To the Graduate Council:

I am submitting herewith a thesis written by William Littell Maxson II entitled "Equivalent Sphere Approximations for Skin, Eye, and Blood Forming Organ Dose Estimation in Space Radiation Protection Studies." I have examined the final copy of this thesis for form and content and I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

L.W. Townsend, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and
Dean of the Graduate School

EQUIVALENT SPHERE APPROXIMATIONS FOR SKIN, EYE, AND BLOOD FORMING ORGAN DOSE ESTIMATION IN SPACE RADIATION PROTECTION STUDIES

A Thesis

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ABSTRACT

Throughout the manned space flight program, protecting astronauts from space radiation has been the subject of continuous and intense study. For interplanetary crews, the two main sources of radiation hazards are solar particle events (SPEs) and galactic cosmic rays (GCR). Solar particle events are composed mainly of high fluxes of protons, neutrons, deuterons, tritons, He-3, and alpha particles which can provide an acute exposure of 200 to 300 cSv from a single event. The galactic cosmic rays are composed of much lower fluxes of high-energy, high-LET, heavy ions which provide stochastic exposures of 12 - 15 cGy/yr or 40 - 50 cSv/yr and can total approximately one Sievert for an extended interplanetary mission. For nearly three decades, assessments of crew doses and related shielding requirements have been made using the assumption that body organ exposures are well approximated by exposures at the center of tissue-equivalent spheres. For the skin and blood forming organs (BFO) these spheres have radii of 0 cm and 5 cm respectively. Recent studies indicate that significant overestimation of organ doses occurs if these models are used instead of realistic human geometry models. The use of the latter, however, requires much longer computational times. In this work, we propose preliminary revisions to these equivalent sphere approximations that yield more realistic dose estimates.

Calculated doses and dose equivalents for the measured spectra from the February 1956, November 1960, August 1972 and August, September, and October 1989 SPEs along with the GCR solar minimum spectra of 1977 and 1986 and solar maximum spectra of 1970-1971 and 1989 are presented. From these calculated doses and dose equivalents,

we recommend a revised equivalent sphere approximation of 9 cm water radius for BFO and 1 cm water radius for skin and ocular lens for SPE. For GCR we recommend a 11 cm radius approximation for BFO and a 3 cm radius approximation for skin and ocular lens.

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NOMENCLATURE

A	Atomic Mass
C	Velocity Dependent Shell Correction Term
D	Absorbed Energy per Unit Mass (Dose)
E	Energy
f	Differential Cross Section for Elastic/Inelastic Collisions
H	Dose Equivalent
h	Step Size
I_t	Mean Excitation Energy
m_{jk}	Multiplicity of Ion j Produced by Ion k in a Collision
N	Number of Target Molecules per Unit Volume
Q_F	Quality Factor
R	Range of the Ion
S(E)	Stopping Power
v	Projectile Velocity
x	Distance
Z	Atomic Number
Z_t	Number of Electrons per Target
β	Ratio of Particle Velocity to Light Speed
ϕ	Flux (Fluence)
η	Coordinate Component
ν	Range Scaling Parameter
π	Pi = 3.14159...
σ	Atomic Cross Section
ζ	Coordinate Component
Ψ	Wave Function
∂	Partial Derivative
Σ	Summation
$\int$	Integral
1-D / 3-D	One Dimensional / Three Dimensional

ABBREVIATIONS

c	10^{-2}
G	10^{9}
M	10^{6}
eV	Electron Volt
g	Gram
Gy	Gray
m	Meter
s	Second
sr	Solar Radius
Sv	Sievert

yr	Year
BFO	Blood Forming Organs
BRYNTRN	Baryon Transport
CAM	Computerized Anatomical Man
CME	Coronal Mass Ejections
GCR	Galactic Cosmic Ray
GCRTRN	Galactic Cosmic Ray Transport
He	Helium
HZE	High Charge and Energy
HZETRN	High Charge and Energy Transport
ICRP	International Commission on Radiation Protection
LET	Linear Energy Transfer
NASA	National Aeronautic and Space Administration
RBE	Relative Biological Effectiveness
SPE	Solar Particle Event

I. Introduction

Background

The first NASA space missions were simple, unmanned satellites designed to travel into space, take pictures, record measurements, and return the data to Earth via radio transmissions or by parachute drops. Early challenges included putting man into space to perform hands-on research. These attempts were driven by the Cold War and the space race with the Soviet Union. Initially, small mammals were put into orbit and returned in an attempt to discover the effects of the space environment on living tissue. From studying the effects of the space environment on these animals, the methods and technology required to ensure safe travel for a human crew began to be understood. In particular, penetrating space radiation with both high linear energy transfer (LET) and high relative biological effectiveness (RBE) are a major source of concern for both spacecraft designers and mission planners. As mission planners begin to look into extended missions which will take place beyond the Earth's magnetosphere, e.g. trips to other planets or Moon colonization, they realize how little is understood about space radiation protection. Recently, much attention has been paid to studies of spacecraft design to meet the shielding requirements[1] which will protect astronauts from potentially lethal or mission-threatening space radiation.

Energetic space radiation originates from a variety of sources including the Sun and other stars. Three portions of the space radiation spectrum are important due to their significance as biological hazards. They are galactic cosmic rays (GCR) originating outside the Solar System, solar particles emitted during large solar events, and trapped particles in the Van Allen belts (See Figure 1). Each of these radiations range widely in energy and intensity as shown in Figure 2. The radiation environment which occurs inside the spacecraft depends on factors such as location, time spent in the Earth's magnetic field, mission trajectory and duration, solar activity levels, and the interdependence of solar activity and galactic cosmic radiation flux levels.

Once a spacecraft leaves the Earth's magnetosphere, trapped particles in the Van Allen belts are no longer of concern. However, the magnetosphere deflects many harmful ions away from the earth, so that the effects of GCR and SPE particles become more pronounced as one travels beyond the magnetosphere. The high-energy, heavy ion component (HZE component) of the GCR spectrum contributes most of the total dose equivalent from GCR exposures. The damage caused by this high LET radiation in biological tissue is thought to be more severe than that caused by high-energy electrons or protons. Hence, chronic exposure to the GCR spectrum alone can provide career-limiting exposures to crews on long, exomagnetosphere missions. Extremely large SPEs are rare events, but contain large fluxes/fluences of energetic protons and alphas which can be mission-threatening and even life-threatening if necessary precautions are not taken[2]. This study will focus on GCR and SPE because these two types of events provide the most risk of whole body external dose from interplanetary space radiation. Radiation from all sources including the Van Allen belts and spacecraft internal sources, however, must be considered and integrated together for estimates of actual mission shielding requirements and exposure levels.

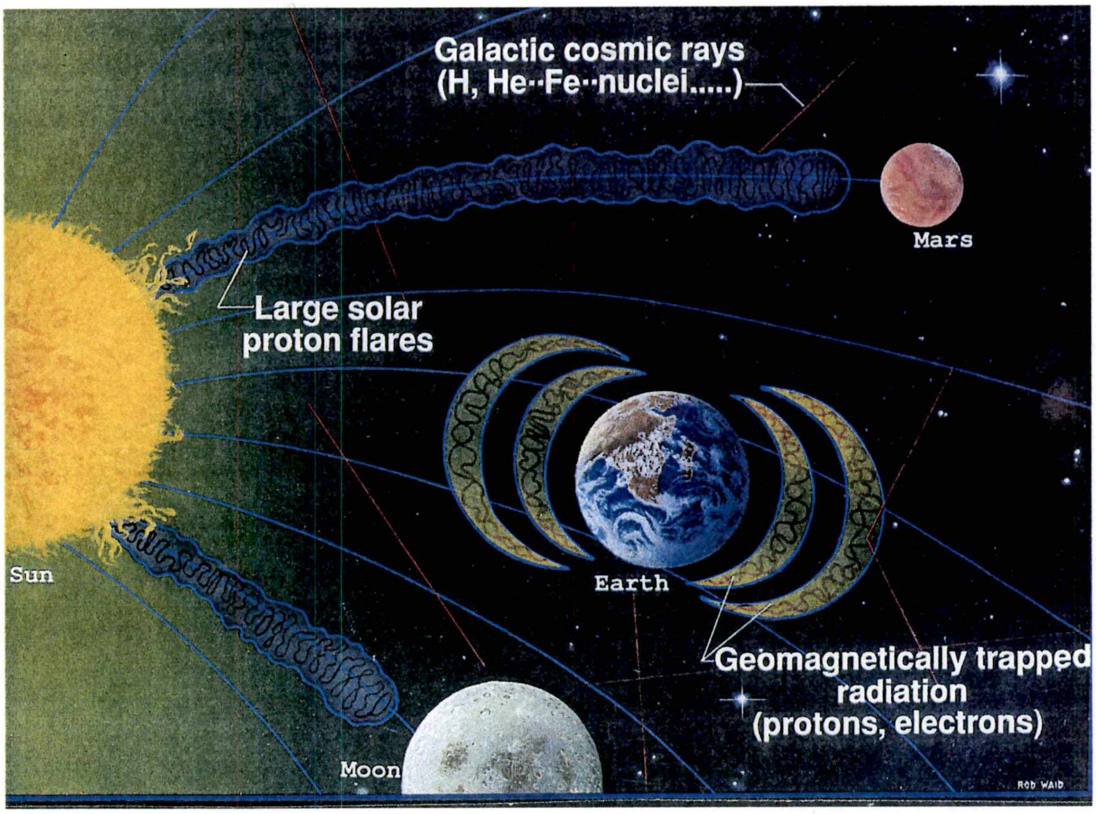

Figure 1. The Space Radiation Environment

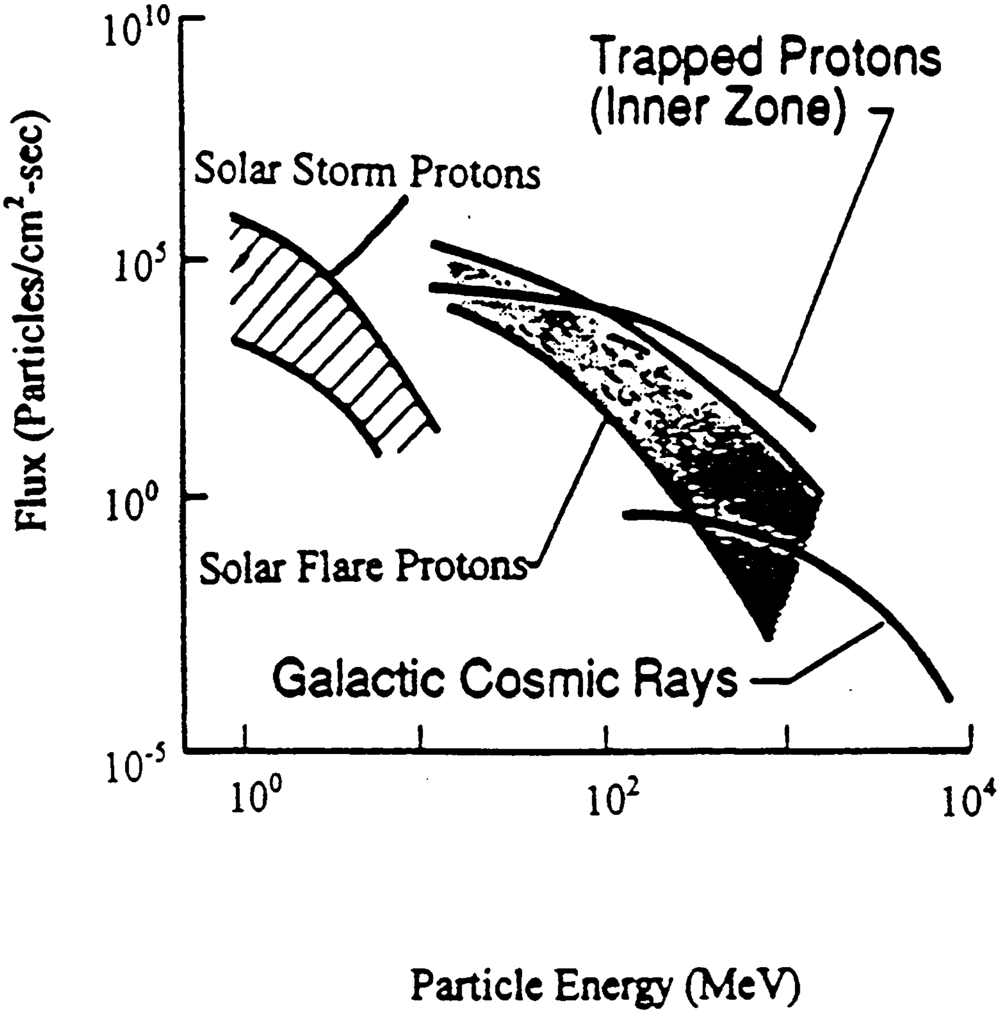

Figure 2. Flux Verses Energy for Space Radiation

Statement of the Problem

Because of the robustness of the space radiation environment and the complexity of spacecraft and human body geometry, many hours of computational time are required to perform a full dose assessment for actual, critical body organs for a particular mission. Due to the limited computational capabilities of the 1950's and 1960's, this part of the spacecraft design process often could take months or years to complete. In 1971, Langley and Billings showed that one could replace the complex human body geometry with simple equivalent sphere approximations and still retain sufficient accuracy for preliminary design studies[3]. Even with today's high-speed computers, using a tissue equivalent sphere instead of detailed body geometry models saves a significant amount of computational time when incorporated into mission planning and spacecraft design studies..

The space radiation transport codes, BRYNTRN and HZETRN, developed at the NASA Langley Research Center, are often used to investigate spacecraft shielding strategies. For the portion of this study focusing on SPEs, the BRYNTRN (short for baryon transport) code was used[4], while the HZETRN (high-charge(z)-and-energy transport) code was used for the GCR data. These codes respectively propagate input SPE proton or GCR proton and heavy ion spectra through a thickness of spherical aluminum spacecraft shielding and then into a sphere of water which simulates human soft tissue. Because space radiation is an isotropic source, we can solve this three dimensional problem with a one dimensional tissue equivalent slab (see figure 3). The code then calculates dose and dose equivalent values at different depths of water. A more complete description of the transport code is contained in section IV.

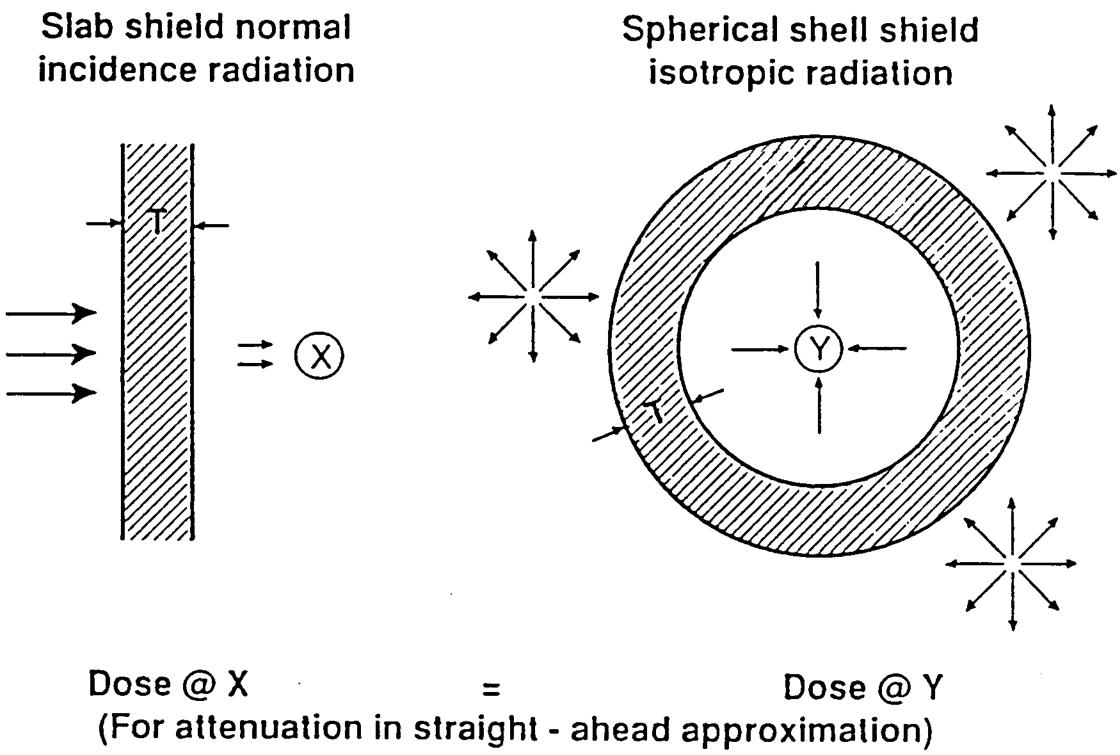

Figure 3. Illustration of Three Dimensional Sphere and One Dimensional Slab Equivalence

For the purpose of estimating bone marrow or blood forming organ (BFO) doses, Langley and Billings recommended a 5 g/cm^2 areal density-radius tissue equivalent sphere model[3]. (Through out this work, we will refer to this areal density in g/cm^2 simply as distance in cm since we are using water (ρ = 1 g/cm^3) as a soft tissue surrogate.) More recent studies[5] have shown that the BFO doses approximated by the 5 cm radius model are as much as 41 percent larger than the doses obtained using newer, more detailed body geometry models, with similar discrepancies expected for skin and eye dose. Errors of this magnitude can result in severe shield weight penalties in the design of interplanetary spacecraft, and the advantage of the equivalent sphere model is lost if the results of the model have to be modified before they can be considered accurate enough to be used in design studies. In this study, we compare doses to tissue equivalent spheres obtained using the BRYNTRN and HZETRN codes to values obtained from these same codes and a Computerized Anatomical Man (CAM) model to obtain a more realistic, yet still conservative, tissue equivalent sphere approximation.

