.83×10^{-2}	6.56×10^{-4}	3.27×10^{-4}
4,000	6.28×10^{-2}	3.64×10^{-4}	1.44×10^{-4}	8.38×10^{-2}	3.10×10^{-4}	1.25×10^{-4}
5,000	6.60×10^{-2}	2.74×10^{-4}	7.91×10^{-5}	8.90×10^{-2}	2.81×10^{-4}	9.36×10^{-5}
7,000	6.97×10^{-2}	3.22×10^{-4}	7.12×10^{-5}	9.45×10^{-2}	3.44×10^{-4}	9.36×10^{-5}
10,000	6.69×10^{-2}	4.01×10^{-4}	7.11×10^{-5}	8.89×10^{-2}	4.22×10^{-4}	9.12×10^{-5}

Table 5. Modification Factor for Light Clothing for Exposures to Mixed Fission Products

Time after detonation	Distance from source plane (cm)							
	1	**20**	**40**	**80**	**100**	**120**	**160**	**200**
1 h	0.59	0.74	0.80	0.83	0.84	0.86	0.87	0.87
2 h	0.59	0.73	0.79	0.84	0.84	0.85	0.87	0.87
6 h	0.57	0.72	0.78	0.83	0.84	0.85	0.86	0.87
1 d	0.52	0.67	0.73	0.78	0.80	0.81	0.82	0.83
1 wk	0.40	0.54	0.66	0.71	0.72	0.74	0.74	0.78
2 wk	0.40	0.55	0.66	0.71	0.72	0.73	0.77	0.74
1 mo	0.41	0.56	0.67	0.73	0.74	0.75	0.78	0.77
1 y	0.42	0.62	0.78	0.86	0.87	0.87	0.88	0.88

Heavier articles of clothing, such as footwear and field jackets, attenuate the beta dose, and thereby reduce the dose ratios, more significantly. The beta-to-gamma dose ratio for the heel of a foot inside a boot is an extreme example. Values of beta-to-gamma dose ratios for this exposure scenario are shown in Table 6. These results were obtained by assuming that a boot sole of 750 mg cm^{-2} density-thickness separated the heel from the radiation source.

Table 6. Beta-to-Gamma Dose Ratios for Heel of Foot inside a Boot

Time	Beta-to-Gamma Dose Ratio
1 h	0.368
1 d	0.181
1 wk	0.013
1 mo	0.041
1 y	1.10

A general formulation to estimate beta-to-gamma dose ratios for arbitrary thicknesses of material between the source plane and the target location was developed by performing a regression analysis of calculated values of $R_{\beta/\gamma}$. These results are expressed as exponential functions with time-dependent coefficients (Barss, 2000):

$$R_{\beta/\gamma}(x,t) = A(t)\, e^{-B(t)x} \tag{1}$$

where

$R_{\beta/\gamma}(x,t)$	=	Beta-gamma dose ratios
$A(t)$	=	Coefficient given in Table 7
$B(t)$	=	Coefficient given in Table 7
x	=	Density-thickness of air, clothing, epidermal layer, or other shielding material between source and basal layer (mg cm^{-2})
t	=	time after detonation (h)

This representation of $R_{\beta/\gamma}$ agrees well with transport-calculated values for density-thicknesses in the range 100 to 500 mg cm^{-2}.

Table 7. Coefficients to Calculate Beta-to-Gamma Dose Ratios

Time (t)	***A(t)***	***B(t)* (cm^2 mg^{-1})**
1 h	17.0	5.43E−03
2 h	16.7	5.66E−03
4 h	19.6	5.53E−03
6 h	23.9	5.47E−03
12 h	29.0	5.82E−03
1 d	27.1	7.09E−03
2 d	26.5	8.97E−03
3 d	26.0	1.02E−02
1 wk	22.6	1.13E−02
2 wk	22.3	1.08E−02
1 mo	24.5	9.82E−03
2 mo	26.2	8.48E−03
4 mo	24.6	7.06E−03
6 mo	25.9	6.28E−03
9 mo	30.4	4.90E−03
1 y	55.1	5.17E−03
2 y	192	5.50E−03

The following example demonstrates the application of Equation 1 for estimating $R_{\beta/\gamma}$. An individual wore both a tee-shirt and a fatigue jacket, each with an estimated thickness equivalent to that of "coverall" material cited above (28 mg cm^{-2}), covering his upper torso when exposed in a large fallout field 6 hours after a nuclear detonation at NTS. He later developed skin cancer on his lower back, at a height of 120 cm. In this case, *A*(6 h) = 23.9 and *B*(6 h) = 0.00547 from Table 7. The density-thickness *x* consists of the contributions from air, clothing, and epidermal layer. The thickness of air from source plane to cancer site is 120 cm; the air density-thickness is obtained by multiplying this (linear) thickness by the density of air, typically taken as 1.05 mg cm^{-3} at NTS (for exposures at Pacific sites, 1.15 mg cm^{-3} is more representative). Thus, the air density-thickness is 120 cm×1.05 mg cm^{-3} = 126 mg cm^{-2}. The density-thickness of the clothing he wore over the nascent cancer site during exposure is 2 layers×28 mg cm^{-2} per layer = 56 mg cm^{-2}, and the density-thickness of the epidermal layer is normally taken as 7 mg cm^{-2}. Therefore, the combined density-thickness x = 189 mg cm^{-2}. Substituting into Equation 1 gives the example:

$$R_{\beta/\gamma} = 23.9\, e^{-0.00547 \times 189} = 8.5 \qquad (2)$$

A modification factor of M = 0.7/0.5 = 1.4 has occasionally been applied to the infinite-plane beta-to-gamma dose ratios to remove the aforementioned body shielding factors for application to face-on exposures. This correction is not exact, however, because the distance between the film badge and the source plane assumed in formulating the infinite-plane ratios is 1.37 m, while the film badge-source distance in a facing exposure may be much different from that. Because the sources in virtually all facing exposure scenarios do not qualify as “infinite” (reference definition of “infinite plane source” in Section 4), it is recommended that the finite source formulation presented in Section 5.2.2 be used in these cases.

5.2.1.3 Skin Dose from Acute Exposures

For an acute exposure (e.g., one for which a single-day mission film badge was issued) to an infinite fallout or activation field, the beta dose at a body target location can be computed using Table 1–Table 4, and the following general equation:

$$D_{\beta skin} = D_{fb} \times [\, R_{\beta/\gamma}(h,t) \times M \,] \qquad (3)$$

where

$D_{\beta skin}$	=	Bare-skin beta dose from exposure to fallout or activation products (rem)
D_{fb}	=	Film badge (or film badge-equivalent) dose accrued over the same time interval (rem)

$R_{\beta/\gamma}(h,t)$	=	Ratio of beta dose to film badge (equivalent) dose as function of distance (h in m) and time after detonation (t in h)
M	=	Modification factor (see Table 5 for light clothing; if it is uncertain that an individual wore clothing over the target skin site during exposure, the default is to assume that he did not and set M = 1)

The total skin dose (D_{skin}) from deposited fallout or activation products is obtained by adding the gamma (film badge) dose to the beta skin dose as shown in the equation:

$$D_{skin} = D_{fb} \times [\, R_{\beta/\gamma}(h,t) \times M + 1 \,] \tag{4}$$

Skin doses at NTS were typically accrued by maneuver troops and observers 0.5–2 h after a detonation. Note from Table 2 that the beta-to-gamma dose ratios are approximately constant over that time interval. Therefore, a simple method of calculating such skin doses is to use the value of $R_{\beta/\gamma}$ at t = 0.5 h (the largest for that time period) in Equation 4. The integrating methodology discussed below for chronic exposures can be used for periods longer than 0.5 to 2 h.

5.2.1.4 Skin Dose from Chronic Exposures

For chronic exposures, it is assumed that an individual was exposed to beta radiation from fallout only while he was outside. The beta skin dose from an infinite fallout field is reconstructed by integrating the product of the gamma intensity and the beta-to-gamma dose ratio over the period of exposure while properly accounting for location (inside vs. outside) and body position (standing vs. sitting). The beta skin dose is thus computed with the following equation:

$$D_{\beta skin} = 0.7 \times F_{OS} \times \int_{t_{start}}^{t_{end}} I_{\gamma}(t)[\, f_{std} \times R_{\beta/\gamma}(h_{std},t) + f_{sit} \times R_{\beta/\gamma}(h_{sit},t) \,]\, dt \tag{5}$$

where

t_{start}	=	Time after detonation at which exposure started (h)
t_{end}	=	Time after detonation at which the exposure ended (h)

$I_{\gamma}(t)$	=	Gamma intensity at time *t* after detonation (this may be based on independent intensity measurements or derived on the basis of a film badge reading) (R h^{-1})
$R_{\beta/\gamma}(h,t)$	=	Beta-to-gamma dose ratio
h_{std}	=	Distance from source plane to target site on body for person standing upright in infinite fallout field, calculated using height of individual (m)
h_{sit}	=	Distance from source plane to target site on body for person sitting in infinite fallout field, calculated using height of individual (m)
0.7	=	Film badge conversion factor
F_{os}	=	Fraction of time spent outside
f_{std}	=	Fraction of outside time in standing position
f_{sit}	=	Fraction of outside time in sitting position

The resulting beta dose is summed with its corresponding film badge (equivalent) gamma dose to determine the skin dose for each fallout episode; a sum of skin dose over fallout episodes yields the central estimate of the total skin dose.

Reference distances above a source plane for three positions are shown in Table 8. These reference distances were determined for a veteran height of 68 inches (173 cm) using Reference Man values, together with modifying factors for the two sitting positions for anatomical locations at mid-thigh and above (Stiver, 2008). To determine values for h_{std} and h_{sit} for veteran heights other than 68 inches, multiply the appropriate reference distance(s) in Table 8 (except foot/ankle) by the ratio of veteran height to 68 inches. For foot and ankle sites, the reference distances are used for all veteran heights. For example, the distance of “face” above the plane for a standing veteran of height 72 inches is 63 inches × (72/68) = 66.7 inches.

Table 8. Reference Distances above a Plane for Various Anatomical Locations

	Reference Distances (inches) for Three Positions*		
Anatomical Location	**Standing**	**Sitting (chair/bench)**	**Sitting (ground/deck)**
foot and ankle	0.4	0.4	2.0
shin	8.0	8.0	6.0
knee	16.0	16.0	6.0
mid-thigh	28.0	20.9	6.0
hand	28.0	20.9	6.0
waist	39.0	22.2	5.5
forearms	39.0	22.2	8.0
stomach	47.0	30.2	13.5
mid-chest	55.0	38.2	21.5
neck	59.0	42.2	25.5
face and head/eyes	63.0	46.2	29.5
top of head	68.0	51.2	34.5

* Reference distances are for a veteran height of 68 inches (173 cm).

5.2.2 Finite Plane Source

Many radiation sources do not qualify as infinite, as defined in Section 4. Finite radiation sources were encountered, for example, by crewmembers exposed to topside fallout while aboard ship, by mechanics performing maintenance on contaminated aircraft engines, and by members of a decontamination team cleaning a contaminated vehicle. In such cases, an application of a beta-to-gamma dose ratio based on the infinite source model may significantly underestimate the beta dose. To address this limitation the methodology was extended to more accurately reconstruct skin doses from exposures to spatially finite radiation sources (Weitz, 2011).

While a beta dose from exposure to an infinite plane source depends on time after detonation (t) and distance from source (h), a similar dose resulting from an exposure to a finite source depends also on the spatial dimension of the source. The methodology described above for infinite sources was generalized to accommodate the additional independent variable by making two simplifying approximations:

- A radiation source of area A and arbitrary shape is represented as a circular source of the same area, facilitated by defining an "equivalent radius" of $r = \sqrt{A/\pi}$.
- The subject is located at the center of this circular source region.

Two-dimensional Monte Carlo transport methods coupled with a source-target transform technique (Weitz, 2011) were employed to calculate the beta and gamma doses to sensitive skin layers from axial exposures to circular fallout sources ranging in radius from 0.1 m to 500 m (the latter qualifying as infinite), for times from 1 hour to 1 year after detonation, and for three substrate materials (soil, aluminum, and iron). These doses are provided in Attachment 1 in units of mrad per unit surface emission density (i.e., mrad β^{-1} cm^2 for beta dose D_β, and mrad γ^{-1} cm^2 for gamma dose D_γ).

5.2.2.1 Skin Dose from Acute Exposures

The following formulations are taken from Weitz (2011).

For a person exposed to a finite fallout-contaminated area while wearing a film badge, the bare skin dose D_{skin} at the target location on his body can be estimated using the equation:

$$D_{skin} = \frac{M_{\beta t}\ N_{\beta\gamma}(t)\, D_\beta(t,h_t,r,mat) + M_{\gamma t}\ D_\gamma(t,h_t,r,mat)}{M_{\gamma fb}\ D_\gamma(t,h_{fb},r,mat)} \times D_{fb} \qquad (6)$$

Where

$D_\beta(t,h,r,mat)$	=	Beta dose (mrad β^{-1} cm^2) for parameters *t, h, r*, and substrate material *mat*, obtained from appropriate table in Attachment 1
$D_\gamma(t,h,r,mat)$	=	Gamma dose (mrad γ^{-1} cm^2) for parameters *t, h, r*, and substrate material *mat*, obtained from appropriate table in Attachment 1
D_{fb}	=	Reading on film badge (rem)
h_{fb}	=	Distance of the film badge from the source plane during exposure (m)
h_t	=	Distance of the target site from the source plane during exposure (m)
$N_{\beta\gamma}(t)$	=	Ratio of beta to gamma emission rates at time *t* (Finn et al., 1979); these values are provided in Table 9
$M_{\beta t}$	=	Modifying factor accounting for body shielding of beta radiation at the target skin site
$M_{\gamma t}$	=	Modifying factor accounting for body shielding of gamma radiation at the target skin site
$M_{\gamma fb}$	=	Modifying factor accounting for body shielding of gamma radiation at the film badge position

The modifying factors (*M*) are all unity for an individual exposed while facing the source. If the individual was exposed while standing upright in a fallout field, $M_{\beta t}$ = 0.5, $M_{\gamma fb}$ = 0.7, and $M_{\gamma t}$ can range from 0.7 for skin sites on the trunk of the body to 1 for sites on the extremities.

Table 9. Beta-to-Gamma Emission Rate Ratios $N_{\beta\gamma}(t)$ at Selected Times after Detonation.

Time after Detonation (*t*)	$N_{\beta\gamma}(t)$
1 h	0.640
1 d	0.948
1 wk	1.05
1 mo	1.38
6 mo	1.86
1 y	3.25

As an example of reconstructing a skin dose on the basis of a film badge reading, consider a person who accrued a film badge dose of 10 mrem while standing in a localized fallout field of 10-meter radius at NTS 1 hour after the detonation. The requirement is to reconstruct the skin dose to his hand ($M_{\gamma t}$= 1), assumed in this example to have been 1 m above the ground during exposure. This analysis is performed as follows:

Step 1: From Table A1-1 (since the contamination was deposited on soil and exposure took place at t = 1 h), obtain D_γ(1 h, 1 m, 10 m, soil) = 4.47×10^{-7} mrad γ^{-1} cm^2 and D_β(1 h, 1 m, 10 m, soil) = 1.85 $\times10^{-5}$ mrad β^{-1} cm^2.

Step 2: Also from Table A1-1, obtain D_γ(1 h, 1.37 m, 10 m, soil) = 3.95×10^{-7} mrad γ^{-1} cm^2 .

Step 3: $N_{\beta\gamma}$(1 h) = 0.640 from Table 9; $M_{\beta t}$ = 0.5 and $M_{\gamma fb}$ = 0.7 for a standing exposure.

Therefore, using Equation 6 yields:

$$D_{skin} = \frac{(0.5)(0.64)(1.85 \text{ x } 10^{-5}) + (1)(4.47 \text{ x } 10^{-7})}{(0.7)(3.95 \text{ x } 10^{-7})}(10) = 230 \text{ mrem} \qquad (7)$$

If a radiation intensity reading was taken in the vicinity of the contaminated surface at the time of the exposure, or at some other time and can be scaled (perhaps via $t^{-1.2}$) to the time of exposure, the skin dose can be estimated using one of the following two equations, depending on the type of measurement made. For a gamma-only (closed window) measurement, the skin dose can be estimated using:

$$D_{skin} = 0.877 \frac{M_{\beta t}\ N_{\beta\gamma}(t)\ D_{\beta}(t, h_t, r, mat) + M_{\gamma t}\ D_{\gamma}(t, h_t, r, mat)}{D_{\gamma}(t, h_m, r, mat)} I_{\gamma}(t)\, \Delta t \quad (8)$$

where

0.877	=	The conversion factor from mR to mrad (in air)
$I_\gamma(t)$	=	Gamma intensity at time of exposure (mR h^{-1})
Δt	=	Duration of exposure (h)
h_m	=	Distance of the detector from the contaminated plane at time of intensity measurement.

Other parameters in Equation 8 were defined previously.

If the intensity measurement is gamma plus beta (open window), the skin dose can be estimated using:

$$D_{skin} = \frac{M_{\beta t}\ N_{\beta\gamma}(t)\ D_{\beta}(t, h_t, r, mat) + M_{\gamma t}\ D_{\gamma}(t, h_t, r, mat)}{D_{\gamma}(t, h_m, r, mat) + 0.9\ N_{\beta\gamma}(t)\ D_{\beta}(t, h_m, r, mat)} I_{\gamma+\beta}(t)\ \Delta t \quad (9)$$

where

$I_{\gamma+\beta}(t)$	=	beta plus gamma intensity reading at time of exposure, in mrad h^{-1};

Other parameters in Equation 9 were defined previously.

NOTE: Intensity measurements were typically made with a Geiger-Muller (GM) instrument during/after decontamination activities; hence both beta and gamma radiation was detected. However, many historical reports and records do not specify instrument and window details. In the absence of specific information, it is presumed that a reported intensity is exclusively gamma. This tends to high-side the skin dose.

As an example of reconstructing a skin dose on the basis of an intensity reading, consider a mechanic who spent 5 hours working on a contaminated aircraft 1 day after the detonation. The intensity was measured at that time to be 10 mR h^{-1} (γ only) at a distance of 10 cm from the surface of the aircraft, and the contaminated section had a radius of approximately 0.5 m. During this task, the mechanic faced toward the aircraft with his body, on average, a distance of 1 m from the contaminated surface. The skin site of interest is on his face. To estimate the skin dose using Equation 8, follow the steps below:

Step 1: From Table A1-8 (since the contamination was deposited on the aluminum surface of the aircraft and exposure took place at t = 1 day), obtain D_γ(1 day, 1 m, 0.5 m, Al) = 1.56×10^{-8} mrad γ^{-1} cm^2 and D_β(1 day, 1 m, 0.5 m, Al) = 1.89×10^{-6} mrad β^{-1} cm^2.

Step 2: From Table A1-8, obtain D_γ(1 day, 0.1 m, 0.5 m, Al) = 2.39 $\times10^{-7}$ mrad γ^{-1} cm^2.

Step 3: $N_{\beta\gamma}$(1 day) = 0.948 from Table 9; $M_{\beta t} = M_{\gamma t}$ = 1 for a face-on exposure.

Then, Equation 8 yields:

$$D_{skin} = 0.877\,\frac{(1)(0.948)(1.89\text{ x }10^{-6}) + (1)(1.56\text{ x }10^{-8})}{(2.39\text{ x }10^{-7})}(10)\,(5) = 330\text{ mrem.} \qquad (10)$$

5.2.2.2 Skin Dose from Chronic Exposures

Chronic skin exposures to finite sources, as experienced by crewmen on a topside-contaminated ship, can be treated using the acute exposure formulation discussed above by dividing the exposure interval into increments, calculating the skin dose accrued during each time increment, and summing the results. An alternative, but numerically equivalent, approach is to adjust the infinite plane source beta-to-gamma dose ratios available in Barss and Weitz (2006) to account for the finite size of a source.

The infinite-plane dose ratio for an individual standing erect in a large fallout field can be written in terms of the normalized doses $D_\gamma(t,h,r,mat)$ and $D_\beta(t,h,r,mat)$ of Attachment 1 as:

$$\mathrm{R}_{\beta/\gamma}(h,t) = N_{\beta\gamma}\,\frac{0.5\times D_\beta(t,h,\infty,soil)}{0.7\times D_\gamma(t,1.37\,m,\infty,soil)} \qquad (11)$$

where

$R_{\beta/\gamma}(h,t)$ = The infinite-plane dose ratio for an individual standing erect

As discussed previously, the factor of 0.7 in the denominator converts free-field gamma dose D_γ to a film badge-equivalent dose by accounting for body shielding of the film badge, and the factor 0.5 in the numerator likewise accounts for body shielding of the target skin site from beta radiation.

A beta-to-gamma dose ratio for an individual standing in a *finite* fallout field of equivalent radius *r* deposited on material *mat*, denoted here by $Q_{\beta/\gamma}(h,t,r,mat)$, can be expressed in an analogous manner:

$$Q_{\beta/\gamma}(h,t,r,mat) = N_{\beta\gamma} \frac{0.5 \times D_{\beta}(t,h,r,mat)}{0.7 \times D_{\gamma}(t,1.37\,m,r,mat)} \qquad (12)$$

The factor that converts $R_{\beta/\gamma}(h,t)$ to $Q_{\beta/\gamma}(h,t,r,mat)$ is defined as the source size modification factor (*SSMF*):

$$SSMF(t,h,r,mat) = \frac{Q_{\beta/\gamma}(h,t,r,mat)}{R_{\beta/\gamma}(h,t)} = \frac{D_{\gamma}(t,1.37\,m,\infty,soil)}{D_{\gamma}(t,1.37\,m,r,mat)} \times \frac{D_{\beta}(t,h,r,mat)}{D_{\beta}(t,h,\infty,soil)} \qquad (13)$$

Equation 13 can be evaluated using the tabular data in Attachment 1. In doing so, it is found that *SSMF* formulated in this manner is nearly independent of time, as seen in Figure 3. Furthermore, *SSMF* is nearly independent of *h* when *r* is greater than 7 meters. Thus, for $r > 7$ meters and *mat* = iron (a representative substrate for ship applications), values of *SSMF* can be read directly from Figure 3, irrespective of *h* and *t*. This greatly facilitates the calculation of skin dose from chronic exposure to fallout using existing parameterizations of the infinite-plane dose ratios, since *SSMF* can be treated as a constant in the summation or integration process.

This formulation is particularly useful when reconstructing skin doses to crewmen from chronic exposure to topside contaminants on naval vessels. The weather decks of most ships can be approximated as ellipses with area $A = ¼\,\pi BL$, where *B* is the beam (maximum width) of the ship and *L* is its length; the corresponding equivalent radius $r = ½\sqrt{BL}$. The weather decks of aircraft carriers are approximately rectangular with area $A = BL$ and equivalent radius $r = \sqrt{BL/\pi}$. The decks of small boats can have either configuration, as illustrated in Attachment 2. Values of *SSMF* derived on this basis are shown in Table 10 for a representative sample of Navy ships and small boats ($h = 1$ m is assumed when $r < 7$ m). The dimensions for ships listed in Attachment 2 and used in this analysis were obtained for specific vessels of each type and may vary somewhat within each category; boat dimensions were taken from Attachment 2. It is seen that the ship-specific *SSMF* values agree well with the generic value of 2 that has typically been used. The *SSMF* values of small boats are somewhat larger.