II. Space Radiation Environment

Introduction

One of the many hazards of space travel, particularly outside the Earth's magnetosphere, is high-energy radiation. This radiation is split into many categories, but the two most significant for the purposes of radiation protection during interplanetary missions are galactic cosmic rays (GCR) originating beyond our galaxy and high-energy charged particles from the sun. The energy spectra of these radiations range from tens of MeV to thousands of GeV, far stronger than any spectra naturally produced on Earth. The proton energy distribution peaks at 0.3 GeV, a velocity corresponding to two thirds light speed, although particles up to 10^{11} GeV have been detected[6]. As a result, the interactions of these radiations with matter are extremely violent. Instead of these high energy, charged particles being easily shielded, as is the case on Earth with low energy alpha particles, these space radiations have energies high enough to penetrate very thick shields and cause fragmentation both in the shield material and of the incident particle. These fragmentation reactions themselves serve as additional sources of high energy radiation. It is these charged particles and their fragments that pose significant risk to crews in interplanetary spacecraft.

Solar Particle Radiation During Periods of Maximum Activity

Particle emissions from the sun during periods of maximum sunspot activity include increased plasma emission and occasional large fluxes of energetic ions. Satellites, navigation and communications are affected when solar plasma interacts with the Earth's magnetosphere and upper atmosphere. Human activities in space may be limited during emissions of large numbers of energetic ions because of the increased hazards to biological tissue[7].

Coronal Mass Ejections

Due to changes in the sun's magnetic field, different amounts of solar mass may be ejected into space. Some smaller mass ejections contribute to coronal heating and additional mass in the solar wind. Some large scale mass ejections can contain up to approximately 10^{16} grams of material[7]. These large scale events, commonly called "magnetic clouds," can result in significant restructuring of the interplanetary magnetic field. Most of these ejections have speeds similar to the solar wind. About one third are fast enough to drive interplanetary shocks, a shock wave which lends energy to the interplanetary medium, accelerating electrons and ions to higher energy states[7]. CMEs may also be a significant source of SPE protons.

Most coronal mass ejections (CME) are a result of activity on the surface of the sun. However, about one third cannot be attributed to surface phenomena. These CME can be used as a measure of solar activity since they are known to follow the solar cycle in frequency, phase, and amplitude. During solar minimum periods, the average CME frequency is about 0.25/day, during solar maximum it can be 2.5/day[7].

Solar Energetic Particle Events

Up through the 1980's much of the literature written on the subject of solar energetic particle events assumed that solar flares were the source of these particles. A new, alternative idea suggests that the source of these energetic ions is the result of acceleration of particles in the interplanetary medium from large coronal mass ejections

(CME). A shock wave accelerates these particles and they stream away from the shock along interplanetary magnetic field lines. Both of these theories on the origin of solar energetic particles have observational support. Many of the large solar particle events are associated with large solar flares. But only about half of the total solar particle events observed on earth can be associated with solar flares. The intensity-time profiles of solar energetic particles leave no doubt that some acceleration due to shock waves also occurs[7].

Solar particle events are most often described in terms of flux, fluence, and spectral hardness. Flux can either be integral, containing the number of particles/cm^2/s/sr above a certain energy, or differential, containing the number of particles/cm^2/sr/MeV at a specific energy. Fluxes are given in units of particles/cm^2/s when originating from an isotropic source. Particle fluence is the total number of particles observed through the course of a given event. Units for particle fluence are usually particles/cm^2/sr or particles/cm^2. Spectral hardness is a relationship between Fluence and Energy which provides information about the radiation effect in living tissue. For the purposes of determining dose, the particle fluence is used since it is representative of the total energy absorbed from the event. Solar energetic particle events are loosely separated into solar electron events and solar proton events. This study focuses on the solar proton events because the dose from solar electron events is relatively insignificant.

Solar Electron Events

Solar electron events are often used to measure solar activity since their motion is confined to interplanetary magnetic field lines. Distortion in the field lines is representative of high solar activity. Events of this type were not discovered until the beginning of the space era (late 1950's) when instrumentation was developed specifically for their observation. The fluxes of electrons resulting from these events do not account for significant radiation dose when compared to other types of energetic ion events. A description of the mechanism of these events can be found in Reference 7 but is not important to this study.

Solar Proton Events

Solar proton events are classified by the observed proton flux and fluence at a specified energy. There is some correlation of proton event frequencies observed near Earth and the solar activity, but there is no distinct pattern in proton event occurrence[7]. The expected flux/fluence and energy of an event are important for planning space missions because it has been shown that when "anomalously large" events occur, they are the largest dose contributors[2]. Some statistical analyses have been performed by Smart and Shea[7] on the last 3 solar cycles (19, 20, 21) in attempt to determine the relative frequency of large events. They found that proton event fluence distribution during periods of maximum solar activity could be approximated by a log-normal distribution. This data could be used to determine probable exposure from solar protons during missions outside the Earth's magnetosphere. The occurrence of very large events, those with at least 10^{10} particles/cm^2 seem to be less frequent than expected using a log-normal distribution. This finding suggests that there may be limits on the acceleration processes[7].

Solar Particle Event Composition

The composition of "small" solar particle events is variable and has been separated into the categories of ^{3}He rich and iron rich. At first, these small events were considered to be anomalies because their composition was different than expected. The fluxes of these events were small and were assumed to have composition similar to large events. More recently, classification has been associated with the origin of the particles, either "impulsive-flare" events or "gradual" events[7].

Large solar particle event composition is consistent with an ion selection process based on the first ionization potential of the elements in the corona or solar wind. Since hydrogen and helium have the lowest first ionization potential, they are the most abundant elements in large solar particle events. The major types of particles are protons, deuterons, tritons, helions, and alphas.

The Galactic Cosmic Ray Spectrum

The GCR spectrum is an isotropic source consisting of approximately 98% protons and heavy ions and 2% electrons and positrons. The spectrum is isotropic because the charged particles are easily deflected by magnetic fields from straight line paths to gyrations with very large radii. The electron and positron portions of the spectrum are unimportant in human exposure studies because their energies are low enough that they are readily shielded by the structure of the spacecraft. The remaining spectra can be broken down as follows: 88% protons, 10% helium ions and 1-2% heavier ions. Although the GCR spectrum contains all elements, ions heavier than iron are neglected for these exposure studies because their fluxes are too low to be of significant biological consequence[2].

Most of these radiations are deflected by the Earth's magnetosphere. Some of the very high energy particles propagate through the magnetosphere and are a source of background radiation on the Earth's surface. Outside the Earth's magnetosphere, there are other forces that can influence the GCR spectrum. Activity of the Sun is one example. The Sun has an approximate 11 year cycle containing periods of maximum and minimum sunspot activity. During periods of maximum activity, the increased solar wind shifts the interplanetary magnetic fields carried by the plasma further away from the sun. The GCR spectrum contains mainly charged particles which are deflected by these changing magnetic fields. Hence, the GCR intensity is anticorrelated with solar activity. Unless a large solar particle event occurs, it is the GCR spectrum that will be the largest total dose equivalent contributor during manned interplanetary missions[3]. It is important to note, however, that the low dose rates from GCR particles do not pose acute health hazards. The danger they pose is from increased lifetime risk of carcinogenesis and possible damage to nonregenative tissue[8].

Space Radiation and Interplanetary Mission Planning

The previous paragraphs outlined the two main contributors to radiation dose during interplanetary travel. For the purposes of mission planning, all sources of potential hazard to the crew must be evaluated to determine that the benefit gained from the mission outweighs the risk to the crew. According to the information on GCR radiation, the dose and dose equivalent contributions from it are lowest during periods of maximum solar activity. Also, the GCR dose contribution will be most significant for long missions[3]. So it would appear that solar maximum would be the best time to begin such a mission. However, Smart and Shea[7] showed that the probability for a large solar particle event is highest just before or just past the maximum of the solar cycle, though one could occur at any point during the cycle. The acute effects from such an event could also be mission-threatening or even life-threatening because of the high dose rate associated with the SPE. This information points towards a mission during solar minimum, but once again, chronic exposure rates from GCR are a threat to future personnel health. This issue of when to carry out these missions is still unresolved.

At present, there is no reliable way to predict a solar particle event[7]. The size of the event is usually not known until the event is over. Therefore, until methods of detection/prediction of these events are more reliable, planning must be for the worst case scenario. Some sort of radiation shelter must be provided for the crew to protect them from a solar particle event. Also, the overall spacecraft must be able to shield from the harmful GCR radiation. For a trip to Mars, the detection equipment available in near Earth orbit could be used to alert the crew of the onset of a solar particle event because the speed of propagation of the particles is less than that of radio signals, which propagate at the speed of light[7].

In this study, the solar particle events of February 1956, November 1960, August 1972 and August, September and October 1989 are used for dose construction and analysis. For galactic cosmic ray data, the solar minimum spectra of 1977 and 1986 were contrasted to the solar maximum spectra of 1970-1971 and 1989. The August 1972 SPE contained the most limiting spectrum, and the October 1989 SPE contained the highest particle fluences of all events on record but was less energetic than 1972. Researchers generally agree that the February 1956 SPE had the most energetic particles of any event on record but with lower intensity than many other events (data obtained from National

Oceanic and Atmospheric Administration). It is important to note that spectra that were not directly measured from earth orbit (i.e. November 1956) were reconstructed from comparison of data measured on the ground to well known ground and orbital data such as the October 1989 event. These events provide a representative range for the two portions of the space radiation spectrum which would provide the most dose to astronauts in deep space.

III. Radiation Interaction in Space

Background

When radiation fields traverse bulk matter, physical characteristics of the propagating radiations are changed through nuclear and electromagnetic interactions with the shield material. Thus the radiation environment inside a shielded spacecraft will contain particles of the external fields and fragments produced by their nuclear interactions with the shield material. In order to properly assess the risk to crew members as a result of a solar particle event, an understanding of the transport and interactions of these radiations through matter is required.

Because of the effects of interplanetary magnetic fields, solar particles will spiral as they move away from the sun, their path resembling a braided rope[7]. The spread of these particles is so large that they appear as an isotropic source incident on the spacecraft outside the earth's magnetosphere. The velocities of these particles are high enough that they continue in straight line paths, even after interaction. Because of this, the much simpler 1-D Boltzmann equation can be effectively used for nucleon transport. This is illustrated in Figure 3, the isotropic source outside a spherical shell is approximated by a unidirectional source incident on a slab of similar thickness T. The dose at Y, the center of the sphere, is highest because particles that reach the center have traversed the shortest shield thickness to get there. Similarly, the dose at X is the point where source particles have traversed the shortest shield thickness. The dose at a depth X in a slab from a normally incident particle beam correlates with a one-to-one ratio into the dose at the center of the sphere Y from isotropic radiations incident on its surface.

Theory of Space Radiation Interaction

To characterize the primary and secondary interactions of solar particles and galactic cosmic rays, a deterministic coupled neutron-proton transport computer program BRYNTRN and a free space ion and nucleon transport and shielding computer program HZETRN have been developed at the NASA Langley Research Center[4]. BRYNTRN propagates neutrons, protons, deuterons, tritons, He-3, and alphas through any shield material. It also accounts for fragments produced by interactions within the shield material. It then propagates the remaining spectra and fragments into a slab of water to simulate soft body tissue. Because of the high energies involved, a straight-ahead approximation is introduced into the 1-D Boltzmann transport equation to yield

$$\left[\frac{\partial}{\partial x} - \frac{\partial}{\partial E} S(E) + \sigma_p(E)\right]\phi_p(x,E) = \sum_j \int_E^{\infty} f_{pj}(E,E')\phi_j(x,E')dE' \qquad (1)$$

for protons and heavier ions. Note that for neutrons, there is no stopping power contribution *S*(*E*), because they carry no charge. The equation for neutrons thus becomes

$$\left[\frac{\partial}{\partial x} + \sigma_n(E)\right]\phi_n(x,E) = \sum_j \int_E^{\infty} f_{nj}(E,E')\phi_j(x,E')dE' \qquad (2)$$

where the f_{ij} (E,E') are the differential cross sections for elastic and inelastic collision processes, $\phi_i(x,E)$ are the flux of i type ions at position x, moving in the x direction with energy E in MeV. $\sigma_i(E)$ are the macroscopic nuclear absorption cross sections in cm^{-1}.

The $\frac{\partial \phi}{\partial x}$ term represents net convective transfer of particles into or out of the material.

The $\frac{\partial S(E)\phi_p}{\partial E}$ term represents energy losses due to coulombic interactions. The

$\sigma(E)\phi(x,E)$ term represents nuclear attenuation. The terms on the right hand sides of these equation represent the production of protons or neutrons from the interactions in the target molecules. Equation (1) is solved to produce

$$\Psi_p(x+h,r_p) = \exp(-\sigma_p h)\Psi_p(x,r_p+h)$$
$$+\sum_k m_{pk}\sigma_k \frac{v_p}{v_k}\left[\frac{\exp(-\sigma_p h)-\exp(-\sigma_k h)}{\sigma_k - \sigma_p}\right]\Psi_k\left(x,r_k+\frac{v_p}{v_k}h\right) \quad (3)$$

which is the basis of the BRYNTRN computer transport code where

$$\Psi_p(x,r_p) = S_p(E)\phi_p(x,E) \equiv \chi_p(\eta_p,\xi_p)\,, \quad (4)$$

$\eta_p \equiv x - R_p(E)$, $\xi_p \equiv x + R_p(E)$,and $r_p = R_p(E)$ where η_p varies along the particle path and ξ_p is constant along the particle trajectory. A similar solution exists for neutrons, but, again the stopping power is neglected. The BRYNTRN algorithms have been verified to within 1-percent accuracy by direct comparison to an exact analytical benchmark solution for a continuous space proton input spectrum[4].

HZETRN, on the other hand, includes a GCR heavy ion transport equation, GCRTRN, along with BRYNTRN to provide a solution to the GCR transport problem. GCRTRN propagates all ions up to Fe along with all possible projectile and target fragments formed through interactions with the shield material. Iron (Z=26) is used as a cutoff for the atomic spectra because the elemental abundance for cosmic ray species heavier than iron is typically two to four orders of magnitude smaller and therefore of negligible importance[9]. Once again the straight ahead approximation is used and the target secondary fragments are neglected. This yields[9]

$$\left[\frac{\partial}{\partial x}-\frac{\partial}{\partial E}\tilde{S}(E)+\sigma_j\right]\phi_j(x,E)=\sum_{k>j} m_{jk}\sigma_j\phi_k(x,E) \tag{5}$$

for multiple charged ions, where $\phi_j(x,E)$ is the flux of ions of type j with atomic mass A_j at x moving along the x-axis at energy E (MeV), σ_j is the corresponding macroscopic nuclear absorption cross section, $\tilde{S}_j(E)$ is the change in E per unit distance (stopping power), and m_{jk} is the multiplicity of ion j produced by ion k in a collision.

This equation is solved to produce

$$\Psi_j(x+h,r_j)=\exp(-\sigma_j h)\Psi_j(x,r_j+h)$$

$$+\sum_k m_{jk}\sigma_k\frac{\nu_j}{\nu_k}\left[\frac{\exp(-\sigma_j h)-\exp(-\sigma_k h)}{\sigma_k-\sigma_j}\right]\Psi_k\left(x,r_k+\frac{\nu_j}{\nu_k}h\right) \tag{6}$$

which is the basis of the GCR computer transport code where

$$\Psi_j(x,r_j)=S_j(E)\phi_j\left(x,\tilde{E}\right)\equiv\chi_j(\eta_j,\xi_j)\ , \tag{7}$$

$\eta_j\equiv x-R_j(E)$, $\xi_j\equiv x+R_j(E)$, and $r_p=R_p(E)$ where η_j varies along the particle path and ξ_j is constant along the particle trajectory.

The integral fluence is $\phi_j(x,>E)=\int_{R_j(E)}^{\infty}\Psi_j(x,r)dr$. (8)

The absorbed energy per gram is $D_j(x,>E)=\int_E^{\infty}A_j\Psi_j\left[x,R_j(E)\right]dE$. (9)

The dose equivalent is $H_j(x,>E) = A_j \int_E^{\infty} Q_F \Psi_j[x, R_j(E)] dE$ (10)

where Q_F is the quality factor based on ICRP 60 (Figure 4).

Radiation Interaction and Dose/Dose Equivalent Calculations

Once the particle fluxes for each species have been determined, the dose in cGy is computed using the following equation.

$$D_i(x,>E) = A_i \int_E^{\infty} S_i(E')\phi_i(x,E')dE' \quad (11)$$

This equation describes the dose at a point x from particles with energy greater than E. The atomic mass numbers of the colliding nuclei are given by A_i, and $S(E)$ is the stopping power described by the equation:

$$S(E) = \frac{4\pi N Z_p^2 Z_t e^4}{mv^2}\left\{\ln\left[\frac{2mv^2}{(1-\beta^2)I_t}\right] - \beta^2 - \frac{C}{Z_t}\right\} \quad (12)$$

where Z_p is the charge of the projectile, N is the number of target molecules per unit volume, Z_t is the number of electrons per target molecule, m is electron mass, v is projectile velocity, β is the ratio of the velocity to the speed of light, I_t is the mean excitation energy, and C is a velocity-dependent shell correction term[4]. For the purposes of risk assessment, the dose equivalent is obtained from

$$H_i(x,>E) = A_i \int_E^{\infty} Q_F(E')S_i(E')\phi_i(x,E')dE' \quad (13)$$

where Q_F is the quality factor that relates absorbed dose to risk. Quality factor is dependent on the LET and is obtained from ICRP-60 (See Figure 4). For target

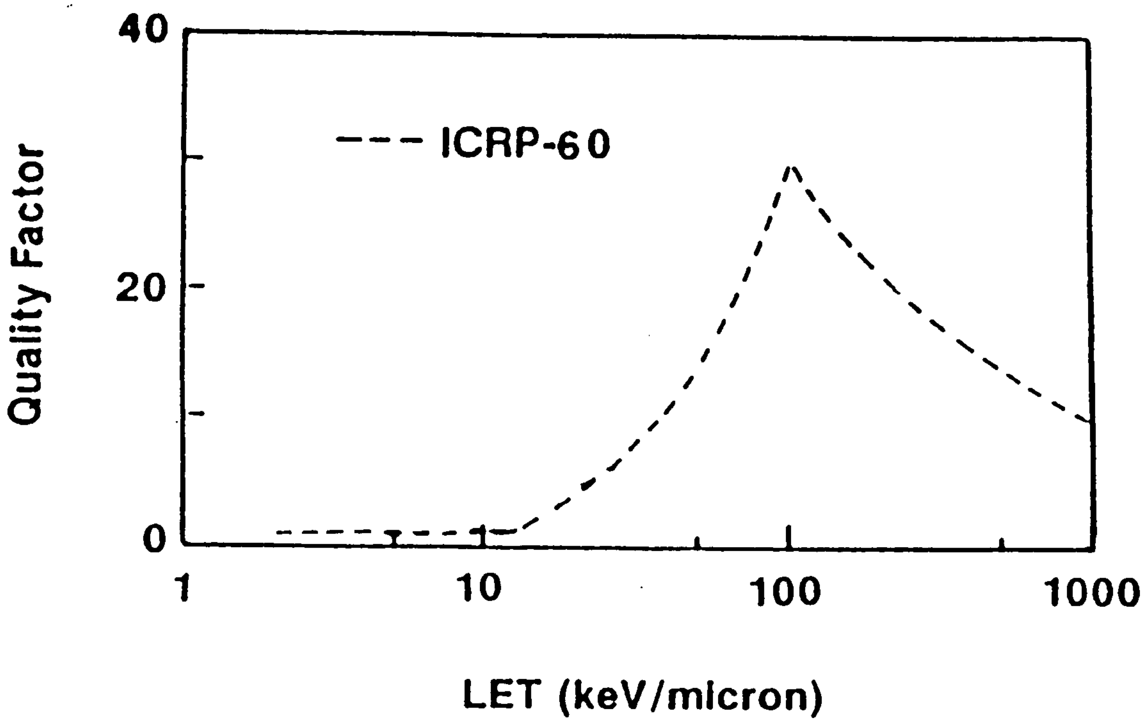

Figure 4. Quality Factor Versus Linear Energy Transfer from ICRP 60

fragments and nuclear recoils produced by the incident protons, the dose and dose equivalent are given by.

$$D_p^*(x, > E) = \sum_j \int_E^\infty \overline{E}_j' \sigma_{jp}(E') \phi_p(x, E') dE' \tag{14}$$

and

$$H_p^*(x, > E) = \sum_j \int_E^\infty \overline{E}_j' Q_{F_j}(E') \sigma_{jp}(E') \phi_p(x, E') dE' \tag{15}$$

where $\overline{E}_j'$ is the average recoil energy of the jth fragment. For propagating neutrons, all dose and dose equivalent contributions result from target nuclei recoils or fragments and are computed using identical equations[4]. Note that any variable or symbol not explicitly defined in this section can be located in the Nomenclature section.

IV. Radiation Transport Computer Codes

Background

BRYNTRN is a code developed at the NASA Langley Research Center for the purpose of estimating crew doses/dose equivalents from exposure to the space radiation proton and light ion environment. It calculates these values using a converging, marching algorithm representing solutions to the 1-D Boltzmann transport equation (1). Since this algorithm is rapidly convergent, large steps of 1 g/cm^2 can be taken for each iteration without loss of accuracy. The space radiation environment is known to contain a continuous energy spectrum, so the code uses an energy grid of 30 points and interpolates functional values for the rest of the spectrum. The predicted results compare well to more complicated 3-D transport codes, but BRYNTRN requires much less computational time[4]. BRYNTRN contains all necessary input data to perform the calculations in equations (1) - (3) and (11)-(15).

The HZETRN transport computer program is developed to address the problems of free-space GCR radiation transport and shielding. It is specifically intended for the design engineer who is interested in obtaining fast and accurate dosimetric information for the design and construction of space modules and other devices. The program is based on a one-dimensional space-marching formulation of the Boltzmann transport equation (5) with a straight ahead approximation. Because data is limited in regard to galactic cosmic ray transport measurements with which to compare HZETRN predictions, alternative methods of validation like the limited available proton transport Monte Carlo results were used[9]. Major shortcomings of the HZETRN calculations include neglect of meson contributions to the propagating radiation fields, target fragments in HZE reactions are not propagated but are treated as a source term, angular dependence is ignored, and all secondary particles from HZE interactions are presently assumed to be produced with a velocity equal to that of the incident particle. HZETRN internally contains all necessary input data to perform the calculations in equations (5) - (10).

Use of the BRYNTRN Code

It is necessary for the user to find the proper spot in the code to customize output for his or her particular situation, because there is no user interface. In this study, only the spectrum and thickness of shield material had to be changed, which would be the case for most other users. Like any other FORTRAN 77 code, it must then be compiled and linked before each run. The results can be saved to file and later printed, or displayed on screen as the code finishes each step. In this study, the code was run remotely on the VAX-4000 series computer at the NASA Langley Research Center. We saved the output files and transferred them to our lab before printing them out. Results of the calculations are shown in Appendix A.

Use of the HZETRN Code

The HZETRN computer code is similar to BRYNTRN because it was written by the same group. Once again, the code must be internally edited to change both the output and the input data fields. One can also change the quantity of output data that the code produces by simply specifying a "small, medium, or large" volume of printed information. The program internally contains seven different GCR spectra, and external spectra can also be used if specified. Both the aluminum shield thickness and water thickness must be specified. Further data on the intricacies of HZETRN execution can be found in reference 9.

For the purpose of detailed body geometry studies, a Computerized Anatomical Man (CAM)[10] model was used to model the skeleton and all internal organs. This model can account for a standing or seated configuration, and the standing configuration was used for this study. The organs of interest, skin, ocular lens, and bone marrow, are used because these organs have prescribed dose limits for low-earth orbit missions. At present, no radiation limits exist for deep space missions, but one would expect limits similar to current low earth orbit radiation protection guidelines. The bone marrow and skin, because they are distributed organs, are averaged over 33 sites, while the eye, a local organ, is represented by one site. The organ depth distribution is obtained by distributing 512 rays over 4π solid angle for each site which also provides a dose reduction calculation for self shielding from the body. Dose and dose equivalent values (using ICRP 60 quality factors to relate dose to dose equivalent) are printed for the organs of interest.

The BRYNTRN and HZETRN codes calculate the dose, dose equivalent, and remaining flux after transporting all particles and their interaction products through a 1 g/cm^2 step of material[4]. However, the output can be customized so that the dose, dose equivalent, and fluxes are given at any desired point. In this study, the first point of output was behind the total thickness of aluminum. Values of 2, 5, and 10 g/cm^2 aluminum were used. These values are representative of a spacesuit, nominal spacecraft, and spacecraft storm shelter, respectively. The second shield material used was water, which simulates soft body tissue. The CAM model is tailored to cover 100 g/cm^2 of water in a certain amount of steps. We used 15 steps as a reasonable compromise which yields good interpolation for any ray length. The organ dose and dose equivalents are obtained by folding the depth-dose/dose equivalent distribution with the organ depth distribution.

V. Data Analysis

Part of the output from the BRYNTRN code are tables representing propagation of the appropriate spectra through the aluminum shield, then through the water slab. These values are analogous to those at the center of a sphere of water surrounded by a spherical shell of aluminum. The CAM model computer code outputs include absorbed dose and dose equivalent within the organs of interest (BFO, skin, and ocular lens). Langley and Billings[3] demonstrated that for the purposes of quick computational time, an equivalent sphere of water could be used to model organs in the body. They recommended a 5 cm radius water sphere be used to simulate BFO, a 0.03 cm radius sphere for eye, and a 0.01 cm radius sphere for skin[11] based primarily on neutron and gamma ray dose profiles[3]. This 5 cm sphere approximation has become a traditional value when performing calculations for spacecraft design studies, and a 0 cm radius sphere is used as a reasonable approximation for the recommended skin and ocular lens values. Even with the speed of today's computers, it is significantly faster for the BRYNTRN and HZETRN codes to propagate through only the equivalent sphere radial thickness than the whole 100 cm thickness required to employ the CAM model. Recently it has become evident that the 5 cm sphere model provides BFO dose estimates that are extremely conservative. Differences of up to 41 percent have been observed[5] in literature and differences of up to 250 percent were observed in this study. If these numbers are used in spacecraft design studies, the resultant shield thickness requirements would impose a severe weight penalty on the design, driving both construction and deployment costs up.

Even though the GCR spectra are quite different in energy, fluence and composition from the SPE spectra, researchers still use a 5 cm approximation for BFO and 0 cm for skin and eye. Like BRYNTRN, HZETRN also provides tabulated output of incremental steps through the water slab. The CAM model takes this data and correlates it to specific dose and dose equivalent for each spectrum in the organ of interest. Although the error we found between the standard approximations for GCR and the CAM values was much smaller than that for SPE, significant error exists.

In this study, we sought to obtain a revised equivalent sphere model which, while still conservative, was more realistic when compared to the organ dose/dose equivalent outputs of the CAM model. Figures 5 and 6 are plots of BFO dose in cGy versus water thickness in cm for each of the aluminum shield thicknesses for the August 1972 and October 1989 events respectively. Note that in these plots 0.741 cm aluminum corresponds to 2 g/cm^2 Al or a typical spacesuit, 1.85 cm Al corresponds to 5 g/cm^2 Al or a nominal spacecraft, and 3.70 cm Al corresponds to 10 g/cm^2 Al or a spacecraft "stormshield". Figures 7 and 8 are the corresponding BFO dose equivalent (cSv) versus water thickness (cm) plots for the same events. Figures 9 and 10 show skin and eye dose for the February 1956 spectrum, and Figures 11 and 12 show the corresponding dose equivalent for this spectrum. Note that here the Y-axis denotes the standard 0 cm equivalent sphere approximation and the proposed 1 cm depth is also indicated. The tabulated data (See Appendix A) for plots like these was input into the CAM model to obtain the BFO, skin, and eye dose and dose equivalent for each thickness of aluminum shield. The BRYNTRN code was then run again for each SPE to obtain output in 1 cm