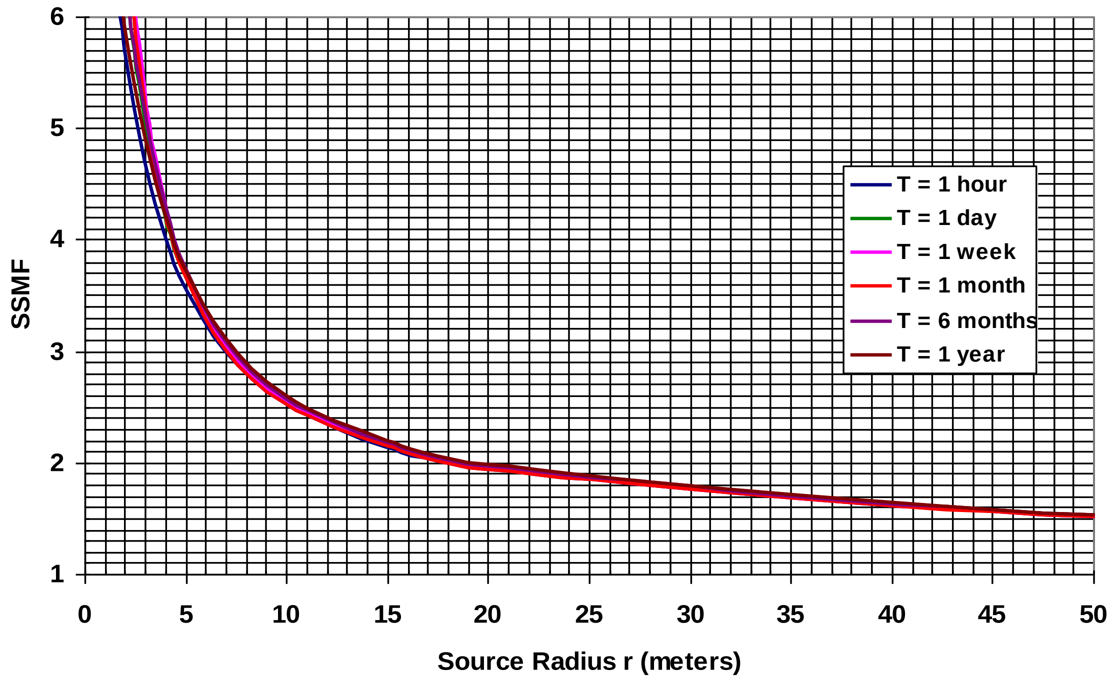

Figure 3. *SSMF* as Function of Source Radius for Various Times after Detonation

Table 10. *SSMF* for Specific Naval Vessels

Vessel Type	Designation	Beam [m]	Length [m]	Equivalent Radius [m]	SSMF
Ships:					
Aircraft Carrier	CVS	28	271	49	1.5
Attack Transport	APA	19	139	26	1.8
Destroyer	DD	12	115	19	2.0
Dock Landing Ship	LSD	22	140	28	1.8
Fleet Tug	ATF	12	62	14	2.2
Salvage Ship	ARS	12	65	14	2.2
Store Ship	AF	15	103	20	2.0
Tank Landing Ship	LST	15	100	20	2.0
Small Boats:					
Whale Boat		2.4	7.9	2.5	6.0
LCVP		3.2	10.9	3.3	4.7
LCM 6		4.3	17.1	4.8	3.8
LCM 8		6.4	22.5	6.8	3.2
LCU 1466 class		10.4	36.3	11.0	2.5
LCU 1600 class		8.8	41.1	10.7	2.5

The *SSMF* can also be evaluated for face-on exposures to sources of finite size. The beta-to-gamma dose ratio for a person who, at time *t*, faces a source of equivalent radius *r* deposited on material *mat* is given by:

$$Q_{\beta/\gamma}(h,t,r,mat) = N_{\beta\gamma}\,\frac{D_\beta(t,\,h,r,mat)}{D_\gamma(t,\,h_{fb},r,mat)} \tag{14}$$

In Equation 14, h and h_{fb} are the distances of the target body site and film badge, respectively, from the source plane during exposure. The values of h and h_{fb} may differ if the target site is on the hand or forearm, which is likely to have been closer to the source than was the torso (film badge) during decontamination and maintenance operations. Note that the body shielding factors do not apply in this case. The corresponding *SSMF* is then:

$$SSMF(t,h,r,mat) = \frac{Q_{\beta/\gamma}(h,t,r,mat)}{R_{\beta/\gamma}(h,t)} = \frac{0.7\times D_\gamma(t,1.37\,m,\infty,soil)}{D_\gamma(t,\,h_{fb},r,mat)} \times \frac{D_\beta(t,\,h,r,mat)}{0.5\times D_\beta(t,\,h,\infty,soil)} \tag{15}$$

As an example, consider an exposure to a contaminated aircraft engine (*mat* = aluminum, r = 0.5 m) from a distance $h = h_{fb}$ = 1 m at t = 1 h. Normalized doses from Tables A1-1 and A1-7 are substituted into Equation 15 to obtain:

$$\text{SSMF}(1\text{ hr},\ 1\text{ m},\ 0.5\text{ m},\ \text{Al}) = \frac{0.7\times 8.93\times 10^{-7}}{2.41\times 10^{-8}} \times \frac{2.21\times 10^{-6}}{0.5\times 1.86\times 10^{-5}} = 6.2 \tag{16}$$

5.2.3 Point Source

A source that is spatially small compared to the source-target distance is considered a point source. Point source geometry has been used in skin dose reconstructions of exposures to radiological "hot spots" such as ship scuppers, aircraft landing gear after decontamination, and cloud sampling filters containing non-uniformly distributed activity. Typically the gamma intensity in the vicinity of the point source was measured or can be estimated. The skin dose accrued while facing a point source can be determined by applying either Equation 8 or Equation 9, depending on the type of intensity information available, with modifying factors $M_{\beta t} = M_{\gamma t} = 1$ (for a face-on exposure) and source radius r = 0.1 m. The doses D_γ and D_β are obtained from Attachment 1.

5.3 Volumetric Source: Skin Dose from Swimming in Contaminated Water

Radiation exposure to the skin may have occurred from fallout-contaminated or neutron-activated sources suspended in seawater when the individual was submerged in the water, such as while swimming or diving.

For skin dose associated with fallout-contaminated seawater, it is assumed the water was uniformly contaminated with unfractionated fallout of age t, measured from the time of detonation. The gamma dose, D_{γ}, accrued in fallout-contaminated water is shown in SM ED02 - *Whole Body External Dose Assessment* is approximated by:

$$D_{\gamma} = 1.4\, I_{ff}\, \Delta t \tag{17}$$

where

D_{γ}	=	External gamma dose accrued by a swimmer during the short duration of swimming Δt (rem)
I_{ff}	=	Free-field gamma intensity above the water surface, assumed to be constant over the short duration of swimming Δt (R h^{-1})
Δt	=	Time spent in the contaminated water (h)

Based on the analysis in Weitz (2012), the beta skin dose for immersion in fallout-contaminated seawater is less than half of the gamma dose for all times less than about 6 months post-detonation. For times of typical exposure scenarios, e.g., between 100 and 500 hours after a detonation, the beta skin dose is roughly one-third or less of the gamma dose.

For skin dose associated with neutron-activated seawater, Na-24, K-42, and Br-82 were the dominant radioisotopes relevant to an immersion scenario produced in a low-altitude nuclear detonation above or in seawater (Weitz, 2012). The gamma and beta doses accrued while swimming for a duration Δt in this neutron-activated seawater are estimated using the following equations (Weitz, 2012):

$$D_{\gamma} = 1.4\, I_{ff}\, \Delta t \tag{18}$$

$$D_{\beta} = 0.13\, I_{ff}\, \Delta t \tag{19}$$

In both cases, the gamma and beta doses are added to determine the total skin dose.

5.4 Uncertainty Analysis

The methods employed to identify, quantify, and combine uncertainties in internal dose estimates are detailed in SM UA01 - *Dose Uncertainty and Upper-Bound Dose Determinations*. Operation-, scenario-, and shot-specific information and data needed to address uncertainty analysis for internal doses are contained in SOP Appendices A-C.

6. Data and Input

Operation and shot-specific data are compiled in SOP Appendices A-C.

Due to the limited range of beta particles and their attenuation characteristics, skin dose assessments require consideration of additional details not normally relevant in gamma dose reconstructions. The parameters that must be defined specifically for skin dose from external sources assessments are listed below. Specific values of these parameters should be determined to the extent possible from statements made by the veteran in his Scenario of Participation and Radiation Exposure or supporting documentation, and/or through personal interview. When these direct sources of information are not available, the analyst can review skin dose reconstructions performed for personnel in the same or similar units to ascertain key parameters. Finally, default values have been established for most parameters when more specific information is lacking, as follows:

- Veteran’s height (default = 1.73 m)
- Anatomical location(s) of skin cancer (e.g., face, forearms, behind ears)
- F_{os}: fraction of time spent outside when on land (default = 0.6)
- F_{ts}: fraction of time spent topside aboard ship (default = 0.4)
- f_{std}: fraction of topside or outdoor time spent standing (default = 0.5)
- f_{sit}: fraction of topside or outdoor time spent sitting (default = 0.5)
- Frequency of shore liberty for ship crew (default = 4 hours every 4 days when ship is near a residence island or recreational area)
- Frequency of swimming in lagoon water (default = 0 or as specified in appropriate SOP Appendix)
- Time spent swimming per event (default = 1 h)

For decontamination and post-decontamination work activities, use the following default values:

- Distance of torso from contaminated surface while decontaminating (default = an average of 1 meter)

- Time spent decontaminating ship or aircraft (default = 6 hours for 1 day after each fallout episode)
- Fraction of decontamination time spent hosing (default = 0.5)
- Fraction of decontamination time spent scrubbing (default = 0.5)
- Time spent performing maintenance or work on decontaminated surface(s) (default = 1 hour each day after decontamination event)
- Distance of intensity measurement from contaminated surface (default = 0.1 meter).

7. Referenced SOPs and Standard Methods from this Manual

(1) SOP RA01 - Radiation Dose Assessment for Cases Requiring Detailed Analysis

(2) SM ED02 - Whole Body External Dose Assessment

(3) SM ED04 - Skin Dose from Dermal Contamination

(4) SM UA01 - Dose Uncertainty and Upper-Bound Dose Determinations

8. References

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Attachment 1.

Normalized Doses for Finite Circular Sources

Gamma and beta doses to the basal cell layer of the skin from axial exposures to circular fallout sources are provided in this Attachment. These doses, calculated using the two-dimensional transport methods described in Weitz (2011), are presented in units of mrad per unit surface emission density: mrad β^{-1} cm^2 for beta dose and mrad $\gamma^{-1} cm^2$ for gamma dose. The doses are organized in tables, with each table corresponding to one time after detonation and one substrate material. The tables are arranged in the following order:

In each table, the gamma doses are listed for vertical heights ranging from 0.1 to 2 meters and source sizes (radii) from 0.1 to 500 m. The gamma doses are followed by the beta doses for a similar range of vertical heights but with source radii extending only to 20 m (sufficient given the limited range of the beta emissions). For many practical applications, it is necessary to interpolate between these discrete values of parameters available in these tables. Doses for radius r = 0.1 m are appropriate for point sources, while those for r = 500 m (gamma) and 20 m (beta) are representative of infinite plane sources.

Table A1-1. Normalized Doses for Circular Sources with *Mat* = Soil and *t* = 1 hour

Gamma

Radius (m)	Height (m)					
	0.1	**0.2**	**0.6**	**1**	**1.37**	**2**
0.10	7.54E-08	2.54E-08	3.23E-09	1.15E-09	5.34E-10	2.81E-10
0.25	2.06E-07	1.06E-07	1.83E-08	6.64E-09	3.27E-09	1.56E-09
0.50	3.13E-07	2.13E-07	5.97E-08	2.43E-08	1.29E-08	5.99E-09
1	4.10E-07	3.21E-07	1.44E-07	7.35E-08	4.48E-08	2.29E-08
2	5.01E-07	4.23E-07	2.56E-07	1.67E-07	1.19E-07	7.19E-08
3	5.54E-07	4.82E-07	3.26E-07	2.34E-07	1.81E-07	1.22E-07
4	5.92E-07	5.24E-07	3.74E-07	2.85E-07	2.29E-07	1.65E-07
5	6.20E-07	5.55E-07	4.12E-07	3.24E-07	2.69E-07	2.02E-07
7	6.63E-07	6.02E-07	4.69E-07	3.84E-07	3.29E-07	2.61E-07
10	7.08E-07	6.52E-07	5.27E-07	4.47E-07	3.95E-07	3.27E-07
15	7.59E-07	7.08E-07	5.93E-07	5.19E-07	4.68E-07	4.02E-07
20	7.94E-07	7.47E-07	6.38E-07	5.67E-07	5.19E-07	4.54E-07
50	9.03E-07	8.65E-07	7.76E-07	7.14E-07	6.70E-07	6.12E-07
100	9.79E-07	9.45E-07	8.68E-07	8.10E-07	7.69E-07	7.16E-07
200	1.04E-06	1.01E-06	9.39E-07	8.84E-07	8.45E-07	7.93E-07
500	1.08E-06	1.05E-06	9.84E-07	9.32E-07	8.93E-07	8.43E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.2**	**0.6**	**1**	**2**
0.10	1.03E-05	3.02E-06	3.08E-07	9.59E-08	1.96E-08
0.25	2.84E-05	1.29E-05	1.77E-06	5.71E-07	1.10E-07
0.50	4.09E-05	2.56E-05	5.77E-06	2.13E-06	4.20E-07
1	4.76E-05	3.58E-05	1.38E-05	6.41E-06	1.52E-06
2	4.98E-05	4.04E-05	2.17E-05	1.31E-05	4.36E-06
3	5.01E-05	4.13E-05	2.42E-05	1.61E-05	6.64E-06
4	5.02E-05	4.15E-05	2.51E-05	1.74E-05	8.04E-06
5	5.02E-05	4.15E-05	2.55E-05	1.80E-05	8.83E-06
7	5.02E-05	4.15E-05	2.57E-05	1.84E-05	9.48E-06
10	5.02E-05	4.15E-05	2.57E-05	1.85E-05	9.71E-06
15	5.02E-05	4.15E-05	2.57E-05	1.86E-05	9.76E-06
20	5.02E-05	4.15E-05	2.57E-05	1.86E-05	9.76E-06

Table A1-2. Normalized Doses for Circular Sources with *Mat* = Soil and *t* = 1 day

Gamma

Radius (m)	**Height (m)**					
	0.1	**0.2**	**0.6**	**1**	**1.37**	**2**
0.10	6.13E-08	2.03E-08	2.18E-09	7.61E-10	3.72E-10	2.60E-10
0.25	1.63E-07	8.34E-08	1.29E-08	4.55E-09	2.50E-09	1.22E-09
0.50	2.48E-07	1.61E-07	4.19E-08	1.65E-08	9.33E-09	4.10E-09
1	3.25E-07	2.44E-07	1.03E-07	5.10E-08	3.16E-08	1.57E-08
2	3.95E-07	3.23E-07	1.84E-07	1.17E-07	8.29E-08	4.81E-08
3	4.35E-07	3.67E-07	2.35E-07	1.66E-07	1.26E-07	8.18E-08
4	4.63E-07	3.98E-07	2.71E-07	2.01E-07	1.61E-07	1.12E-07
5	4.84E-07	4.21E-07	2.98E-07	2.30E-07	1.89E-07	1.37E-07
7	5.15E-07	4.55E-07	3.38E-07	2.73E-07	2.31E-07	1.79E-07
10	5.48E-07	4.92E-07	3.81E-07	3.17E-07	2.76E-07	2.25E-07
15	5.84E-07	5.30E-07	4.27E-07	3.67E-07	3.27E-07	2.76E-07
20	6.09E-07	5.59E-07	4.59E-07	4.00E-07	3.61E-07	3.11E-07
50	6.87E-07	6.43E-07	5.55E-07	4.99E-07	4.65E-07	4.16E-07
100	7.39E-07	6.99E-07	6.17E-07	5.63E-07	5.31E-07	4.84E-07
200	7.81E-07	7.42E-07	6.63E-07	6.11E-07	5.80E-07	5.34E-07
500	8.06E-07	7.67E-07	6.90E-07	6.38E-07	6.08E-07	5.62E-07

Beta

Radius (m)	**Height (m)**				
	0.1	**0.2**	**0.6**	**1**	**2**
0.10	1.10E-05	3.23E-06	2.86E-07	8.28E-08	1.26E-08
0.25	2.85E-05	1.32E-05	1.66E-06	5.11E-07	7.52E-08
0.50	3.87E-05	2.45E-05	5.31E-06	1.82E-06	2.81E-07
1	4.32E-05	3.20E-05	1.19E-05	5.24E-06	9.78E-07
2	4.44E-05	3.47E-05	1.70E-05	9.59E-06	2.64E-06
3	4.46E-05	3.51E-05	1.83E-05	1.12E-05	3.74E-06
4	4.46E-05	3.52E-05	1.87E-05	1.17E-05	4.32E-06
5	4.46E-05	3.52E-05	1.88E-05	1.19E-05	4.61E-06
7	4.46E-05	3.52E-05	1.89E-05	1.20E-05	4.83E-06
10	4.46E-05	3.52E-05	1.89E-05	1.21E-05	4.89E-06
15	4.46E-05	3.52E-05	1.89E-05	1.21E-05	4.90E-06
20	4.46E-05	3.52E-05	1.89E-05	1.21E-05	4.90E-06

Table A1-3. Normalized Doses for Circular Sources with *Mat* = Soil and *t* = 1 week

Gamma

Radius (m)	**Height (m)**					
	0.1	**0.2**	**0.6**	**1**	**1.37**	**2**
0.10	5.77E-08	2.00E-08	2.09E-09	7.79E-10	3.95E-10	1.66E-10
0.25	1.58E-07	8.08E-08	1.29E-08	4.61E-09	2.59E-09	1.29E-09
0.50	2.39E-07	1.59E-07	4.24E-08	1.72E-08	9.66E-09	4.56E-09
1	3.13E-07	2.41E-07	1.03E-07	5.33E-08	3.25E-08	1.69E-08
2	3.84E-07	3.19E-07	1.85E-07	1.20E-07	8.51E-08	5.04E-08
3	4.23E-07	3.63E-07	2.35E-07	1.70E-07	1.29E-07	8.65E-08
4	4.51E-07	3.92E-07	2.72E-07	2.06E-07	1.65E-07	1.17E-07
5	4.73E-07	4.17E-07	2.99E-07	2.36E-07	1.94E-07	1.43E-07
7	5.05E-07	4.52E-07	3.42E-07	2.80E-07	2.38E-07	1.86E-07
10	5.38E-07	4.88E-07	3.86E-07	3.28E-07	2.84E-07	2.33E-07
15	5.76E-07	5.30E-07	4.34E-07	3.78E-07	3.36E-07	2.87E-07
20	6.03E-07	5.59E-07	4.68E-07	4.13E-07	3.72E-07	3.25E-07
50	6.85E-07	6.44E-07	5.67E-07	5.16E-07	4.80E-07	4.37E-07
100	7.40E-07	7.02E-07	6.33E-07	5.85E-07	5.50E-07	5.09E-07
200	7.83E-07	7.48E-07	6.84E-07	6.37E-07	6.02E-07	5.63E-07
500	8.09E-07	7.74E-07	7.13E-07	6.66E-07	6.32E-07	5.94E-07

Beta

Radius (m)	**Height (m)**				
	0.1	**0.2**	**0.6**	**1**	**2**
0.10	1.13E-05	3.18E-06	1.98E-07	5.16E-08	4.83E-09
0.25	2.63E-05	1.20E-05	1.12E-06	3.04E-07	3.33E-08
0.50	3.29E-05	2.01E-05	3.41E-06	1.07E-06	1.29E-07
1	3.53E-05	2.42E-05	7.18E-06	2.96E-06	4.28E-07
2	3.57E-05	2.53E-05	9.50E-06	4.89E-06	1.06E-06
3	3.57E-05	2.54E-05	9.88E-06	5.39E-06	1.37E-06
4	3.57E-05	2.54E-05	9.95E-06	5.51E-06	1.49E-06
5	3.57E-05	2.54E-05	9.97E-06	5.54E-06	1.53E-06
7	3.57E-05	2.54E-05	9.97E-06	5.55E-06	1.55E-06
10	3.57E-05	2.54E-05	9.97E-06	5.56E-06	1.55E-06
15	3.57E-05	2.54E-05	9.97E-06	5.56E-06	1.55E-06
20	3.57E-05	2.54E-05	9.97E-06	5.56E-06	1.55E-06

Table A1-4. Normalized Doses for Circular Sources with *Mat* = Soil and *t* = 1 month

Gamma

Radius (m)	**Height (m)**					
	0.1	**0.2**	**0.6**	**1**	**1.37**	**2**
0.10	6.66E-08	2.25E-08	2.69E-09	9.12E-10	4.58E-10	2.90E-10
0.25	1.79E-07	9.16E-08	1.54E-08	5.41E-09	2.90E-09	1.37E-09
0.50	2.71E-07	1.81E-07	4.93E-08	2.00E-08	1.04E-08	4.94E-09
1	3.54E-07	2.74E-07	1.19E-07	6.09E-08	3.65E-08	1.90E-08
2	4.32E-07	3.61E-07	2.13E-07	1.37E-07	9.67E-08	5.81E-08
3	4.77E-07	4.12E-07	2.70E-07	1.93E-07	1.47E-07	9.82E-08
4	5.08E-07	4.46E-07	3.11E-07	2.34E-07	1.87E-07	1.33E-07
5	5.31E-07	4.73E-07	3.41E-07	2.66E-07	2.19E-07	1.63E-07
7	5.67E-07	5.12E-07	3.87E-07	3.15E-07	2.69E-07	2.12E-07
10	6.03E-07	5.53E-07	4.36E-07	3.66E-07	3.21E-07	2.64E-07
15	6.46E-07	5.99E-07	4.90E-07	4.23E-07	3.80E-07	3.24E-07
20	6.75E-07	6.32E-07	5.27E-07	4.63E-07	4.21E-07	3.66E-07
50	7.66E-07	7.29E-07	6.40E-07	5.82E-07	5.41E-07	4.92E-07
100	8.26E-07	7.94E-07	7.13E-07	6.60E-07	6.21E-07	5.74E-07
200	8.74E-07	8.46E-07	7.69E-07	7.18E-07	6.81E-07	6.34E-07
500	9.04E-07	8.78E-07	8.04E-07	7.53E-07	7.16E-07	6.72E-07

Beta

Radius (m)	**Height (m)**				
	0.1	**0.2**	**0.6**	**1**	**2**
0.10	1.12E-05	3.15E-06	2.01E-07	5.29E-08	6.09E-09
0.25	2.63E-05	1.20E-05	1.15E-06	3.14E-07	3.61E-08
0.50	3.33E-05	2.04E-05	3.54E-06	1.13E-06	1.42E-07
1	3.59E-05	2.47E-05	7.51E-06	3.13E-06	4.95E-07
2	3.64E-05	2.60E-05	1.01E-05	5.35E-06	1.25E-06
3	3.64E-05	2.61E-05	1.06E-05	5.99E-06	1.67E-06
4	3.64E-05	2.62E-05	1.07E-05	6.16E-06	1.84E-06
5	3.64E-05	2.62E-05	1.08E-05	6.21E-06	1.90E-06
7	3.64E-05	2.62E-05	1.08E-05	6.23E-06	1.94E-06
10	3.64E-05	2.62E-05	1.08E-05	6.24E-06	1.95E-06
15	3.64E-05	2.62E-05	1.08E-05	6.24E-06	1.95E-06
20	3.64E-05	2.62E-05	1.08E-05	6.24E-06	1.95E-06

Table A1-5. Normalized Doses for Circular Sources with *Mat* = Soil and *t* = 6 months