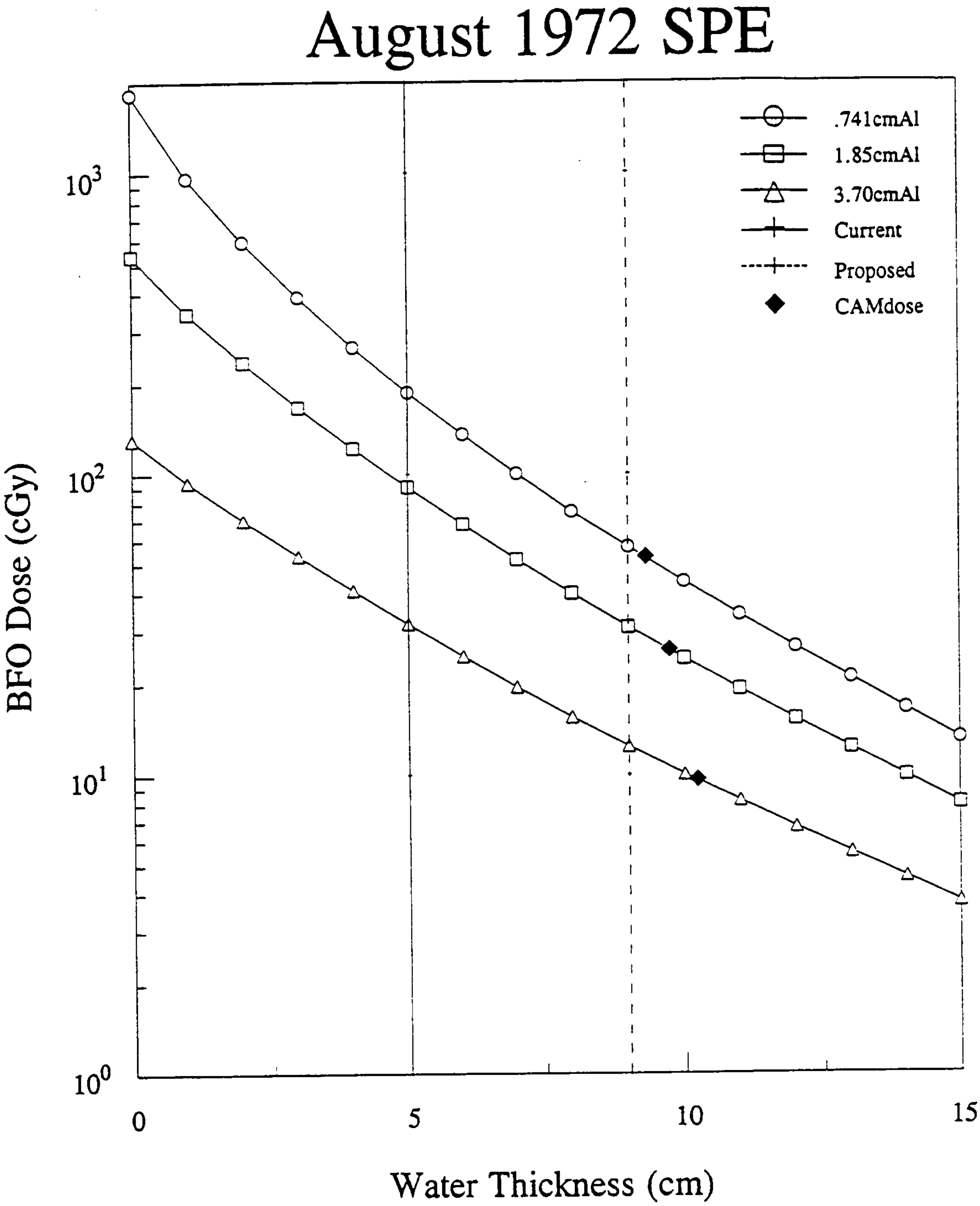

Figure 5. BFO Dose Versus Water Depth for August 1972 SPE

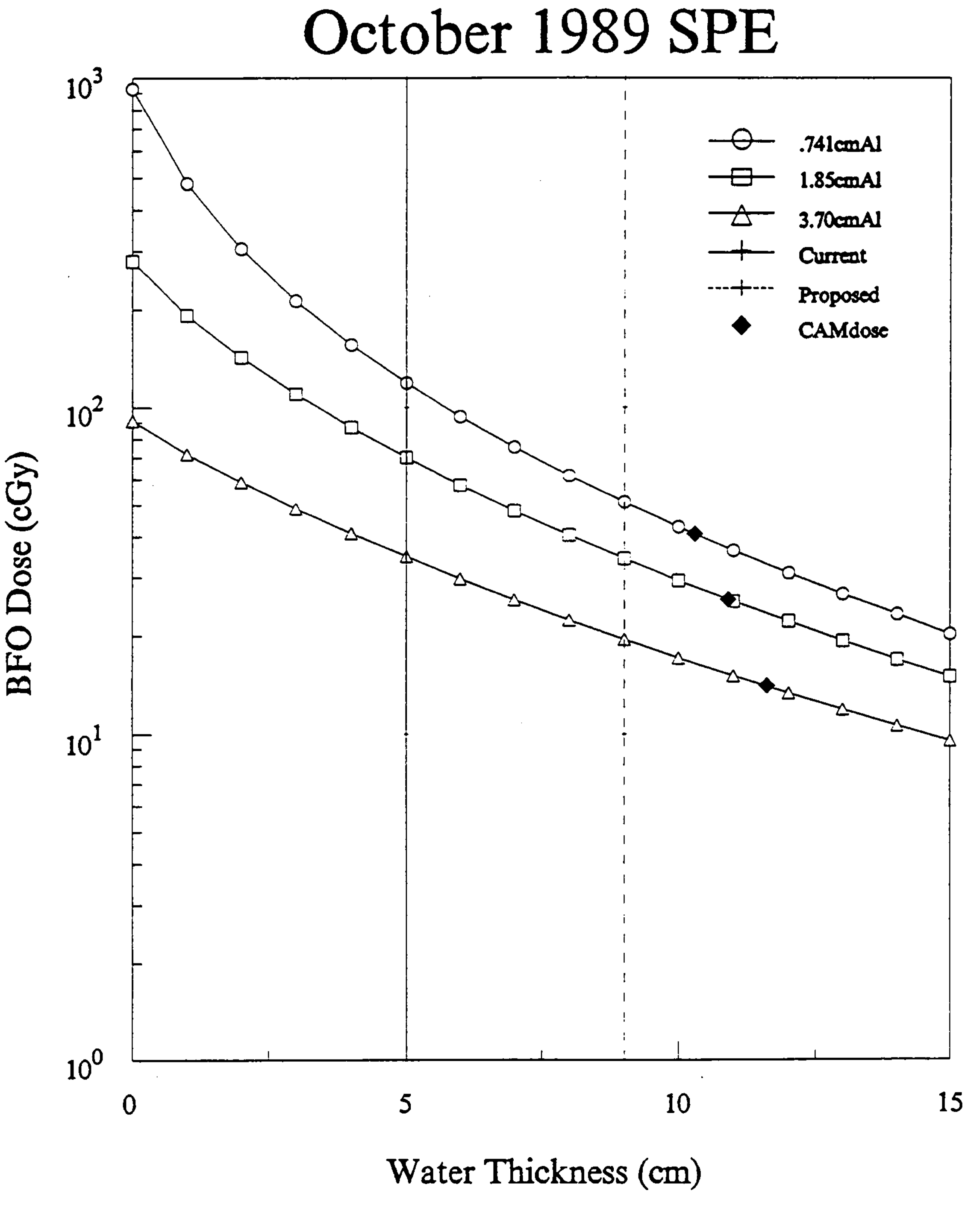

Figure 6. BFO Dose Versus Water Depth for October 1989 SPE

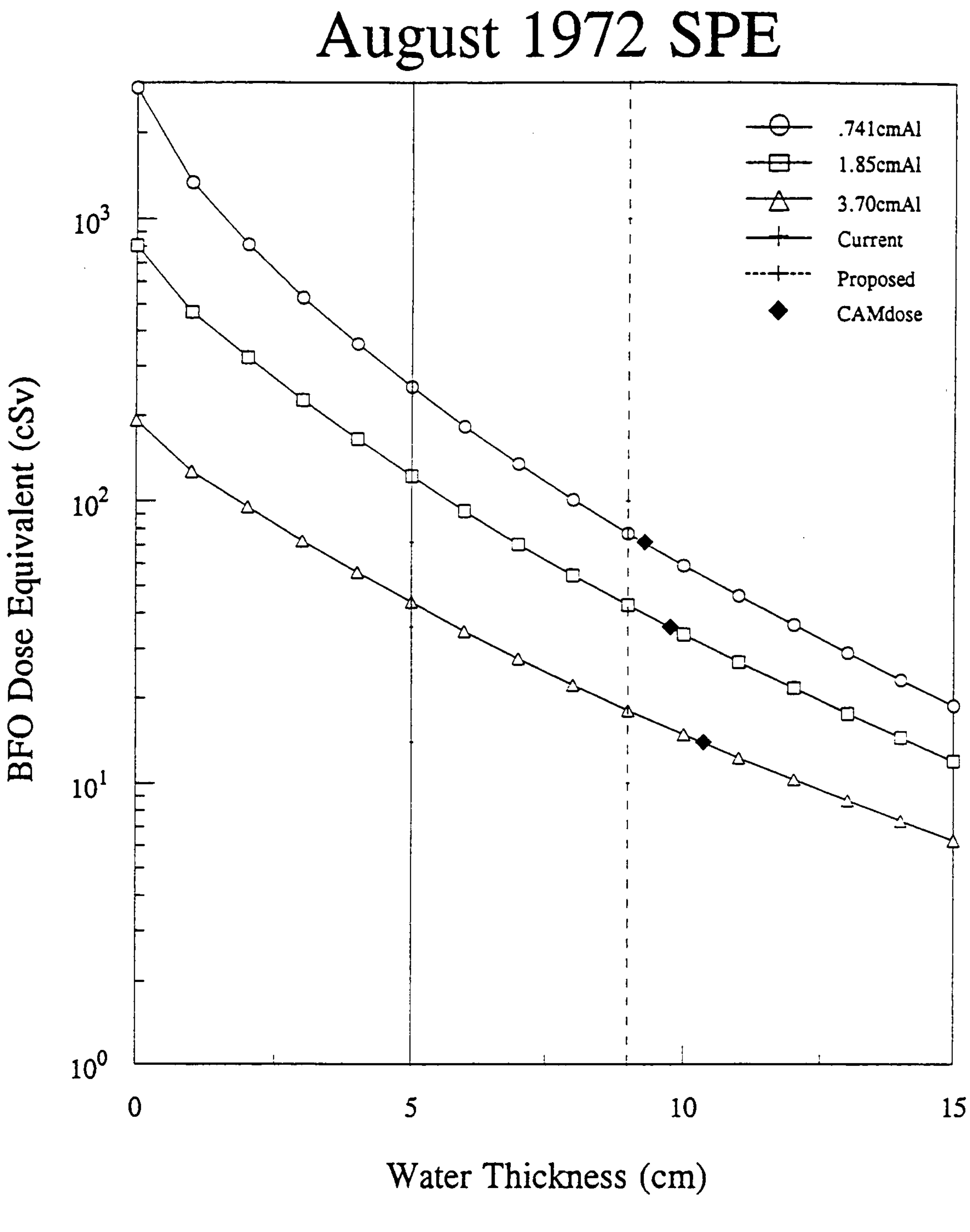

Figure 7. BFO Dose Equivalent Versus Water Depth for August 1972 SPE

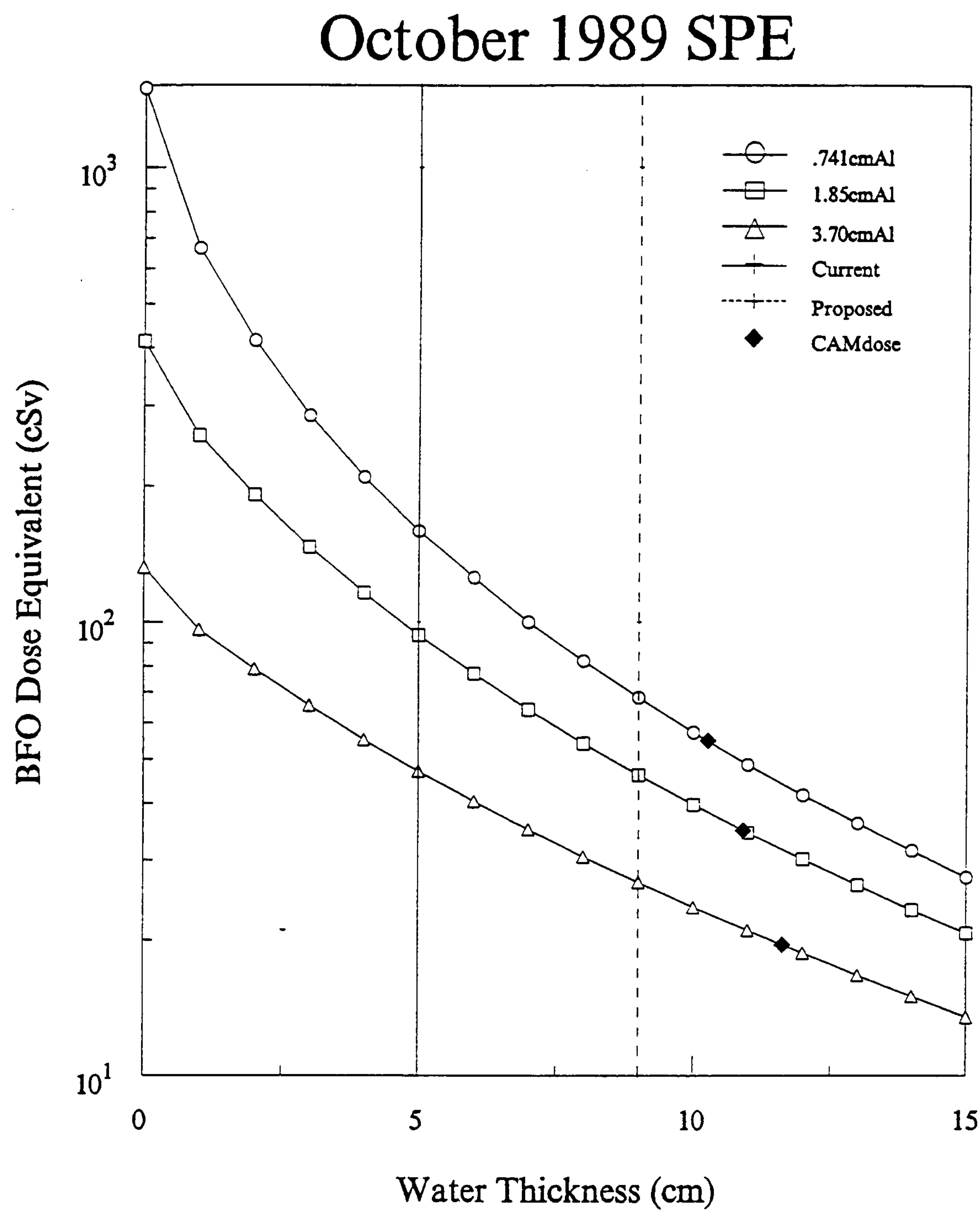

Figure 8. BFO Dose Equivalent Versus Water Depth for October 1989 SPE

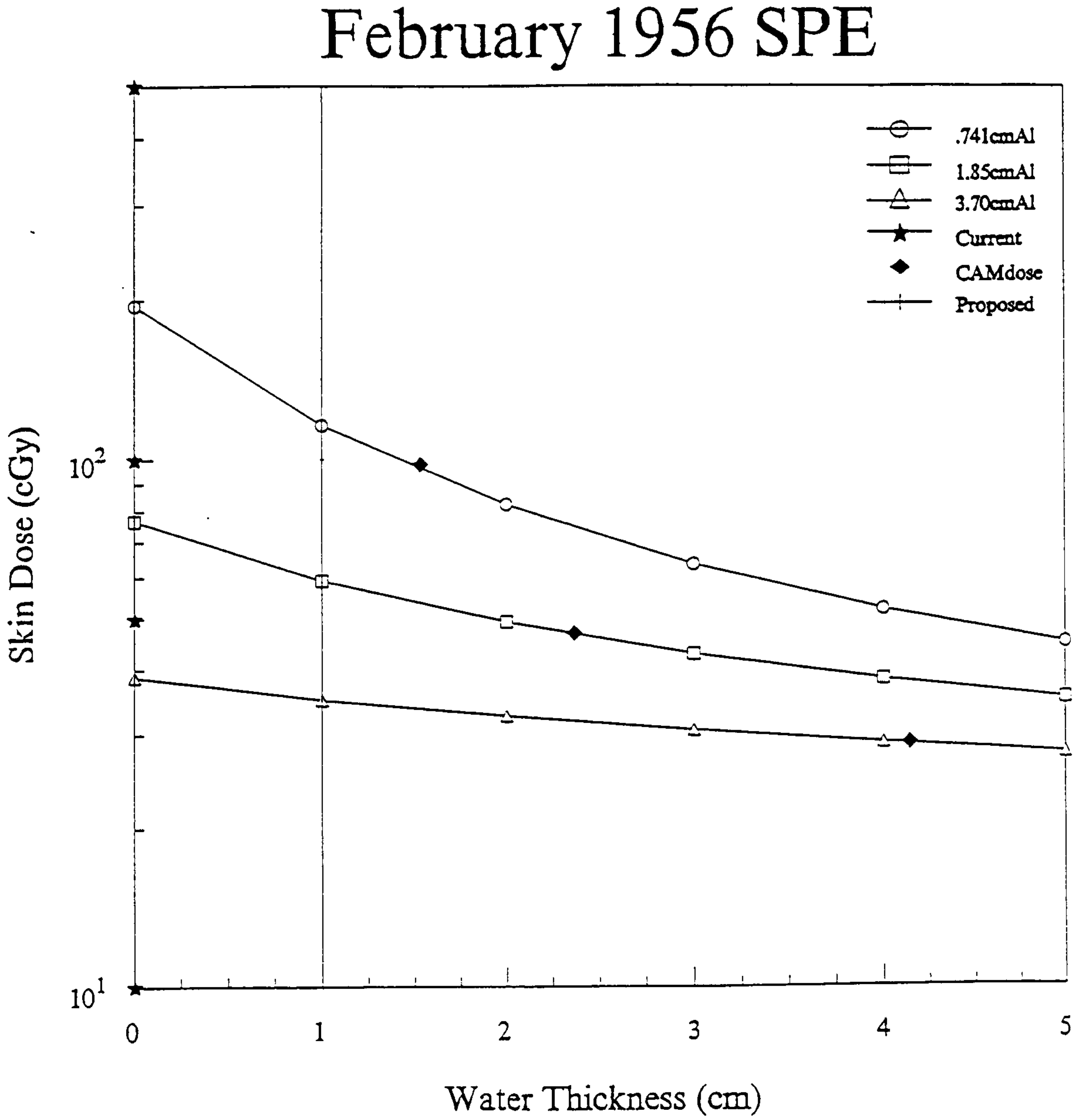

Figure 9. Skin Dose Versus Water Depth for February 1956 SPE

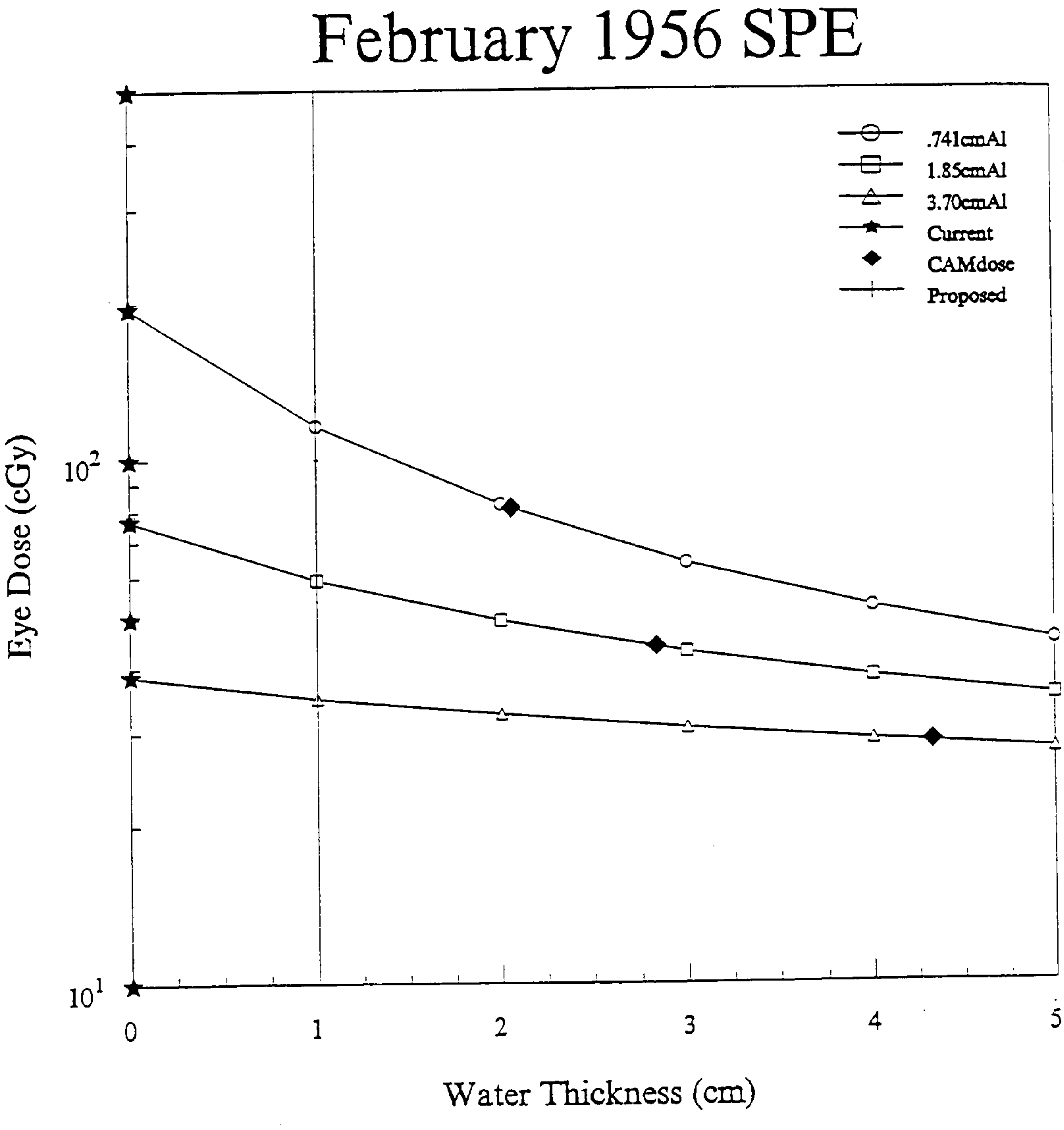

Figure 10. Eye Dose Versus Water Depth for February 1956 SPE

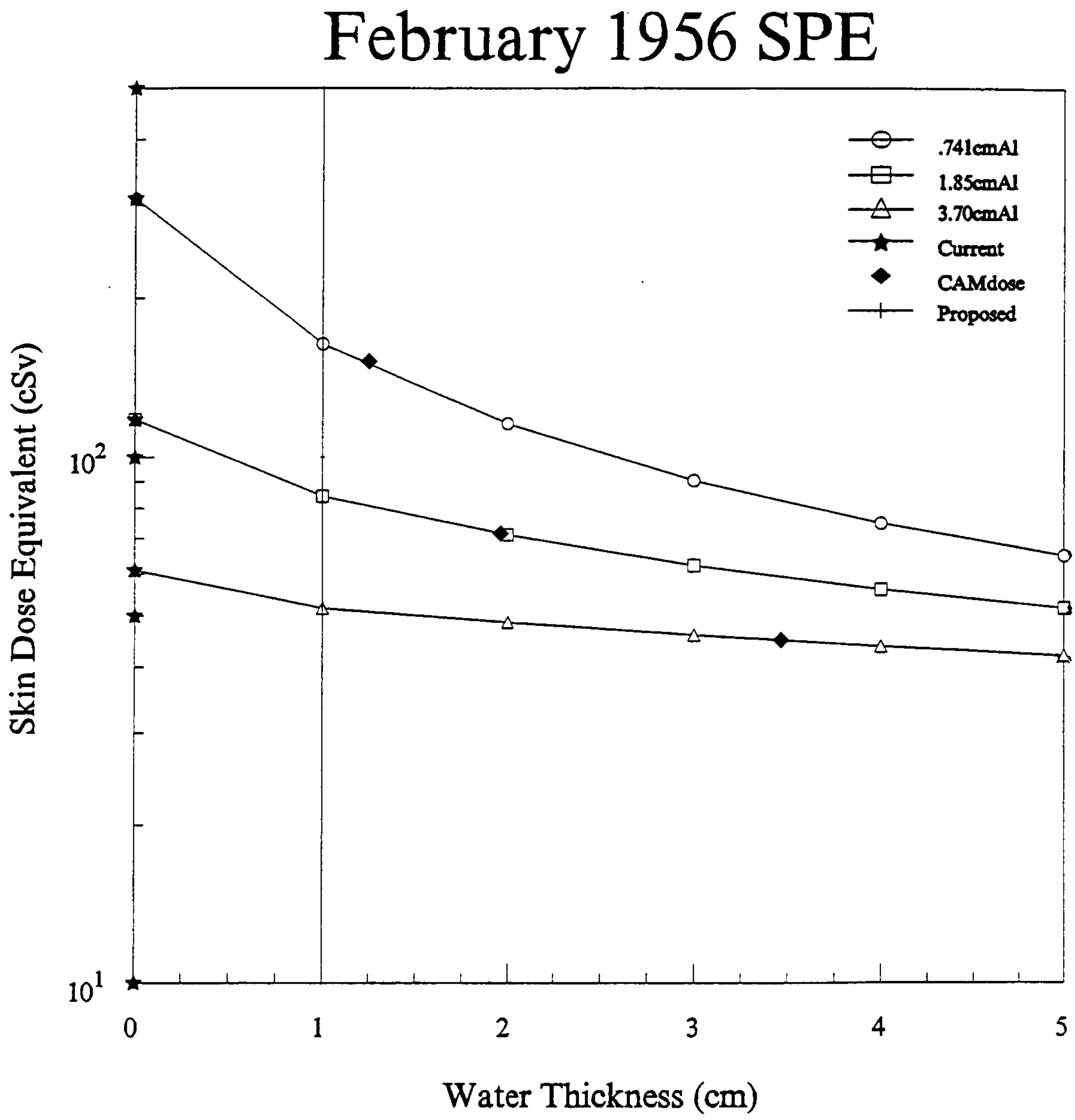

Figure 11. Skin Dose Equivalent Versus Water Depth for February 1956 SPE

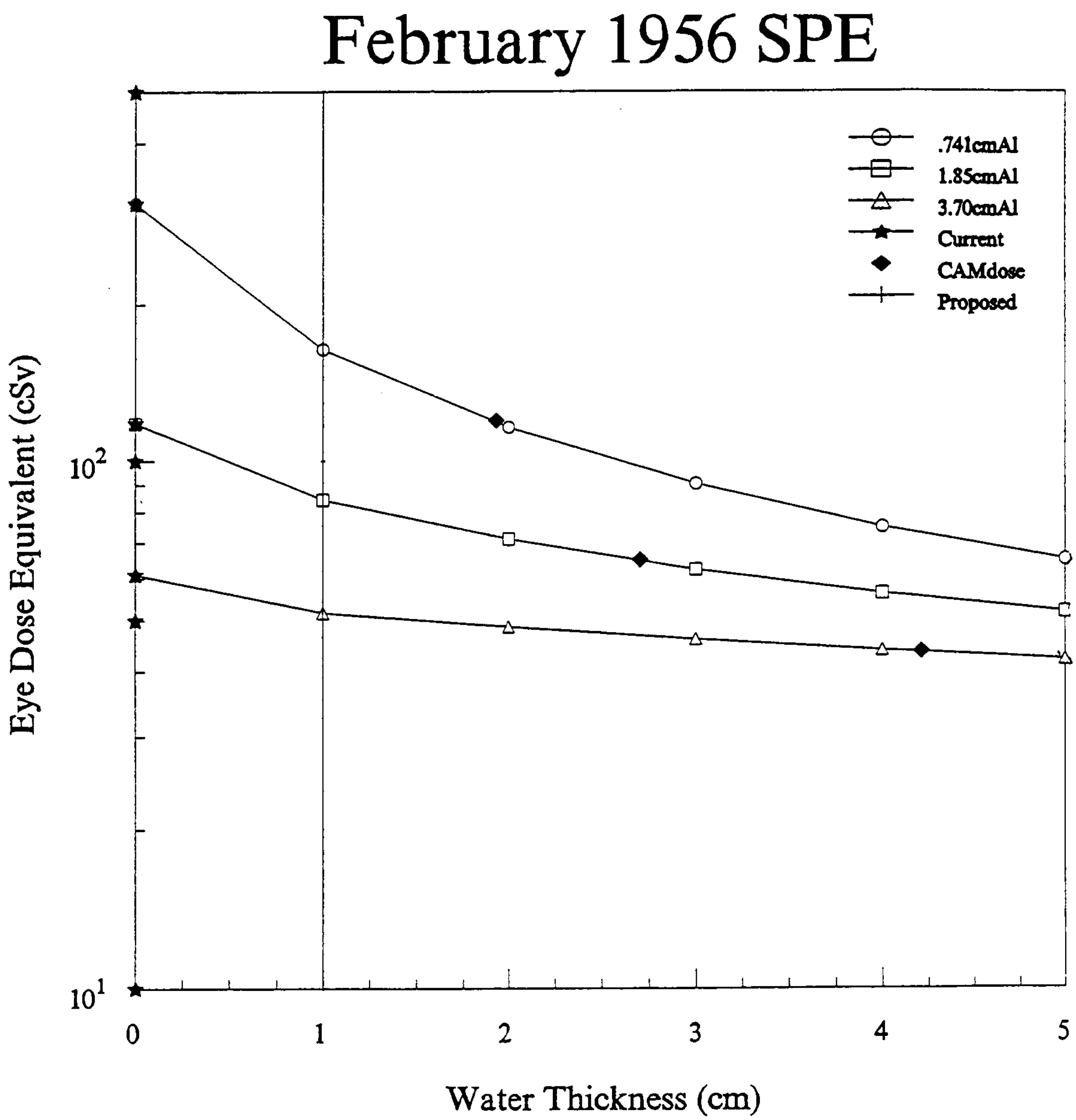

Figure 12. Eye Dose Equivalent Versus Water Depth for February 1956 SPE

steps from 1-20 cm water thickness. These results were compared to the CAM model output of dose/dose equivalent to determine what one thickness of water was most representative of the actual CAM organ values. The results for eye dose/dose equivalent from the October 1989 SPE are shown in Figures 13 and 14 respectively. Similarly, the skin dose/dose equivalent results are shown in Figures 15 and 16. The horizontal scales for these plots were expanded to include only the relevant data so the differences between the models could be more easily seen. For several cases this approximation was not conservative, but we will show that this lack of conservatism provides insignificant error. The CAM model showed that an astronaut would receive more dose or dose equivalent than our revised equivalent sphere approximation would indicate in limited, specific instances. For dose equivalent, this occurred in August 1989 BFO, and in August 1989 and November 1960 skin results. For dose, approximation underestimation occurred again in August 1989 BFO and skin, and each time this was with 2 g/cm^2 aluminum equivalent shielding. All results indicate that the proposed equivalent sphere thickness value is more realistic than the old value when compared to the CAM output. Tables 1-6 show the differences in dose and dose equivalent when comparing the old and the revised equivalent sphere model. We can see from these tables that underestimation of dose like that which occurred with 2 g/cm^2 Al shielding for the August 1989 skin dose equivalent (the largest nonconservative result) is still quite close to the CAM value when compared to the error incurred from the old approximation. It is also important to note that this code is created for design engineers to perform preliminary shielding studies, and its results are not included in a final radiation risk estimation report but are only a stepping

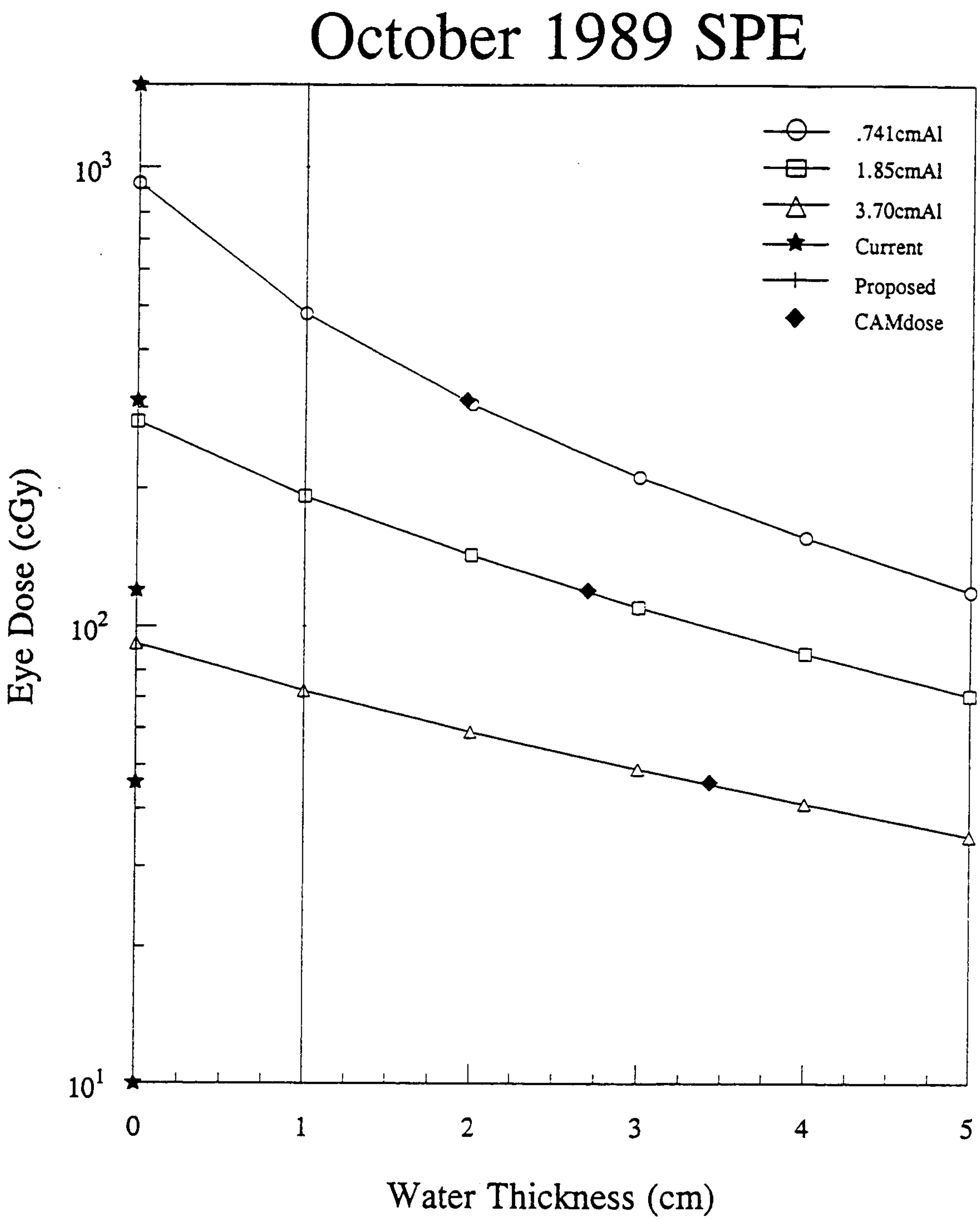

Figure 13. Eye Dose Versus Water Depth for October 1989 SPE

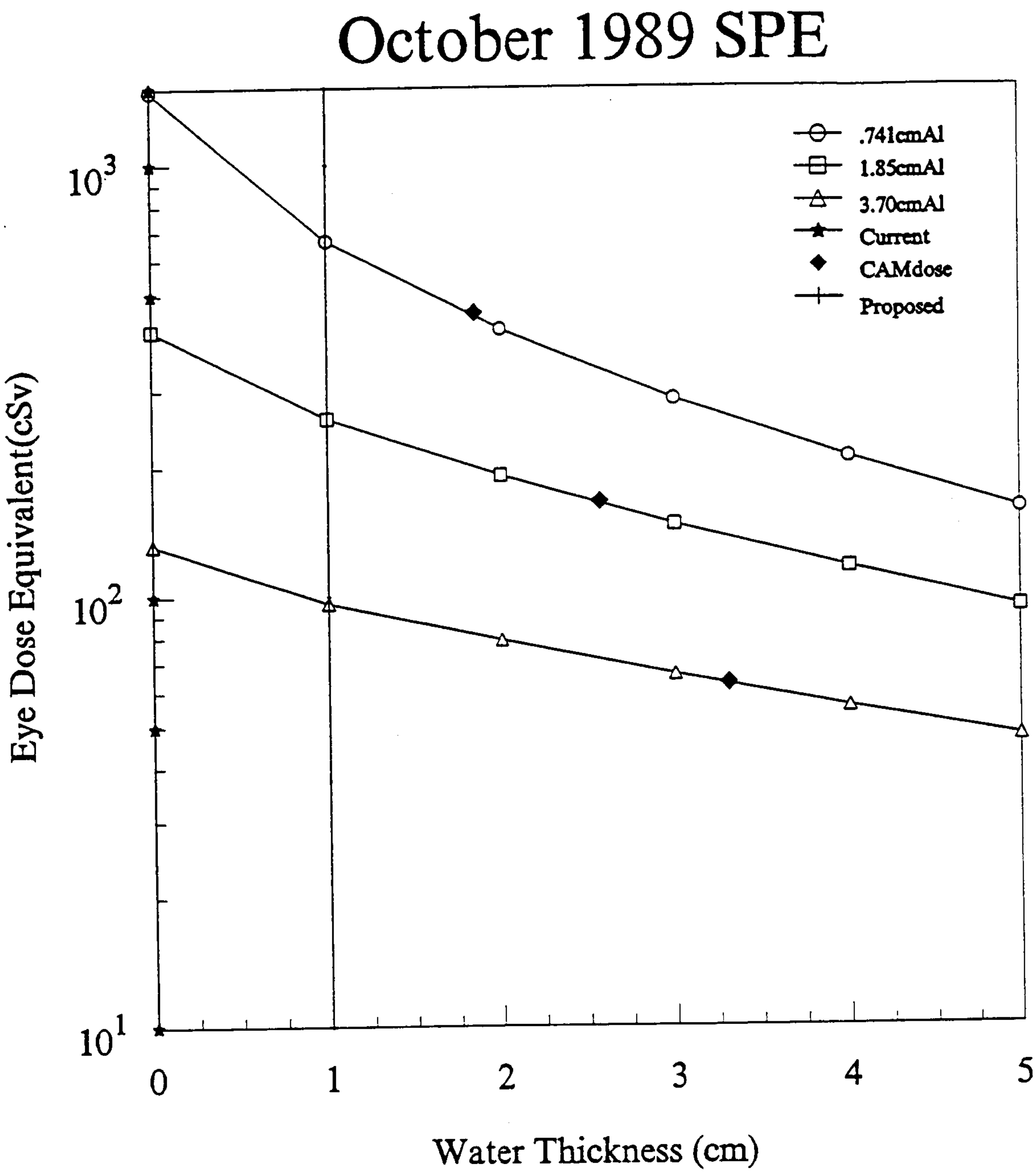

Figure 14. Eye Dose Equivalent Versus Water Depth for October 1989 SPE

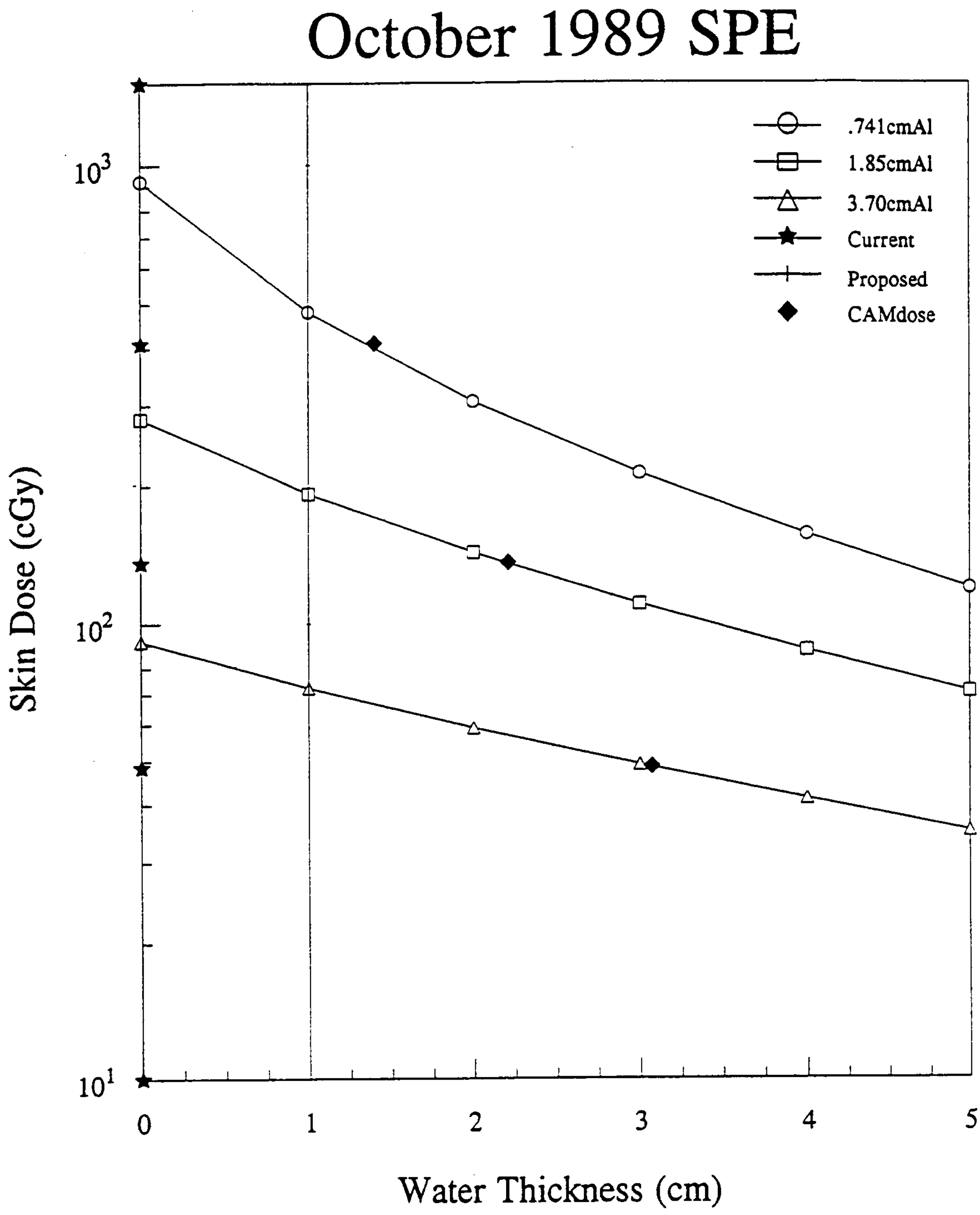

Figure 15. Skin Dose Versus Water Depth for October 1989 SPE

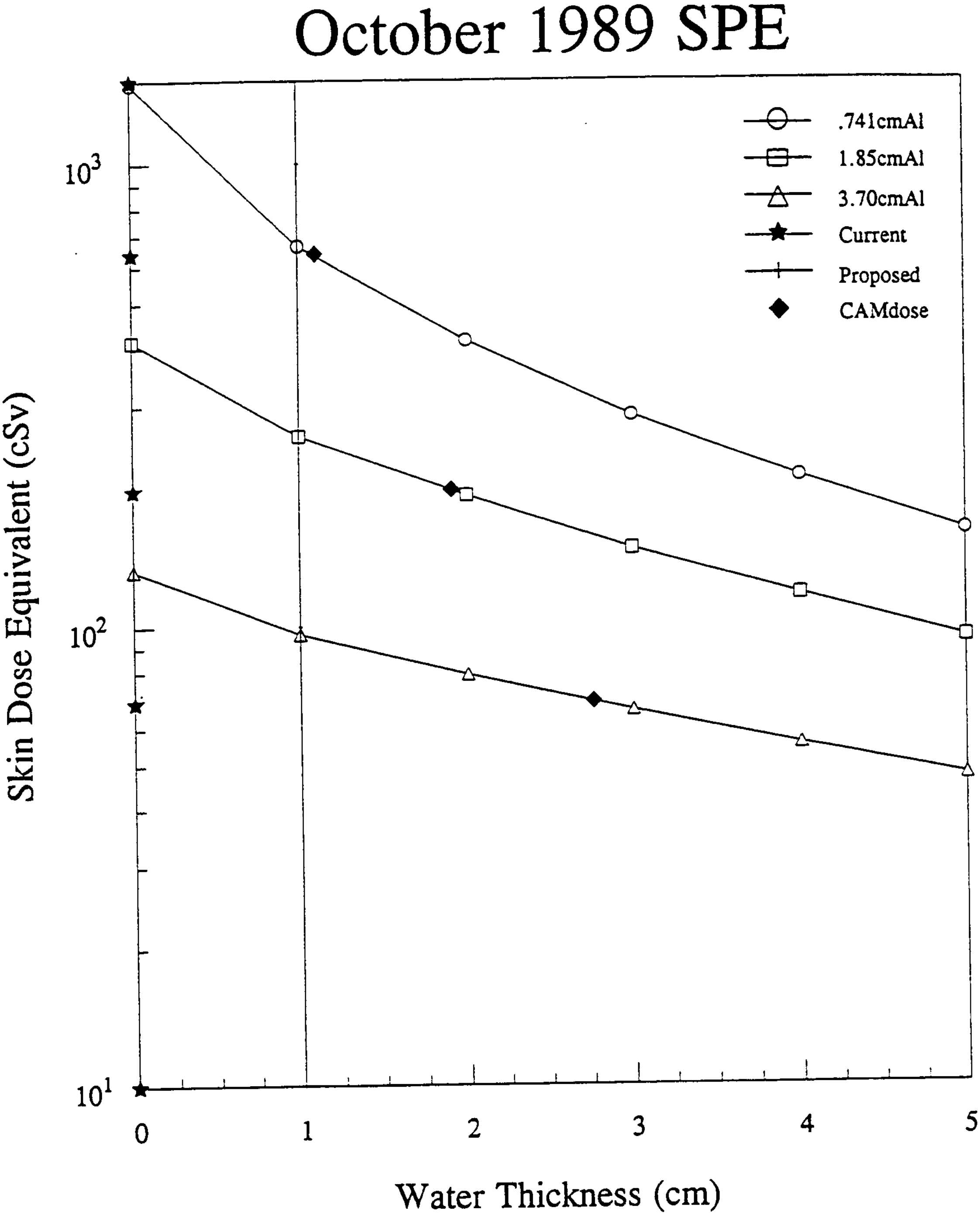

Figure 16. Skin Dose Equivalent Versus Water Thickness for October 1989 SPE

Table 1. SPE Percent Differences in BFO Dose

	February 1956			November 1960			August 1972			August 1989			September 1989			October 1989		
Aluminum Thickness (g/cm^2)	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**
5 cm Dose (cGy)	45	35	28	72	53	36	188	90	32	17	8	3	46	28	20	119	70	35
9 cm Dose (cGy)	31	28	24	45	35	25	57	31	12	5	3	1	21	15	12	51	34	20
CAM Dose (cGy)	27	24	21	34	26	19	52	26	10	5	2	0.9	17	11	6	41	26	14
% Difference from 5 cm to CAM	62	45	31	114	103	91	258	249	230	244	235	207	179	158	216	192	174	147
% Difference from 9 cm to CAM	13	14	14	32	35	35	8	19	29	-2	16	30	28	34	89	25	34	38

Table 2. SPE Percent Differences in Skin Dose

	February 1956			November 1960			August 1972			August 1989			September 1989			October 1989		
Aluminum Thickness (g/cm^2)	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**
0 cm Dose (cGy)	195	77	39	466	128	61	1826	538	131	328	58	11	306	101	36	926	280	91
1 cm Dose (cGy)	116	59	35	213	97	54	967	345	94	128	34	8	166	72	29	479	192	72
CAM Dose (cGy)	98	47	29	211	71	38	795	246	63	136	26	6	138	50	20	410	136	48
% Difference from 0 cm to CAM	99	64	34	121	81	62	130	119	109	141	124	92	122	101	85	126	106	89
% Difference from 1 cm to CAM	18	26	21	1	37	41	22	40	50	-6	30	35	20	42	48	17	41	49

Table 3. SPE Percent Differences in Eye Dose

	February 1956			November 1960			August 1972			August 1989			September 1989			October 1989		
Aluminum Thickness (g/cm^2)	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**
0 cm Dose (cGy)	195	77	39	466	128	61	1826	538	131	328	58	11	306	101	36	926	280	91
1 cm Dose (cGy)	116	59	35	213	97	54	967	345	94	128	34	8	166	72	29	479	192	72
CAM Dose (cGy)	81	44	29	153	66	38	607	208	56	89	21	5	108	45	19	311	120	46
% Difference from 0 cm to CAM	141	75	35	205	94	63	201	159	132	269	180	134	184	124	93	198	133	100
% Difference from 1 cm to CAM	43	35	22	39	47	43	59	66	67	44	62	65	54	59	55	54	60	57

Table 4. SPE Percent Difference in BFO Dose Equivalent

	February 1956			November 1960			August 1972			August 1989			September 1989			October 1989		
Aluminum Thickness (g/cm^2)	2	5	10	2	5	10	2	5	10	2	5	10	2	5	10	2	5	10
5 cm Dose Equivalent (cSv)	65	52	41	96	71	48	253	122	44	23	10	4	61	38	20	159	94	47
9 cm Dose Equivalent (cSv)	47	42	37	59	48	34	77	43	18	7	4	2	28	20	12	68	46	27
CAM Dose Equivalent (cSv)	42	37	33	45	35	26	72	36	14	7	3	1	22	15	9	55	35	20
% Difference from 5 cm to CAM	55	39	25	111	100	87	253	241	213	238	224	190	175	155	129	190	169	141
% Difference from 9 cm to CAM	12	13	13	31	34	34	7	19	29	-3	16	31	27	34	37	24	33	37

Table 5. SPE Percent Differences in Skin Dose Equivalent

	February 1956			November 1960			August 1972			August 1989			September 1989			October 1989		
Aluminum Thickness (g/cm^2)	2	5	10	2	5	10	2	5	10	2	5	10	2	5	10	2	5	10
0 cm Dose Equivalent (cSv)	309	118	61	777	188	88	2877	806	193	557	90	17	484	149	59	1480	414	132
1 cm Dose Equivalent (cSv)	164	84	52	299	129	71	1342	468	127	185	47	11	229	96	39	665	258	96
CAM Dose Equivalent (cSv)	152	72	45	340	101	53	1230	363	914	227	40	8	213	72	28	640	197	69
% Difference from 0 cm to CAM	103	65	35	129	86	65	134	122	111	145	128	111	127	106	88	131	110	92
% Difference from 1 cm to CAM	8	18	15	-12	28	35	9	29	39	-18	18	36	8	32	40	4	31	40

Table 6. SPE Percent Differences in Eye Dose Equivalent

	February 1956			November 1960			August 1972			August 1989			September 1989			October 1989		
Aluminum Thickness (g/cm^2)	2	5	10	2	5	10	2	5	10	2	5	10	2	5	10	2	5	10
0 cm Dose Equivalent (cSv)	309	118	61	777	188	88	2877	806	193	557	90	17	484	149	59	1480	414	132
1 cm Dose Equivalent (cSv)	164	84	52	299	129	71	1342	468	127	185	47	11	229	96	39	665	258	96
CAM Dose Equivalent (cSv)	120	65	44	227	90	51	880	291	79	138	30	7	155	62	26	453	165	63
% Difference from 0 cm to CAM	158	82	40	242	109	72	227	177	145	304	201	146	212	141	103	227	151	111
% Difference from 1 cm to CAM	37	30	19	32	43	40	52	61	61	34	56	59	48	55	51	47	56	54

stone to full spacecraft characterization. The use of this revised model will avoid the addition of significant shield material in the design stage, and the doses using the new model are still calculated much faster than a full dose profile using the CAM model, so engineers can spend less time running calculations on the computer and more time at the drawing board.

The galactic cosmic ray spectra run through HZETRN produces much less variation in dose values found in a single event because the high energy GCR is much "harder" and not easily attenuated by the spacecraft shielding. We found that the 9 cm BFO equivalent sphere approximation could be shifted to 11 cm radius for GCR spectra evaluation because of values derived from the CAM code, and the 1 cm skin and eye approximations could be shifted to 3 cm water. We examined two GCR spectra each at minimum and maximum because they vary significantly between solar minimum and solar maximum.