Gamma

Radius (m)	Height (m)					
	0.1	**0.2**	**0.6**	**1**	**1.37**	**2**
0.10	7.27E-08	2.51E-08	2.74E-09	8.43E-10	4.48E-10	2.26E-10
0.25	1.96E-07	1.01E-07	1.58E-08	5.37E-09	2.95E-09	1.37E-09
0.50	2.97E-07	1.96E-07	5.03E-08	1.98E-08	1.06E-08	4.95E-09
1	3.86E-07	2.95E-07	1.21E-07	6.09E-08	3.64E-08	1.83E-08
2	4.69E-07	3.87E-07	2.19E-07	1.39E-07	9.76E-08	5.75E-08
3	5.14E-07	4.39E-07	2.79E-07	1.97E-07	1.49E-07	9.79E-08
4	5.46E-07	4.75E-07	3.22E-07	2.42E-07	1.91E-07	1.33E-07
5	5.71E-07	5.03E-07	3.56E-07	2.76E-07	2.24E-07	1.64E-07
7	6.07E-07	5.45E-07	4.06E-07	3.28E-07	2.75E-07	2.13E-07
10	6.46E-07	5.88E-07	4.58E-07	3.81E-07	3.30E-07	2.67E-07
15	6.89E-07	6.35E-07	5.14E-07	4.41E-07	3.91E-07	3.30E-07
20	7.19E-07	6.69E-07	5.54E-07	4.83E-07	4.33E-07	3.71E-07
50	8.11E-07	7.71E-07	6.72E-07	6.06E-07	5.58E-07	4.97E-07
100	8.75E-07	8.38E-07	7.48E-07	6.85E-07	6.39E-07	5.80E-07
200	9.24E-07	8.91E-07	8.05E-07	7.44E-07	6.97E-07	6.39E-07
500	9.53E-07	9.22E-07	8.37E-07	7.76E-07	7.30E-07	6.72E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.2**	**0.6**	**1**	**2**
0.10	1.07E-05	2.97E-06	1.48E-07	3.92E-08	6.94E-09
0.25	2.46E-05	1.10E-05	8.29E-07	2.37E-07	4.29E-08
0.50	3.11E-05	1.81E-05	2.54E-06	8.72E-07	1.68E-07
1	3.37E-05	2.22E-05	5.81E-06	2.61E-06	6.04E-07
2	3.45E-05	2.39E-05	8.86E-06	5.21E-06	1.69E-06
3	3.45E-05	2.42E-05	9.75E-06	6.32E-06	2.50E-06
4	3.46E-05	2.42E-05	1.00E-05	6.74E-06	2.96E-06
5	3.46E-05	2.43E-05	1.01E-05	6.92E-06	3.20E-06
7	3.46E-05	2.43E-05	1.02E-05	7.03E-06	3.39E-06
10	3.46E-05	2.43E-05	1.02E-05	7.05E-06	3.44E-06
15	3.46E-05	2.43E-05	1.02E-05	7.05E-06	3.44E-06
20	3.46E-05	2.43E-05	1.02E-05	7.05E-06	3.44E-06

Table A1-6. Normalized Doses for Circular Sources with *Mat* = Soil and *t* = 1 year

Gamma

Radius (m)	**Height (m)**					
	0.1	**0.2**	**0.6**	**1**	**1.37**	**2**
0.10	7.25E-08	2.50E-08	2.76E-09	8.53E-10	4.34E-10	2.52E-10
0.25	1.94E-07	1.01E-07	1.61E-08	5.08E-09	2.63E-09	1.35E-09
0.50	2.94E-07	1.97E-07	5.16E-08	1.93E-08	1.06E-08	5.25E-09
1	3.83E-07	2.95E-07	1.23E-07	6.06E-08	3.70E-08	1.89E-08
2	4.64E-07	3.88E-07	2.21E-07	1.40E-07	9.83E-08	5.85E-08
3	5.11E-07	4.40E-07	2.82E-07	1.98E-07	1.51E-07	1.00E-07
4	5.43E-07	4.76E-07	3.26E-07	2.42E-07	1.93E-07	1.37E-07
5	5.68E-07	5.04E-07	3.61E-07	2.77E-07	2.27E-07	1.67E-07
7	6.04E-07	5.45E-07	4.10E-07	3.29E-07	2.78E-07	2.17E-07
10	6.43E-07	5.89E-07	4.62E-07	3.84E-07	3.34E-07	2.73E-07
15	6.87E-07	6.37E-07	5.20E-07	4.45E-07	3.96E-07	3.36E-07
20	7.17E-07	6.71E-07	5.60E-07	4.87E-07	4.39E-07	3.79E-07
50	8.12E-07	7.75E-07	6.80E-07	6.12E-07	5.65E-07	5.08E-07
100	8.75E-07	8.45E-07	7.59E-07	6.94E-07	6.47E-07	5.91E-07
200	9.26E-07	8.98E-07	8.17E-07	7.54E-07	7.08E-07	6.52E-07
500	9.56E-07	9.29E-07	8.50E-07	7.88E-07	7.42E-07	6.87E-07

Beta

Radius (m)	**Height (m)**				
	0.1	**0.2**	**0.6**	**1**	**2**
0.10	1.04E-05	2.90E-06	1.51E-07	4.55E-08	1.03E-08
0.25	2.45E-05	1.08E-05	8.49E-07	2.63E-07	5.77E-08
0.50	3.19E-05	1.84E-05	2.69E-06	9.80E-07	2.16E-07
1	3.53E-05	2.36E-05	6.49E-06	3.01E-06	7.83E-07
2	3.65E-05	2.61E-05	1.06E-05	6.49E-06	2.34E-06
3	3.67E-05	2.66E-05	1.21E-05	8.24E-06	3.67E-06
4	3.67E-05	2.68E-05	1.26E-05	9.02E-06	4.51E-06
5	3.67E-05	2.68E-05	1.28E-05	9.37E-06	4.99E-06
7	3.67E-05	2.68E-05	1.29E-05	9.60E-06	5.37E-06
10	3.67E-05	2.68E-05	1.30E-05	9.65E-06	5.48E-06
15	3.67E-05	2.68E-05	1.30E-05	9.65E-06	5.49E-06
20	3.67E-05	2.68E-05	1.30E-05	9.65E-06	5.49E-06

Table A1-7. Normalized Doses for Circular Sources with *Mat* = Aluminum and *t* = 1 hour

Gamma

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	7.53E-08	1.28E-08	3.01E-09	1.03E-09	2.40E-10
0.25	2.01E-07	6.07E-08	1.81E-08	6.68E-09	1.72E-09
0.50	3.02E-07	1.46E-07	5.86E-08	2.41E-08	6.23E-09
1	3.97E-07	2.54E-07	1.40E-07	7.22E-08	2.14E-08
2	4.88E-07	3.62E-07	2.50E-07	1.62E-07	6.86E-08
3	5.41E-07	4.24E-07	3.17E-07	2.27E-07	1.16E-07
4	5.78E-07	4.68E-07	3.64E-07	2.76E-07	1.57E-07
5	6.06E-07	5.03E-07	4.00E-07	3.15E-07	1.93E-07
7	6.50E-07	5.53E-07	4.56E-07	3.75E-07	2.50E-07
10	6.95E-07	6.06E-07	5.17E-07	4.36E-07	3.13E-07
15	7.46E-07	6.65E-07	5.83E-07	5.07E-07	3.86E-07
20	7.81E-07	7.05E-07	6.29E-07	5.56E-07	4.37E-07
50	8.89E-07	8.28E-07	7.67E-07	7.00E-07	5.91E-07
100	9.63E-07	9.13E-07	8.56E-07	7.94E-07	6.92E-07
200	1.02E-06	9.75E-07	9.23E-07	8.66E-07	7.67E-07
500	1.06E-06	1.02E-06	9.67E-07	9.10E-07	8.15E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.07E-05	1.41E-06	3.07E-07	9.37E-08	1.69E-08
0.25	2.93E-05	7.05E-06	1.84E-06	5.99E-07	1.08E-07
0.50	4.22E-05	1.73E-05	6.02E-06	2.21E-06	4.38E-07
1	4.91E-05	2.86E-05	1.43E-05	6.65E-06	1.56E-06
2	5.14E-05	3.50E-05	2.24E-05	1.35E-05	4.47E-06
3	5.17E-05	3.65E-05	2.50E-05	1.66E-05	6.79E-06
4	5.18E-05	3.69E-05	2.59E-05	1.80E-05	8.21E-06
5	5.18E-05	3.71E-05	2.63E-05	1.86E-05	9.02E-06
7	5.18E-05	3.71E-05	2.66E-05	1.90E-05	9.69E-06
10	5.18E-05	3.72E-05	2.66E-05	1.91E-05	9.94E-06
15	5.18E-05	3.72E-05	2.66E-05	1.91E-05	9.99E-06
20	5.18E-05	3.72E-05	2.66E-05	1.91E-05	9.99E-06

Table A1-8. Normalized Doses for Circular Sources with *Mat* = Aluminum and *t* = 1 day

Gamma

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	6.04E-08	9.36E-09	2.23E-09	6.90E-10	1.82E-10
0.25	1.58E-07	4.56E-08	1.28E-08	4.51E-09	1.08E-09
0.50	2.39E-07	1.08E-07	4.14E-08	1.56E-08	4.01E-09
1	3.14E-07	1.87E-07	9.87E-08	4.92E-08	1.47E-08
2	3.84E-07	2.68E-07	1.76E-07	1.12E-07	4.58E-08
3	4.24E-07	3.14E-07	2.24E-07	1.57E-07	7.85E-08
4	4.51E-07	3.47E-07	2.59E-07	1.91E-07	1.07E-07
5	4.73E-07	3.71E-07	2.86E-07	2.18E-07	1.32E-07
7	5.05E-07	4.08E-07	3.25E-07	2.60E-07	1.72E-07
10	5.38E-07	4.46E-07	3.67E-07	3.03E-07	2.15E-07
15	5.74E-07	4.88E-07	4.13E-07	3.50E-07	2.66E-07
20	6.00E-07	5.18E-07	4.46E-07	3.84E-07	3.01E-07
50	6.77E-07	6.06E-07	5.38E-07	4.83E-07	4.05E-07
100	7.28E-07	6.62E-07	5.98E-07	5.47E-07	4.70E-07
200	7.66E-07	7.04E-07	6.42E-07	5.93E-07	5.18E-07
500	7.89E-07	7.28E-07	6.67E-07	6.18E-07	5.44E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.15E-05	1.43E-06	2.96E-07	8.68E-08	1.24E-08
0.25	2.95E-05	7.12E-06	1.73E-06	5.18E-07	7.47E-08
0.50	4.00E-05	1.65E-05	5.52E-06	1.89E-06	2.88E-07
1	4.47E-05	2.53E-05	1.23E-05	5.40E-06	1.01E-06
2	4.60E-05	2.92E-05	1.76E-05	9.90E-06	2.71E-06
3	4.61E-05	2.99E-05	1.89E-05	1.15E-05	3.84E-06
4	4.61E-05	3.01E-05	1.92E-05	1.21E-05	4.43E-06
5	4.61E-05	3.01E-05	1.94E-05	1.23E-05	4.73E-06
7	4.61E-05	3.01E-05	1.95E-05	1.24E-05	4.95E-06
10	4.61E-05	3.01E-05	1.95E-05	1.25E-05	5.01E-06
15	4.61E-05	3.01E-05	1.95E-05	1.25E-05	5.01E-06
20	4.61E-05	3.01E-05	1.95E-05	1.25E-05	5.01E-06

Table A1-9. Normalized Doses for Circular Sources with *Mat* = Aluminum and *t* = 1 week

Gamma

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	5.96E-08	8.93E-09	2.24E-09	7.01E-10	1.58E-10
0.25	1.55E-07	4.46E-08	1.26E-08	4.55E-09	1.09E-09
0.50	2.34E-07	1.06E-07	4.09E-08	1.68E-08	4.09E-09
1	3.08E-07	1.85E-07	9.93E-08	5.10E-08	1.55E-08
2	3.78E-07	2.67E-07	1.77E-07	1.15E-07	4.83E-08
3	4.18E-07	3.15E-07	2.27E-07	1.63E-07	8.06E-08
4	4.46E-07	3.47E-07	2.63E-07	1.98E-07	1.10E-07
5	4.67E-07	3.72E-07	2.91E-07	2.26E-07	1.35E-07
7	4.99E-07	4.09E-07	3.32E-07	2.68E-07	1.76E-07
10	5.33E-07	4.48E-07	3.74E-07	3.13E-07	2.22E-07
15	5.70E-07	4.92E-07	4.22E-07	3.63E-07	2.74E-07
20	5.97E-07	5.22E-07	4.55E-07	3.98E-07	3.09E-07
50	6.75E-07	6.14E-07	5.53E-07	5.01E-07	4.18E-07
100	7.30E-07	6.73E-07	6.16E-07	5.67E-07	4.88E-07
200	7.72E-07	7.17E-07	6.63E-07	6.14E-07	5.38E-07
500	7.97E-07	7.43E-07	6.90E-07	6.42E-07	5.67E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.17E-05	1.33E-06	2.10E-07	4.93E-08	5.58E-09
0.25	2.71E-05	6.16E-06	1.17E-06	3.11E-07	3.19E-08
0.50	3.40E-05	1.29E-05	3.54E-06	1.11E-06	1.25E-07
1	3.65E-05	1.77E-05	7.39E-06	3.04E-06	4.38E-07
2	3.69E-05	1.94E-05	9.79E-06	5.05E-06	1.08E-06
3	3.69E-05	1.96E-05	1.02E-05	5.55E-06	1.40E-06
4	3.69E-05	1.97E-05	1.03E-05	5.67E-06	1.52E-06
5	3.69E-05	1.97E-05	1.03E-05	5.70E-06	1.56E-06
7	3.69E-05	1.97E-05	1.03E-05	5.71E-06	1.58E-06
10	3.69E-05	1.97E-05	1.03E-05	5.71E-06	1.59E-06
15	3.69E-05	1.97E-05	1.03E-05	5.71E-06	1.59E-06
20	3.69E-05	1.97E-05	1.03E-05	5.72E-06	1.59E-06

Table A1-10. Normalized Doses for Circular Sources with *Mat* = Aluminum and *t* = 1 month

Gamma

Radius (m)	Height (m)				
	0.1	0.3	0.6	1	2
0.10	6.49E-08	1.03E-08	2.74E-09	8.37E-10	2.11E-10
0.25	1.75E-07	5.11E-08	1.51E-08	5.43E-09	1.15E-09
0.50	2.63E-07	1.21E-07	4.89E-08	1.98E-08	4.63E-09
1	3.46E-07	2.11E-07	1.16E-07	5.99E-08	1.78E-08
2	4.22E-07	3.02E-07	2.06E-07	1.33E-07	5.51E-08
3	4.68E-07	3.56E-07	2.61E-07	1.87E-07	9.31E-08
4	4.99E-07	3.93E-07	3.01E-07	2.27E-07	1.26E-07
5	5.23E-07	4.22E-07	3.33E-07	2.60E-07	1.56E-07
7	5.59E-07	4.63E-07	3.79E-07	3.07E-07	2.03E-07
10	5.98E-07	5.06E-07	4.27E-07	3.57E-07	2.55E-07
15	6.40E-07	5.54E-07	4.81E-07	4.13E-07	3.14E-07
20	6.69E-07	5.88E-07	5.17E-07	4.52E-07	3.56E-07
50	7.58E-07	6.88E-07	6.26E-07	5.67E-07	4.79E-07
100	8.18E-07	7.54E-07	6.97E-07	6.41E-07	5.58E-07
200	8.65E-07	8.04E-07	7.50E-07	6.96E-07	6.15E-07
500	8.94E-07	8.35E-07	7.82E-07	7.29E-07	6.48E-07

Beta

Radius (m)	Height (m)				
	0.1	0.3	0.6	1	2
0.10	1.16E-05	1.33E-06	2.08E-07	5.66E-08	7.23E-09
0.25	2.73E-05	6.20E-06	1.18E-06	3.33E-07	4.03E-08
0.50	3.45E-05	1.31E-05	3.63E-06	1.18E-06	1.50E-07
1	3.71E-05	1.83E-05	7.73E-06	3.26E-06	5.12E-07
2	3.77E-05	2.03E-05	1.04E-05	5.54E-06	1.30E-06
3	3.77E-05	2.05E-05	1.09E-05	6.19E-06	1.72E-06
4	3.77E-05	2.06E-05	1.11E-05	6.37E-06	1.90E-06
5	3.77E-05	2.06E-05	1.11E-05	6.42E-06	1.96E-06
7	3.77E-05	2.06E-05	1.11E-05	6.45E-06	2.00E-06
10	3.77E-05	2.06E-05	1.11E-05	6.45E-06	2.01E-06
15	3.77E-05	2.06E-05	1.11E-05	6.45E-06	2.01E-06
20	3.77E-05	2.06E-05	1.11E-05	6.45E-06	2.01E-06

Table A1-11. Normalized Doses for Circular Sources with *Mat* = Aluminum and *t* = 6 months

Gamma

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	7.34E-08	1.19E-08	2.92E-09	8.49E-10	2.75E-10
0.25	1.92E-07	5.69E-08	1.64E-08	5.13E-09	1.27E-09
0.50	2.89E-07	1.35E-07	5.06E-08	1.84E-08	4.64E-09
1	3.78E-07	2.30E-07	1.18E-07	5.67E-08	1.74E-08
2	4.62E-07	3.26E-07	2.11E-07	1.31E-07	5.45E-08
3	5.08E-07	3.81E-07	2.71E-07	1.85E-07	9.22E-08
4	5.40E-07	4.20E-07	3.12E-07	2.27E-07	1.26E-07
5	5.64E-07	4.51E-07	3.46E-07	2.60E-07	1.56E-07
7	6.02E-07	4.94E-07	3.95E-07	3.10E-07	2.03E-07
10	6.41E-07	5.40E-07	4.47E-07	3.64E-07	2.55E-07
15	6.84E-07	5.92E-07	5.03E-07	4.23E-07	3.15E-07
20	7.15E-07	6.27E-07	5.42E-07	4.64E-07	3.57E-07
50	8.05E-07	7.33E-07	6.57E-07	5.82E-07	4.80E-07
100	8.66E-07	8.02E-07	7.30E-07	6.59E-07	5.58E-07
200	9.12E-07	8.53E-07	7.83E-07	7.13E-07	6.15E-07
500	9.39E-07	8.82E-07	8.12E-07	7.43E-07	6.46E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.12E-05	1.20E-06	1.56E-07	4.12E-08	7.55E-09
0.25	2.55E-05	5.42E-06	8.71E-07	2.49E-07	4.39E-08
0.50	3.22E-05	1.10E-05	2.65E-06	8.98E-07	1.71E-07
1	3.48E-05	1.56E-05	6.00E-06	2.72E-06	6.16E-07
2	3.57E-05	1.80E-05	9.14E-06	5.38E-06	1.74E-06
3	3.58E-05	1.85E-05	1.01E-05	6.52E-06	2.56E-06
4	3.58E-05	1.86E-05	1.04E-05	6.96E-06	3.03E-06
5	3.58E-05	1.87E-05	1.05E-05	7.14E-06	3.28E-06
7	3.58E-05	1.87E-05	1.05E-05	7.26E-06	3.48E-06
10	3.58E-05	1.87E-05	1.06E-05	7.28E-06	3.53E-06
15	3.58E-05	1.87E-05	1.06E-05	7.28E-06	3.54E-06
20	3.58E-05	1.87E-05	1.06E-05	7.28E-06	3.54E-06

Table A1-12. Normalized Doses for Circular Sources with *Mat* = Aluminum and *t* = 1 year

Gamma

Radius (m)			**Height (m)**		
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	7.26E-08	1.16E-08	2.71E-09	8.35E-10	1.63E-10
0.25	1.90E-07	5.62E-08	1.59E-08	5.19E-09	1.17E-09
0.50	2.86E-07	1.32E-07	4.96E-08	1.87E-08	5.04E-09
1	3.75E-07	2.26E-07	1.18E-07	5.80E-08	1.80E-08
2	4.58E-07	3.21E-07	2.10E-07	1.33E-07	5.61E-08
3	5.04E-07	3.77E-07	2.69E-07	1.89E-07	9.48E-08
4	5.36E-07	4.16E-07	3.12E-07	2.32E-07	1.29E-07
5	5.61E-07	4.46E-07	3.46E-07	2.65E-07	1.60E-07
7	5.98E-07	4.91E-07	3.96E-07	3.17E-07	2.07E-07
10	6.37E-07	5.37E-07	4.47E-07	3.71E-07	2.61E-07
15	6.81E-07	5.89E-07	5.04E-07	4.32E-07	3.22E-07
20	7.12E-07	6.25E-07	5.44E-07	4.74E-07	3.64E-07
50	8.06E-07	7.32E-07	6.62E-07	5.96E-07	4.90E-07
100	8.68E-07	8.02E-07	7.36E-07	6.74E-07	5.70E-07
200	9.15E-07	8.55E-07	7.92E-07	7.32E-07	6.27E-07
500	9.44E-07	8.84E-07	8.23E-07	7.63E-07	6.58E-07

Beta

Radius (m)			**Height (m)**		
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.08E-05	1.17E-06	1.54E-07	4.32E-08	7.16E-09
0.25	2.53E-05	5.37E-06	8.83E-07	2.73E-07	5.65E-08
0.50	3.29E-05	1.12E-05	2.78E-06	1.00E-06	2.23E-07
1	3.65E-05	1.68E-05	6.70E-06	3.12E-06	8.21E-07
2	3.78E-05	2.02E-05	1.10E-05	6.67E-06	2.42E-06
3	3.80E-05	2.10E-05	1.25E-05	8.48E-06	3.78E-06
4	3.80E-05	2.13E-05	1.30E-05	9.29E-06	4.64E-06
5	3.80E-05	2.14E-05	1.32E-05	9.66E-06	5.13E-06
7	3.80E-05	2.14E-05	1.34E-05	9.90E-06	5.53E-06
10	3.80E-05	2.14E-05	1.34E-05	9.95E-06	5.64E-06
15	3.80E-05	2.14E-05	1.34E-05	9.96E-06	5.65E-06
20	3.80E-05	2.14E-05	1.34E-05	9.96E-06	5.65E-06

Table A1-13. Normalized Doses for Circular Sources with *Mat* = Iron and *t* = 1 hour

Gamma

Radius (m)	Height (m)					
	0.1	**0.3**	**0.6**	**1**	**1.37**	**2**
0.10	9.28E-08	1.51E-08	3.79E-09	1.31E-09	6.70E-10	2.23E-10
0.25	2.25E-07	7.15E-08	2.18E-08	7.72E-09	3.85E-09	1.77E-09
0.50	3.29E-07	1.64E-07	6.79E-08	2.81E-08	1.48E-08	6.78E-09
1	4.27E-07	2.75E-07	1.58E-07	8.23E-08	5.05E-08	2.54E-08
2	5.22E-07	3.87E-07	2.72E-07	1.78E-07	1.26E-07	7.56E-08
3	5.78E-07	4.53E-07	3.42E-07	2.46E-07	1.88E-07	1.25E-07
4	6.18E-07	4.98E-07	3.91E-07	2.97E-07	2.38E-07	1.68E-07
5	6.48E-07	5.33E-07	4.29E-07	3.36E-07	2.78E-07	2.05E-07
7	6.94E-07	5.86E-07	4.85E-07	3.96E-07	3.39E-07	2.64E-07
10	7.42E-07	6.41E-07	5.45E-07	4.59E-07	4.04E-07	3.30E-07
15	7.96E-07	7.02E-07	6.11E-07	5.30E-07	4.76E-07	4.04E-07
20	8.34E-07	7.45E-07	6.56E-07	5.79E-07	5.27E-07	4.55E-07
50	9.50E-07	8.72E-07	7.93E-07	7.24E-07	6.77E-07	6.11E-07
100	1.03E-06	9.58E-07	8.82E-07	8.18E-07	7.73E-07	7.12E-07
200	1.09E-06	1.02E-06	9.51E-07	8.90E-07	8.45E-07	7.87E-07
500	1.13E-06	1.07E-06	9.94E-07	9.35E-07	8.91E-07	8.33E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.21E-05	1.62E-06	3.57E-07	1.08E-07	2.02E-08
0.25	3.25E-05	8.06E-06	2.10E-06	6.92E-07	1.25E-07
0.50	4.62E-05	1.93E-05	6.81E-06	2.53E-06	4.87E-07
1	5.36E-05	3.16E-05	1.60E-05	7.54E-06	1.74E-06
2	5.61E-05	3.85E-05	2.48E-05	1.50E-05	4.99E-06
3	5.65E-05	4.02E-05	2.77E-05	1.85E-05	7.52E-06
4	5.65E-05	4.06E-05	2.87E-05	1.99E-05	9.04E-06
5	5.65E-05	4.08E-05	2.91E-05	2.06E-05	9.92E-06
7	5.65E-05	4.09E-05	2.94E-05	2.11E-05	1.06E-05
10	5.65E-05	4.09E-05	2.95E-05	2.12E-05	1.09E-05
15	5.65E-05	4.09E-05	2.95E-05	2.12E-05	1.10E-05
20	5.65E-05	4.09E-05	2.95E-05	2.12E-05	1.10E-05