The HZETRN code was run through 100 steps of 1 cm water for each of the three shield thicknesses and for four GCR spectra. The data from this run was then used to find the CAM values for skin, ocular lens, and BFO dose and dose equivalent. The HZETRN code is next run to provide data points for 0 - 14 cm H_2O so that the old and revised equivalent sphere approximations can be compared to the CAM data. A complete data set from the 1970 - 1971 solar maximum GCR is presented in Figures 17 - 22. One can see that the solar maximum provides much lower dose from GCR by examining plots from the 1986 solar minimum GCR spectrum (Figures 23 - 28). In these plots, the revised BFO tissue equivalent sphere radius is at 11 cm and the revised skin and ocular lens tissue

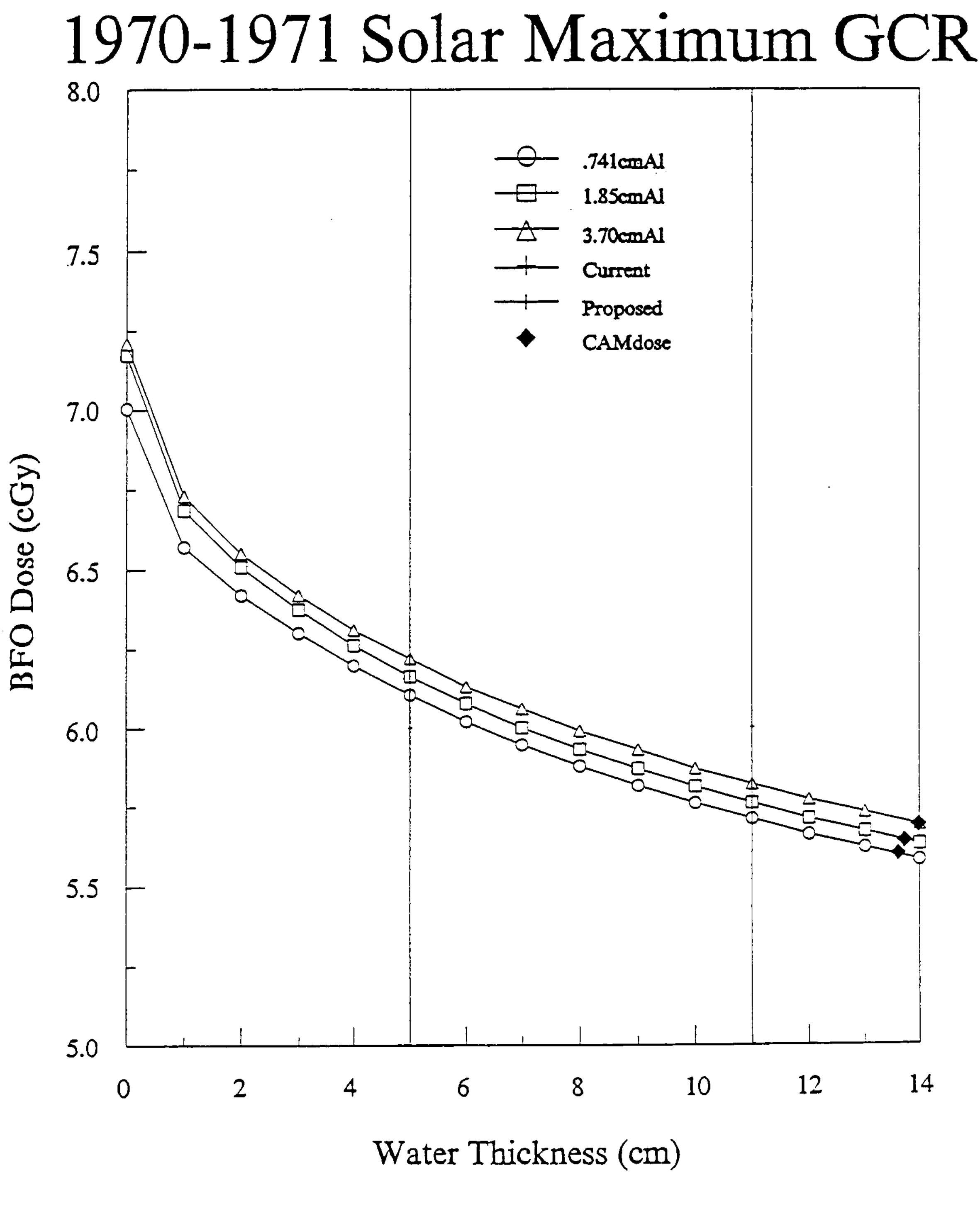

Figure 17. BFO Dose Versus Water Depth for 1970 - 1971 Solar Maximum GCR

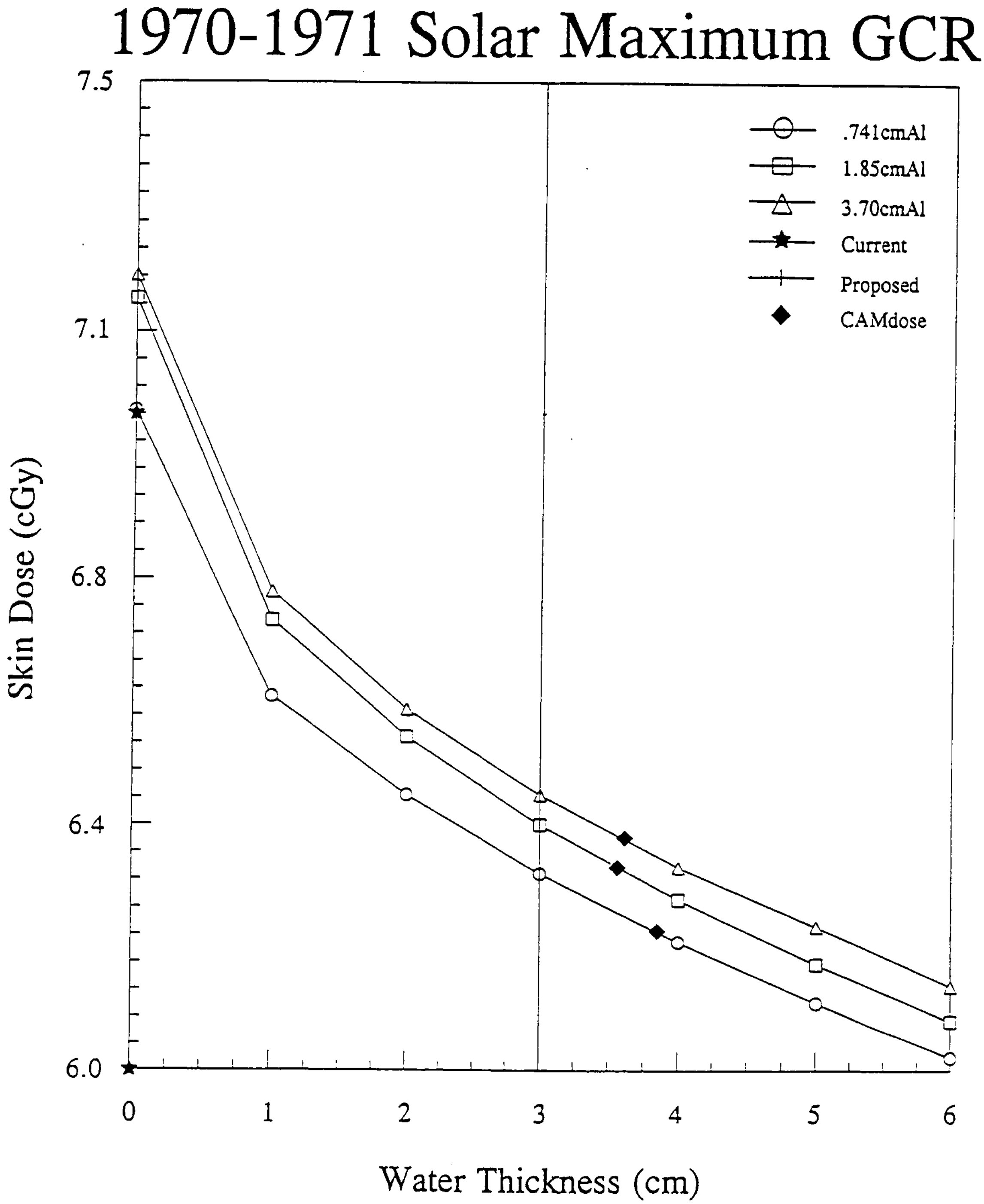

Figure 18. Skin Dose Versus Water Depth for 1970 - 1971 Solar Maximum GCR

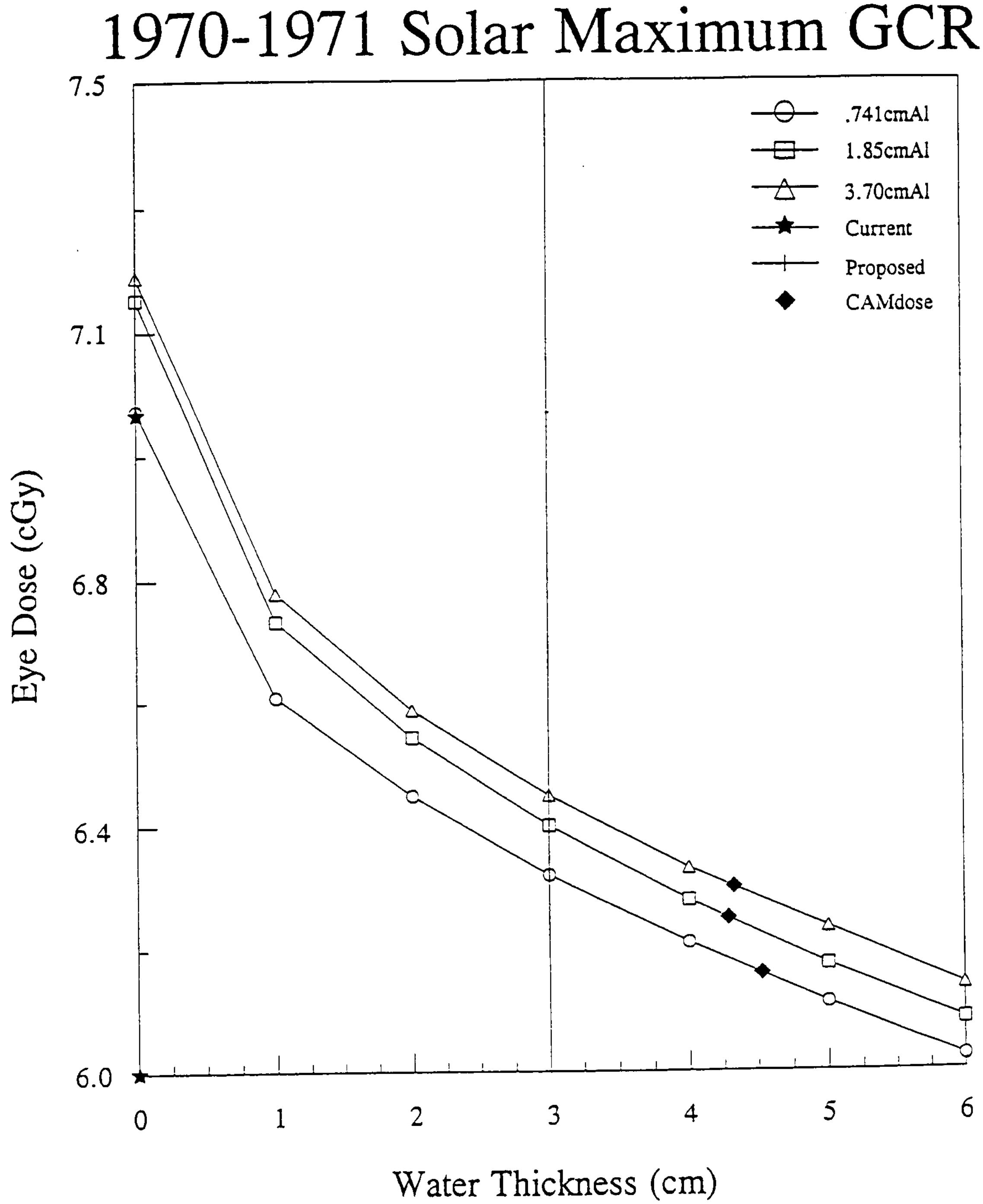

Figure 19. Eye Dose Versus Water Depth for 1970 - 1971 Solar Maximum GCR

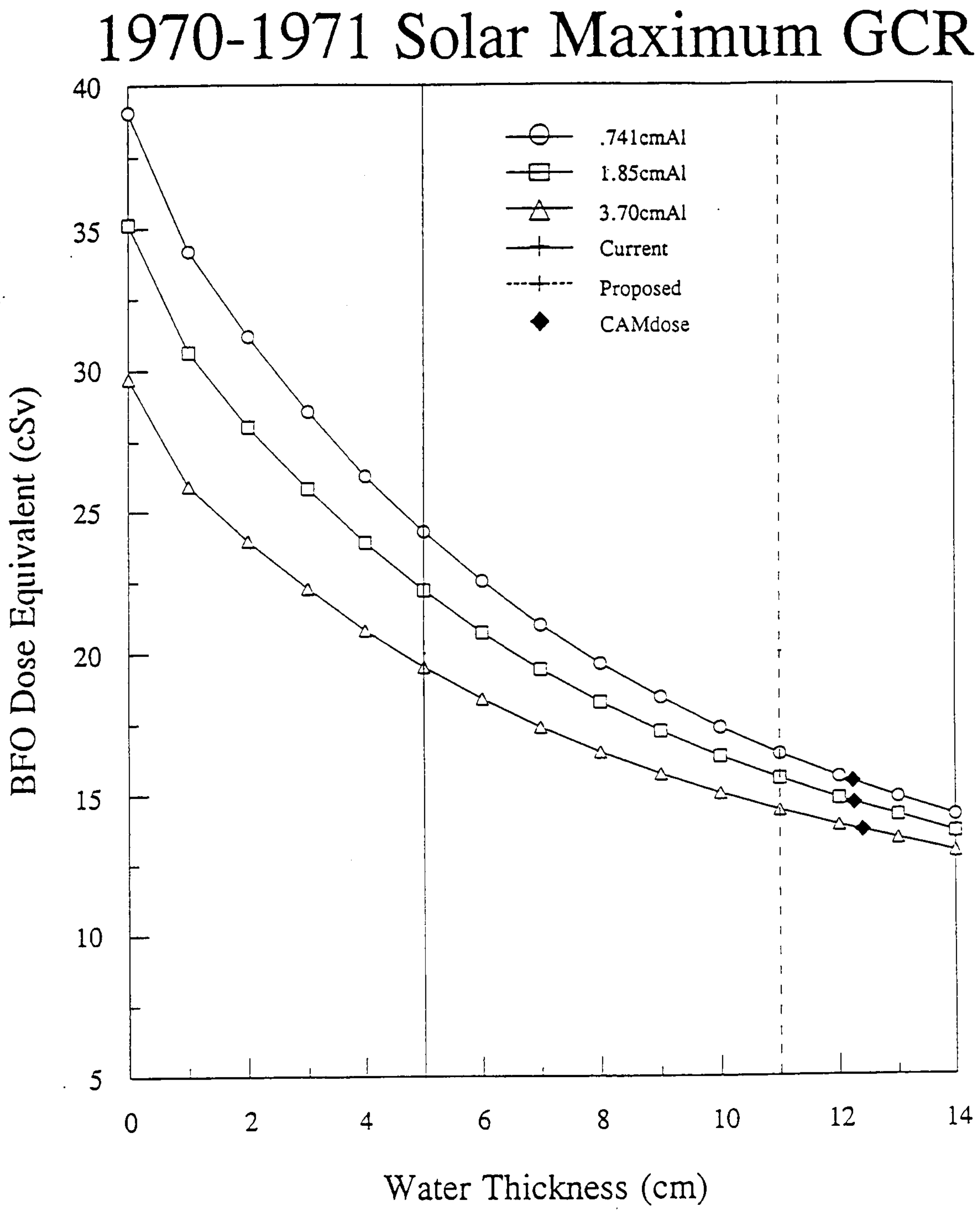

Figure 20. BFO Dose Equivalent Versus Water Depth for 1970 - 1971 Solar Maximum GCR

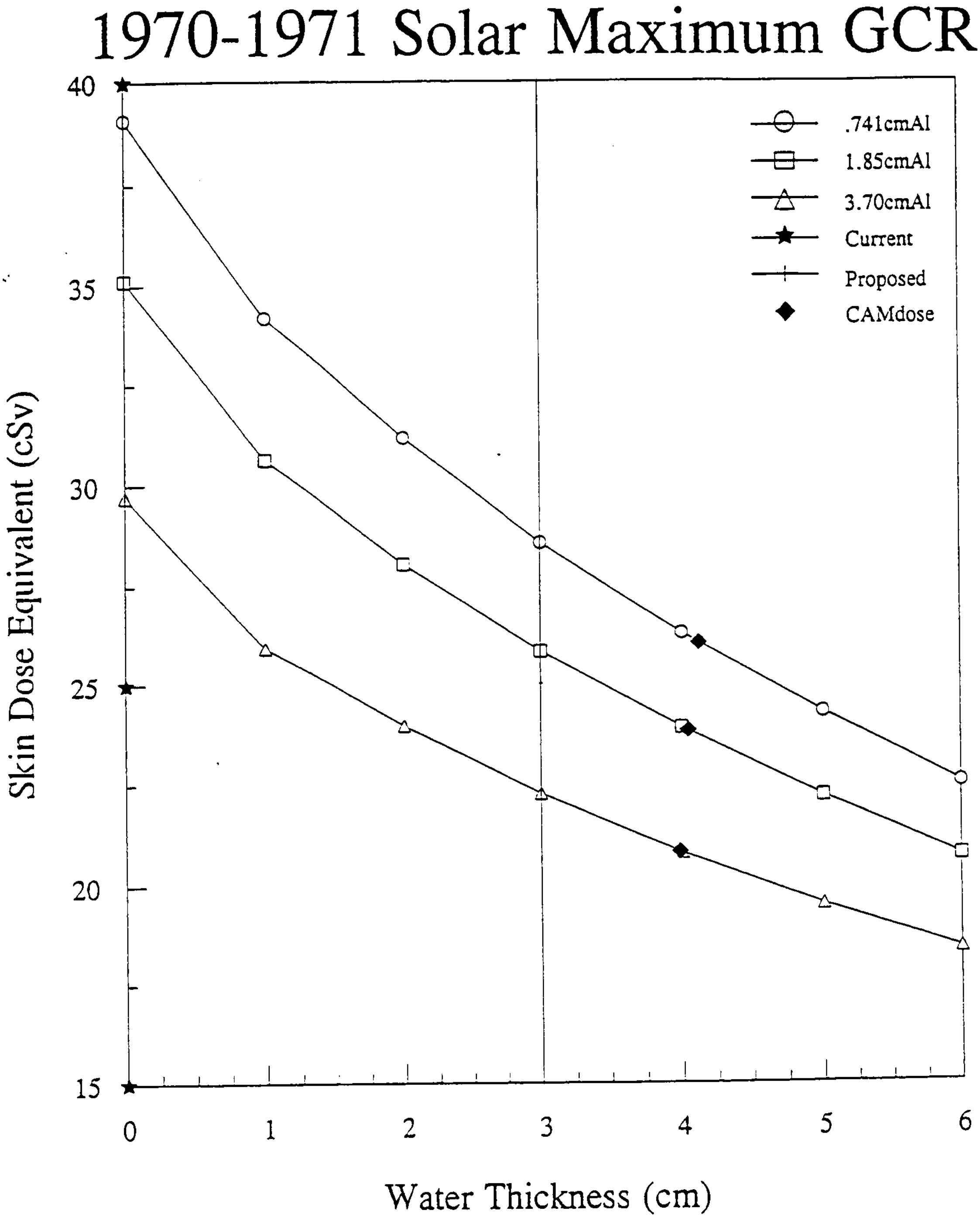

Figure 21. Skin Dose Equivalent Versus Water Depth for 1970 - 1971 Solar Maximum GCR