Table A1-14. Normalized Doses for Circular Sources with *Mat* = Iron and *t* = 1 day

Gamma

Radius (m)	Height (m)					
	0.1	**0.3**	**0.6**	**1**	**1.37**	**2**
0.10	7.37E-08	1.15E-08	2.67E-09	8.79E-10	4.45E-10	1.77E-10
0.25	1.82E-07	5.44E-08	1.51E-08	5.05E-09	2.59E-09	1.06E-09
0.50	2.68E-07	1.23E-07	4.71E-08	1.83E-08	9.61E-09	4.27E-09
1	3.46E-07	2.08E-07	1.11E-07	5.41E-08	3.26E-08	1.57E-08
2	4.20E-07	2.91E-07	1.92E-07	1.21E-07	8.47E-08	4.83E-08
3	4.61E-07	3.39E-07	2.42E-07	1.68E-07	1.27E-07	8.11E-08
4	4.91E-07	3.72E-07	2.77E-07	2.04E-07	1.61E-07	1.10E-07
5	5.14E-07	3.96E-07	3.05E-07	2.31E-07	1.88E-07	1.35E-07
7	5.46E-07	4.34E-07	3.45E-07	2.73E-07	2.29E-07	1.75E-07
10	5.80E-07	4.73E-07	3.86E-07	3.17E-07	2.73E-07	2.20E-07
15	6.19E-07	5.16E-07	4.33E-07	3.66E-07	3.23E-07	2.70E-07
20	6.45E-07	5.45E-07	4.64E-07	4.00E-07	3.57E-07	3.05E-07
50	7.27E-07	6.33E-07	5.59E-07	4.98E-07	4.57E-07	4.07E-07
100	7.82E-07	6.90E-07	6.19E-07	5.61E-07	5.21E-07	4.72E-07
200	8.24E-07	7.33E-07	6.64E-07	6.06E-07	5.66E-07	5.19E-07
500	8.48E-07	7.58E-07	6.89E-07	6.32E-07	5.92E-07	5.45E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.30E-05	1.67E-06	3.39E-07	1.02E-07	1.34E-08
0.25	3.28E-05	8.12E-06	1.99E-06	6.03E-07	8.55E-08
0.50	4.41E-05	1.86E-05	6.28E-06	2.17E-06	3.27E-07
1	4.92E-05	2.81E-05	1.37E-05	6.09E-06	1.13E-06
2	5.06E-05	3.24E-05	1.95E-05	1.10E-05	2.98E-06
3	5.07E-05	3.32E-05	2.09E-05	1.28E-05	4.19E-06
4	5.07E-05	3.34E-05	2.13E-05	1.34E-05	4.83E-06
5	5.07E-05	3.34E-05	2.15E-05	1.36E-05	5.15E-06
7	5.07E-05	3.34E-05	2.16E-05	1.38E-05	5.39E-06
10	5.07E-05	3.34E-05	2.16E-05	1.38E-05	5.46E-06
15	5.07E-05	3.34E-05	2.16E-05	1.38E-05	5.47E-06
20	5.07E-05	3.34E-05	2.16E-05	1.38E-05	5.47E-06

Table A1-15. Normalized Doses for Circular Sources with *Mat* = Iron and *t* = 1 week

Gamma

Radius (m)	**Height (m)**					
	0.1	**0.3**	**0.6**	**1**	**1.37**	**2**
0.10	7.31E-08	1.13E-08	2.51E-09	8.27E-10	3.84E-10	1.67E-10
0.25	1.77E-07	5.23E-08	1.51E-08	5.11E-09	2.41E-09	1.06E-09
0.50	2.58E-07	1.21E-07	4.83E-08	1.88E-08	9.75E-09	4.48E-09
1	3.36E-07	2.04E-07	1.12E-07	5.62E-08	3.43E-08	1.65E-08
2	4.08E-07	2.87E-07	1.94E-07	1.24E-07	8.66E-08	5.09E-08
3	4.49E-07	3.35E-07	2.46E-07	1.73E-07	1.31E-07	8.62E-08
4	4.78E-07	3.69E-07	2.81E-07	2.09E-07	1.65E-07	1.16E-07
5	5.01E-07	3.95E-07	3.09E-07	2.37E-07	1.94E-07	1.42E-07
7	5.35E-07	4.33E-07	3.51E-07	2.80E-07	2.37E-07	1.83E-07
10	5.69E-07	4.73E-07	3.94E-07	3.26E-07	2.82E-07	2.27E-07
15	6.09E-07	5.17E-07	4.41E-07	3.76E-07	3.34E-07	2.79E-07
20	6.37E-07	5.48E-07	4.73E-07	4.10E-07	3.69E-07	3.15E-07
50	7.22E-07	6.41E-07	5.73E-07	5.13E-07	4.75E-07	4.23E-07
100	7.78E-07	7.02E-07	6.36E-07	5.79E-07	5.42E-07	4.91E-07
200	8.22E-07	7.46E-07	6.82E-07	6.27E-07	5.90E-07	5.41E-07
500	8.48E-07	7.72E-07	7.09E-07	6.55E-07	6.18E-07	5.69E-07

Beta

Radius (m)	**Height (m)**				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.34E-05	1.52E-06	2.30E-07	6.07E-08	6.12E-09
0.25	3.03E-05	7.00E-06	1.31E-06	3.54E-07	3.66E-08
0.50	3.78E-05	1.44E-05	4.00E-06	1.25E-06	1.43E-07
1	4.05E-05	1.97E-05	8.27E-06	3.39E-06	4.85E-07
2	4.10E-05	2.16E-05	1.09E-05	5.59E-06	1.19E-06
3	4.10E-05	2.18E-05	1.13E-05	6.14E-06	1.53E-06
4	4.10E-05	2.18E-05	1.14E-05	6.27E-06	1.65E-06
5	4.10E-05	2.18E-05	1.14E-05	6.31E-06	1.70E-06
7	4.10E-05	2.18E-05	1.14E-05	6.32E-06	1.72E-06
10	4.10E-05	2.18E-05	1.14E-05	6.32E-06	1.72E-06
15	4.10E-05	2.18E-05	1.14E-05	6.32E-06	1.72E-06
20	4.10E-05	2.18E-05	1.14E-05	6.32E-06	1.72E-06

Table A1-16. Normalized Doses for Circular Sources with *Mat* = Iron and *t* = 1 month

Gamma

Radius (m)	**Height (m)**					
	0.1	**0.3**	**0.6**	**1**	**1.37**	**2**
0.10	8.09E-08	1.29E-08	3.05E-09	1.04E-09	5.02E-10	2.02E-10
0.25	1.99E-07	6.02E-08	1.78E-08	6.06E-09	3.17E-09	1.29E-09
0.50	2.90E-07	1.38E-07	5.57E-08	2.20E-08	1.18E-08	5.42E-09
1	3.76E-07	2.33E-07	1.31E-07	6.60E-08	3.91E-08	2.02E-08
2	4.58E-07	3.28E-07	2.25E-07	1.45E-07	1.01E-07	5.92E-08
3	5.04E-07	3.82E-07	2.83E-07	2.00E-07	1.51E-07	1.00E-07
4	5.37E-07	4.21E-07	3.24E-07	2.43E-07	1.92E-07	1.35E-07
5	5.62E-07	4.49E-07	3.56E-07	2.74E-07	2.23E-07	1.65E-07
7	6.00E-07	4.93E-07	4.02E-07	3.23E-07	2.73E-07	2.13E-07
10	6.39E-07	5.37E-07	4.51E-07	3.73E-07	3.25E-07	2.65E-07
15	6.83E-07	5.86E-07	5.05E-07	4.29E-07	3.84E-07	3.25E-07
20	7.14E-07	6.20E-07	5.42E-07	4.67E-07	4.24E-07	3.67E-07
50	8.08E-07	7.23E-07	6.52E-07	5.82E-07	5.44E-07	4.90E-07
100	8.72E-07	7.90E-07	7.24E-07	6.57E-07	6.20E-07	5.69E-07
200	9.21E-07	8.41E-07	7.78E-07	7.12E-07	6.77E-07	6.27E-07
500	9.52E-07	8.72E-07	8.10E-07	7.44E-07	7.11E-07	6.62E-07

Beta

Radius (m)	**Height (m)**				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.33E-05	1.53E-06	2.37E-07	6.34E-08	7.35E-09
0.25	3.05E-05	7.04E-06	1.36E-06	3.80E-07	4.26E-08
0.50	3.83E-05	1.46E-05	4.15E-06	1.34E-06	1.60E-07
1	4.12E-05	2.03E-05	8.68E-06	3.64E-06	5.56E-07
2	4.18E-05	2.24E-05	1.16E-05	6.13E-06	1.40E-06
3	4.18E-05	2.27E-05	1.22E-05	6.83E-06	1.87E-06
4	4.18E-05	2.27E-05	1.23E-05	7.02E-06	2.06E-06
5	4.18E-05	2.27E-05	1.23E-05	7.08E-06	2.13E-06
7	4.18E-05	2.27E-05	1.24E-05	7.11E-06	2.17E-06
10	4.18E-05	2.28E-05	1.24E-05	7.11E-06	2.18E-06
15	4.18E-05	2.28E-05	1.24E-05	7.11E-06	2.18E-06
20	4.18E-05	2.28E-05	1.24E-05	7.11E-06	2.18E-06

Table A1-17. Normalized Doses for Circular Sources with *Mat* = Iron and *t* = 6 months

Gamma

Radius (m)	Height (m) 0.1	0.3	0.6	1	1.37	2
0.10	8.51E-08	1.44E-08	3.31E-09	9.51E-10	4.58E-10	1.97E-10
0.25	2.11E-07	6.62E-08	1.86E-08	5.83E-09	2.76E-09	1.22E-09
0.50	3.13E-07	1.52E-07	5.91E-08	2.09E-08	1.03E-08	4.73E-09
1	4.09E-07	2.53E-07	1.35E-07	6.27E-08	3.59E-08	1.80E-08
2	4.96E-07	3.53E-07	2.32E-07	1.39E-07	9.53E-08	5.56E-08
3	5.45E-07	4.09E-07	2.92E-07	1.95E-07	1.45E-07	9.47E-08
4	5.79E-07	4.49E-07	3.35E-07	2.38E-07	1.85E-07	1.29E-07
5	6.04E-07	4.78E-07	3.68E-07	2.71E-07	2.18E-07	1.59E-07
7	6.43E-07	5.24E-07	4.18E-07	3.21E-07	2.69E-07	2.07E-07
10	6.83E-07	5.70E-07	4.70E-07	3.74E-07	3.23E-07	2.60E-07
15	7.28E-07	6.22E-07	5.26E-07	4.33E-07	3.83E-07	3.21E-07
20	7.60E-07	6.58E-07	5.66E-07	4.74E-07	4.25E-07	3.63E-07
50	8.56E-07	7.66E-07	6.84E-07	5.94E-07	5.46E-07	4.86E-07
100	9.20E-07	8.36E-07	7.58E-07	6.70E-07	6.23E-07	5.65E-07
200	9.70E-07	8.88E-07	8.12E-07	7.25E-07	6.79E-07	6.21E-07
500	9.99E-07	9.18E-07	8.41E-07	7.57E-07	7.10E-07	6.53E-07

Beta

Radius (m)	Height (m) 0.1	0.3	0.6	1	2
0.10	1.27E-05	1.36E-06	1.72E-07	4.70E-08	8.18E-09
0.25	2.84E-05	6.11E-06	9.73E-07	2.84E-07	5.01E-08
0.50	3.56E-05	1.23E-05	3.00E-06	1.03E-06	1.96E-07
1	3.85E-05	1.73E-05	6.73E-06	3.05E-06	6.94E-07
2	3.94E-05	1.99E-05	1.01E-05	5.97E-06	1.93E-06
3	3.95E-05	2.05E-05	1.11E-05	7.20E-06	2.84E-06
4	3.95E-05	2.06E-05	1.15E-05	7.69E-06	3.35E-06
5	3.95E-05	2.07E-05	1.16E-05	7.89E-06	3.62E-06
7	3.95E-05	2.07E-05	1.17E-05	8.01E-06	3.82E-06
10	3.95E-05	2.07E-05	1.17E-05	8.04E-06	3.87E-06
15	3.95E-05	2.07E-05	1.17E-05	8.04E-06	3.88E-06
20	3.95E-05	2.07E-05	1.17E-05	8.04E-06	3.88E-06

Table A1-18. Normalized Doses for Circular Sources with *Mat* = Iron and *t* = 1 year

Gamma

Radius (m)	Height (m)					
	0.1	**0.3**	**0.6**	**1**	**1.37**	**2**
0.10	8.50E-08	1.39E-08	3.48E-09	9.33E-10	4.53E-10	1.75E-10
0.25	2.09E-07	6.54E-08	1.90E-08	6.07E-09	2.95E-09	1.34E-09
0.50	3.09E-07	1.51E-07	5.90E-08	2.12E-08	1.10E-08	4.91E-09
1	4.05E-07	2.53E-07	1.35E-07	6.41E-08	3.68E-08	1.82E-08
2	4.92E-07	3.53E-07	2.32E-07	1.43E-07	9.70E-08	5.65E-08
3	5.41E-07	4.09E-07	2.93E-07	2.00E-07	1.47E-07	9.67E-08
4	5.75E-07	4.49E-07	3.37E-07	2.43E-07	1.88E-07	1.32E-07
5	6.01E-07	4.80E-07	3.69E-07	2.77E-07	2.21E-07	1.61E-07
7	6.41E-07	5.25E-07	4.19E-07	3.28E-07	2.72E-07	2.10E-07
10	6.81E-07	5.73E-07	4.70E-07	3.83E-07	3.27E-07	2.63E-07
15	7.28E-07	6.24E-07	5.28E-07	4.42E-07	3.87E-07	3.24E-07
20	7.59E-07	6.61E-07	5.68E-07	4.84E-07	4.29E-07	3.67E-07
50	8.58E-07	7.71E-07	6.87E-07	6.08E-07	5.55E-07	4.95E-07
100	9.23E-07	8.41E-07	7.63E-07	6.87E-07	6.33E-07	5.75E-07
200	9.74E-07	8.95E-07	8.19E-07	7.43E-07	6.91E-07	6.34E-07
500	1.00E-06	9.25E-07	8.50E-07	7.75E-07	7.22E-07	6.66E-07

Beta

Radius (m)	Height (m)				
	0.1	**0.3**	**0.6**	**1**	**2**
0.10	1.23E-05	1.33E-06	1.77E-07	4.71E-08	1.07E-08
0.25	2.82E-05	6.02E-06	9.96E-07	3.07E-07	6.67E-08
0.50	3.63E-05	1.25E-05	3.14E-06	1.14E-06	2.58E-07
1	4.01E-05	1.85E-05	7.48E-06	3.51E-06	9.28E-07
2	4.15E-05	2.22E-05	1.21E-05	7.46E-06	2.71E-06
3	4.17E-05	2.31E-05	1.37E-05	9.40E-06	4.20E-06
4	4.17E-05	2.34E-05	1.43E-05	1.03E-05	5.15E-06
5	4.17E-05	2.35E-05	1.46E-05	1.07E-05	5.67E-06
7	4.17E-05	2.35E-05	1.47E-05	1.09E-05	6.11E-06
10	4.17E-05	2.35E-05	1.47E-05	1.10E-05	6.23E-06
15	4.17E-05	2.35E-05	1.47E-05	1.10E-05	6.24E-06
20	4.17E-05	2.35E-05	1.47E-05	1.10E-05	6.24E-06

Attachment 2.

Small Boat Information

The following insert containing information on the types of small boats used during Pacific testing operations is a reproduction of page 695 in *Jane's Fighting Ships 1983-1984*, John Moore, editor, Jane's Publishing Company, LTD. London, England, 1983 (ISBN 07106-0774-1).

51 "LCU 1610" CLASS: UTILITY LANDING CRAFT (LCU)

LCU 1616	LCU 1630	LCU 1646	LCU 1656	LCU 1665	LCU 1674
LCU 1617	LCU 1631	LCU 1648	LCU 1657	LCU 1666	LCU 1675
LCU 1619	LCU 1632	LCU 1649	LCU 1658	LCU 1667	LCU 1676
LCU 1621	LCU 1633	LCU 1650	LCU 1659	LCU 1668	LCU 1677
LCU 1623	LCU 1634	LCU 1651	LCU 1660	LCU 1669	LCU 1678
LCU 1624	LCU 1635	LCU 1652	LCU 1661	LCU 1670	LCU 1679
LCU 1627	LCU 1643	LCU 1653	LCU 1662	LCU 1671	
LCU 1628	LCU 1644	LCU 1654	LCU 1663	LCU 1672	
LCU 1629	LCU 1645	LCU 1655	LCU 1664	LCU 1673	

Displacement, tons: 200 light; 375 full load
Dimensions, feet (metres): 134·9 × 29 × 6·1 *(41·1 × 8·8 × 1·9)*
Guns: 2—50 MGs
Main engines: 4 diesels (Detroit); 1 000 bhp; 2 shafts (Kort nozzles) = 11 knots
Range, miles: 1 200 at 8 knots
Complement: 12 to 14 (enlisted men)

Improved landing craft, larger than previous series; can carry three M-103 or M-48 tanks (approx 64 tons and 48 tons respectively). Cargo capacity 170 tons.
LCU 1616-1619, 1623, 1624 built by Gunderson Bros Engineering Corp, Portland, Oregon; LCU 1621, 1626, 1629, 1630 built by Southern Shipbuilding Corp, Slidell, Louisiana; LCU 1627, 1628, 1631-1635 built by General Ship and Engine Works (last five units completed in 1968); LCU 1643-1645 built by Marinette Marine Corp, Marinette, Wisconsin (completed 1969-70); LCU 1646-1666 built by Defoe Shipbuilding Co, Bay City, Michigan (completed 1970-71). The one-of-a-kind aluminium hull, 133·8 ft LCU 1637 built by Pacific Coast Engineering Co, Alameda, California. She was later converted to an "at sea" simulator in 1979 and is stationed at Roosevelt Roads Naval Base. Rated as "floating equipment". LCU 1667-1670 built by General Ship & Engine Works, East Boston, in 1973-74; LCU 1671-1679 built by Marinette Marine Corp, 1974-76.
LCU 1636, 1638, 1639, 1640 reclassified as YFB 88-91 in October 1969 LCU 1620 and 1625 to YFU 92 and 93 respectively, in April 1971; LCU 1611, 1615, 1622 to YFU 97-99 in February 1972; LCU 1610, 1612 to YFU 100 and 101 respectively, in August 1972; LCU 1618 to IX 508 on 1 December 1979. LCU 1667-1679 under operational control of the Army.

Engineering: Only two diesels fitted with vertical cycloidal propellers shipped in LCU 1621.

LCU 1660 — *5/1982, G. Gyssels*

4 "LCU 1466" CLASS: UTILITY LANDING CRAFT (LCU)

LCU 1473 **LCU 1544** **LCU 1564** **LCU 1578**

Displacement, tons: 180 light; 360 full load
Dimensions, feet (metres): 119 × 34 × 6 *(36·3 × 10·4 × 1·8)*
Guns: 2—20 mm
Main engines: 3 diesels (Gray Marine); 675 bhp; 3 shafts = 10 knots
Complement: 14

These are enlarged versions of the Second World War-built LCTs; constructed during the early 1950s. LCU 1496 reclassified as YFU 70 on 1 March 1966; LCU 1471 to YFU 88 in May 1968; LCU 1576, 1582 and 1608 to YFU 89-91, respectively, in June 1970; LCU 1488, 1491, and 1609 to YFU 94-96 on 1 June 1971; YFU 94 reverted to LCU 1488 on 1 February 1972 (since deleted).
LCUs 1473, 1564 and 1578 acquired from the US Army in September 1978. All of this class are classified as LCUs and rated as "floating equipment", although not all are actually employed as such.
LCU 1473 is attached to the NRF at Buffalo, New York State. The remaining three were reclassified as utility boats in 1982.

"LCU 1466" Class — *1965, USN*

MECHANISED LANDING CRAFT: LCM 8 TYPE

Displacement, tons: 115 full load (steel) or 105 full load (aluminium)
Dimensions, feet (metres): 73·7 × 21 × 5·2 *(22·5 × 6·4 × 1·6)*
Main engines: 2 diesels (Detroit or General Motors); 650 bhp; 2 shafts = 9 knots
Complement: 5 (enlisted men)

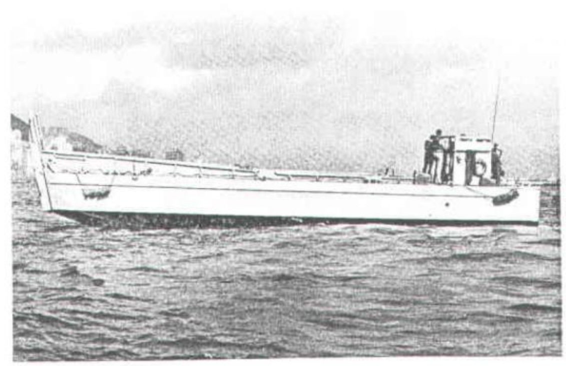
Constructed of welded-steel or (later units) aluminium. Can carry one M-48 or M-60 tank (both approx 48 tons) or 60 tons cargo; range is 150 nautical miles at full load. Also operated in large numbers by the US Army.

LCM 8 — *5/1982, G. Gyssels*

MECHANISED LANDING CRAFT: LCM 6 TYPE

Displacement, tons: 60 to 62 full load
Dimensions, feet (metres): 56·2 × 14 × 3·9 *(17·1 × 4·3 × 1·2)*
Main engines: Diesels; 2 shafts; 450 bhp = 9 knots

Welded-steel construction. Cargo capacity is 34 tons or 80 troops.



LCM 6 — *7/1979, Dr. Giorgio Arra*

LANDING CRAFT VEHICLE AND PERSONNEL (LCVP)

Displacement, tons: 13·5 full load
Dimensions, feet (metres): 35·8 × 10·5 × 3·5 *(10·9 × 3·2 × 1·1)*
Main engine: Diesel; 325 bhp; 1 shaft = 9 knots

Constructed of wood or GRP. Fitted with 30-calibre machine guns when in combat areas. Cargo capacity, 8 000 lb; range, 110 n. miles at full load.

LCVP — *9/1978, Gerhard Koop*