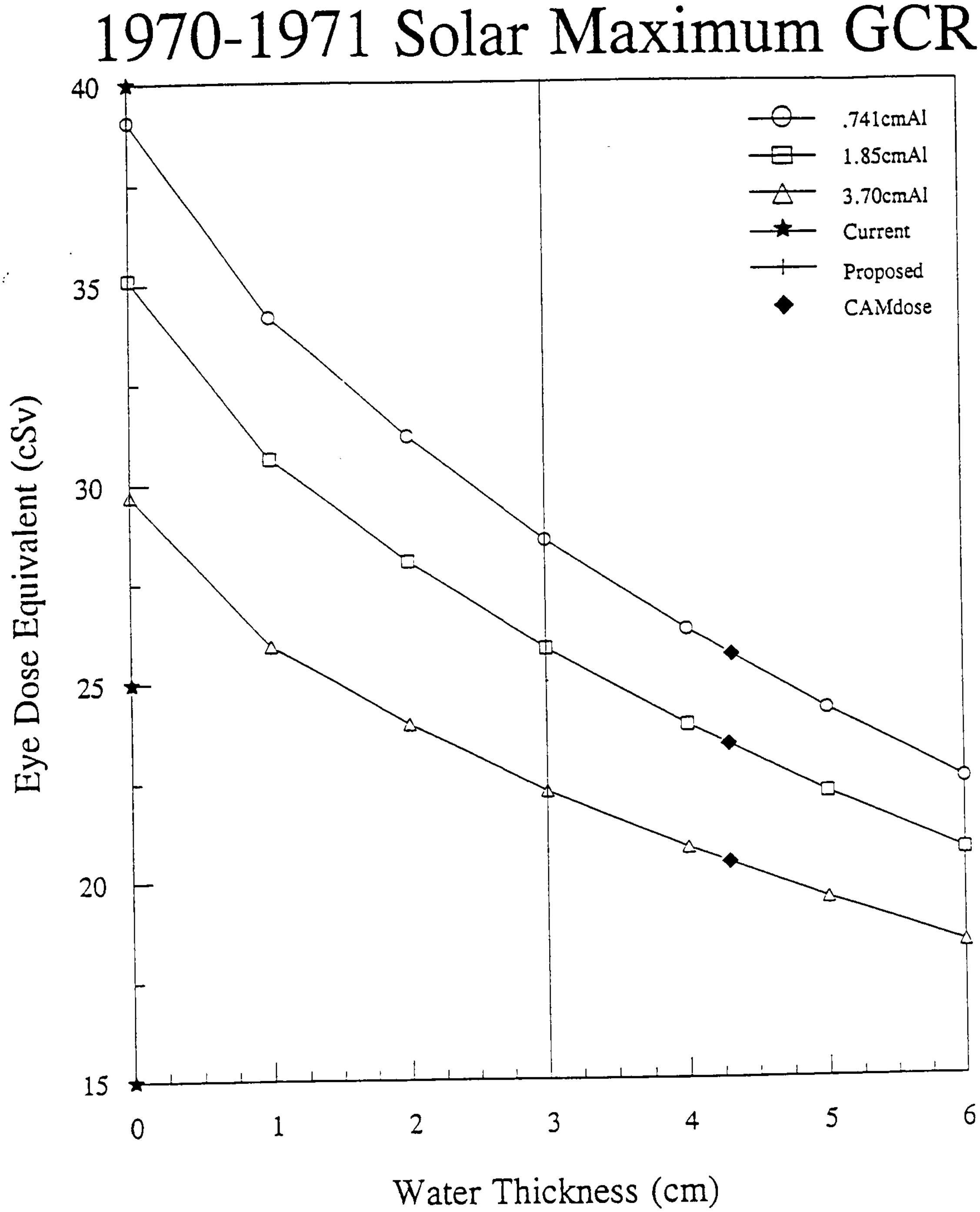

Figure 22. Eye Dose Equivalent Versus Water Depth for 1970 - 1971 Solar Maximum GCR

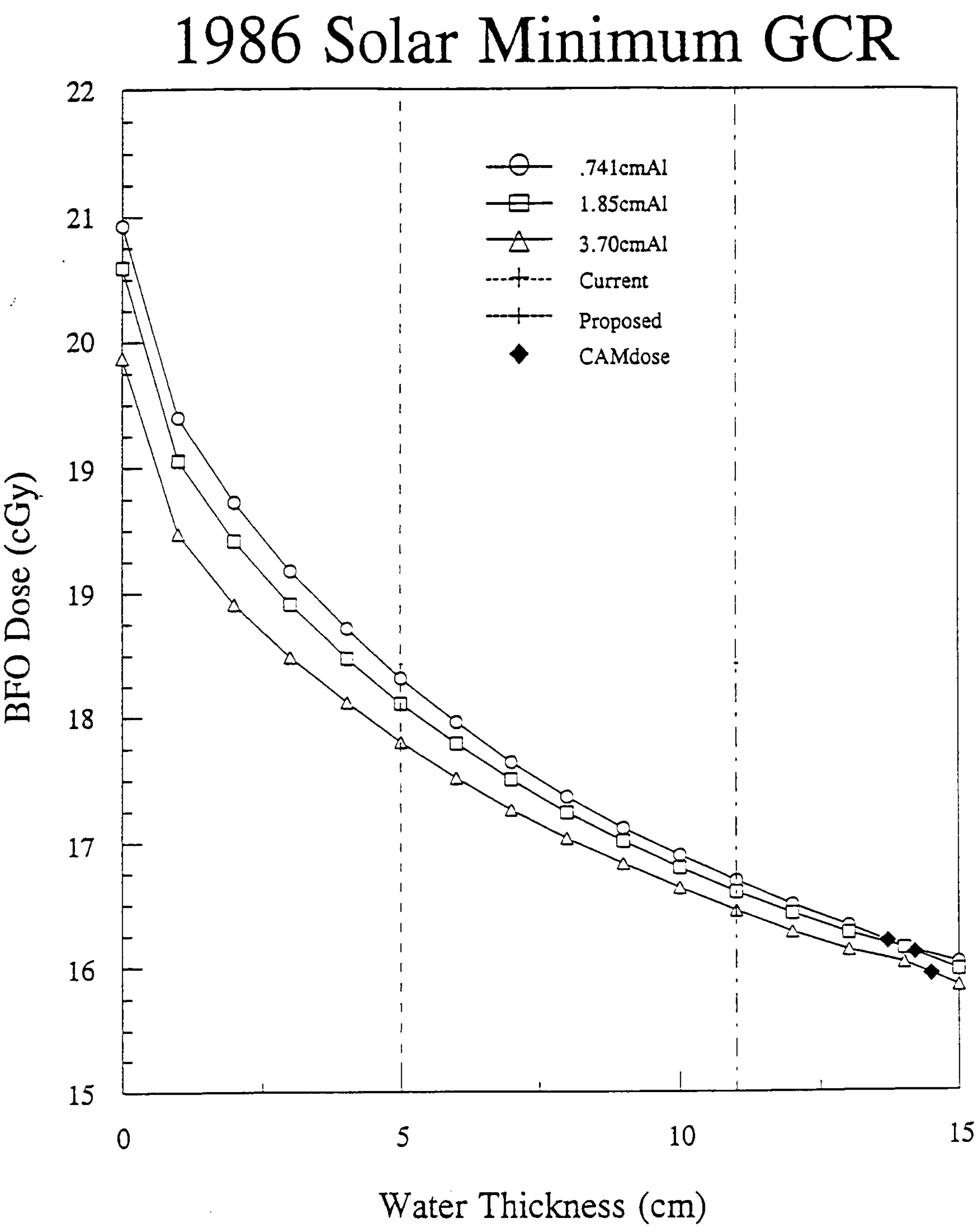

Figure 23. BFO Dose Versus Water Depth for 1986 Solar Minimum GCR

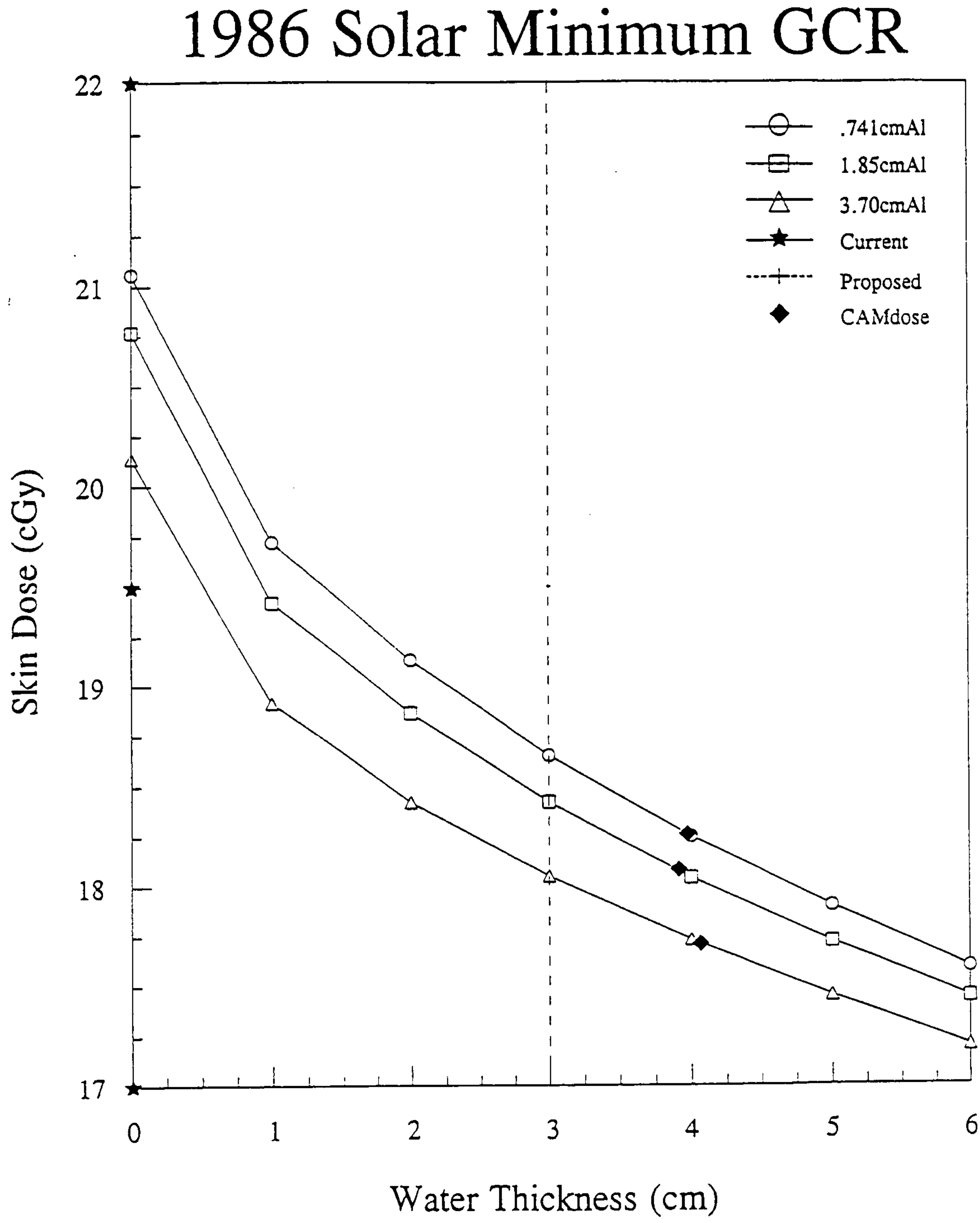

Figure 24. Skin Dose Versus Water Depth for 1986 Solar Minimum GCR

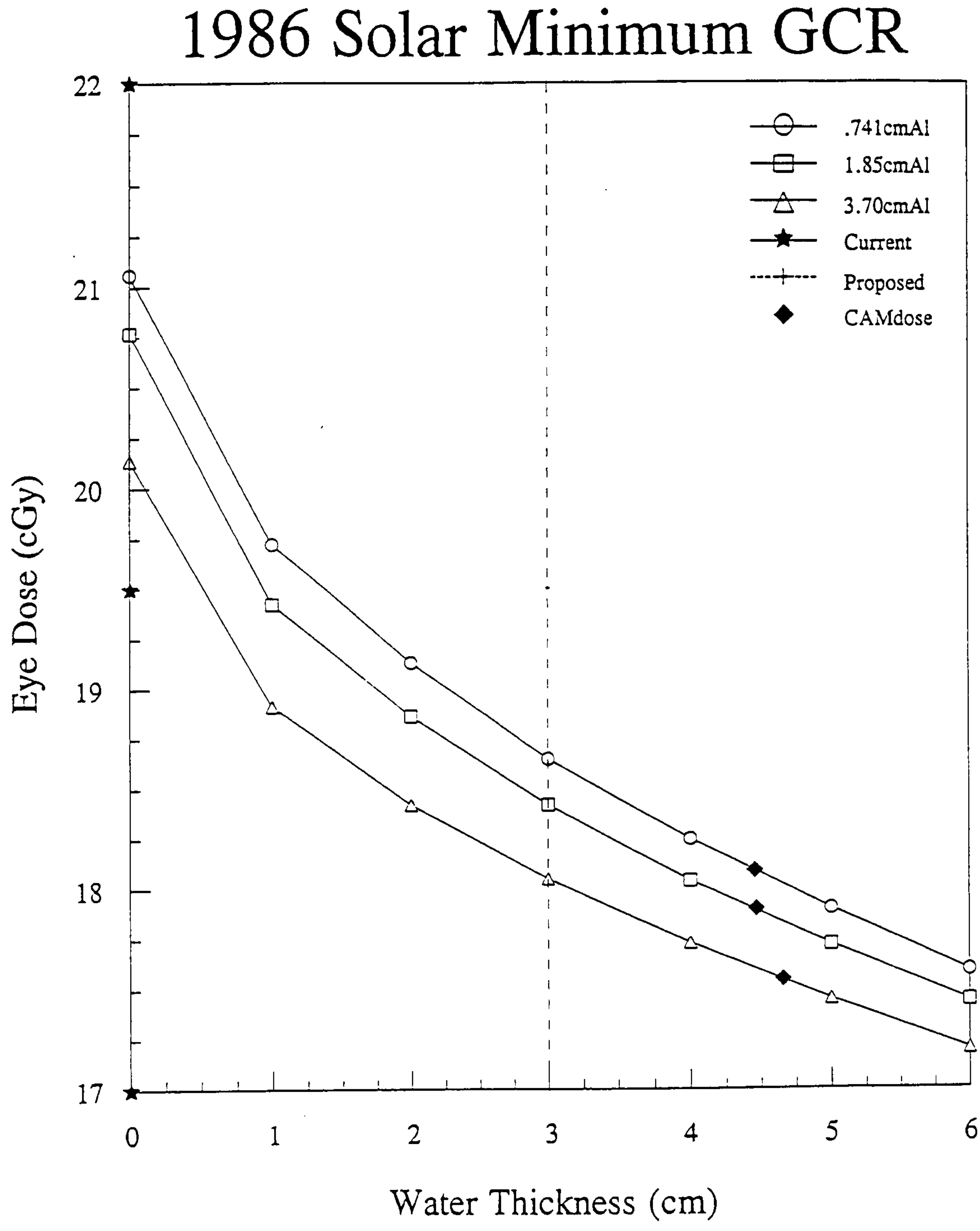

Figure 25. Eye Dose Versus Water Depth for 1986 Solar Minimum GCR

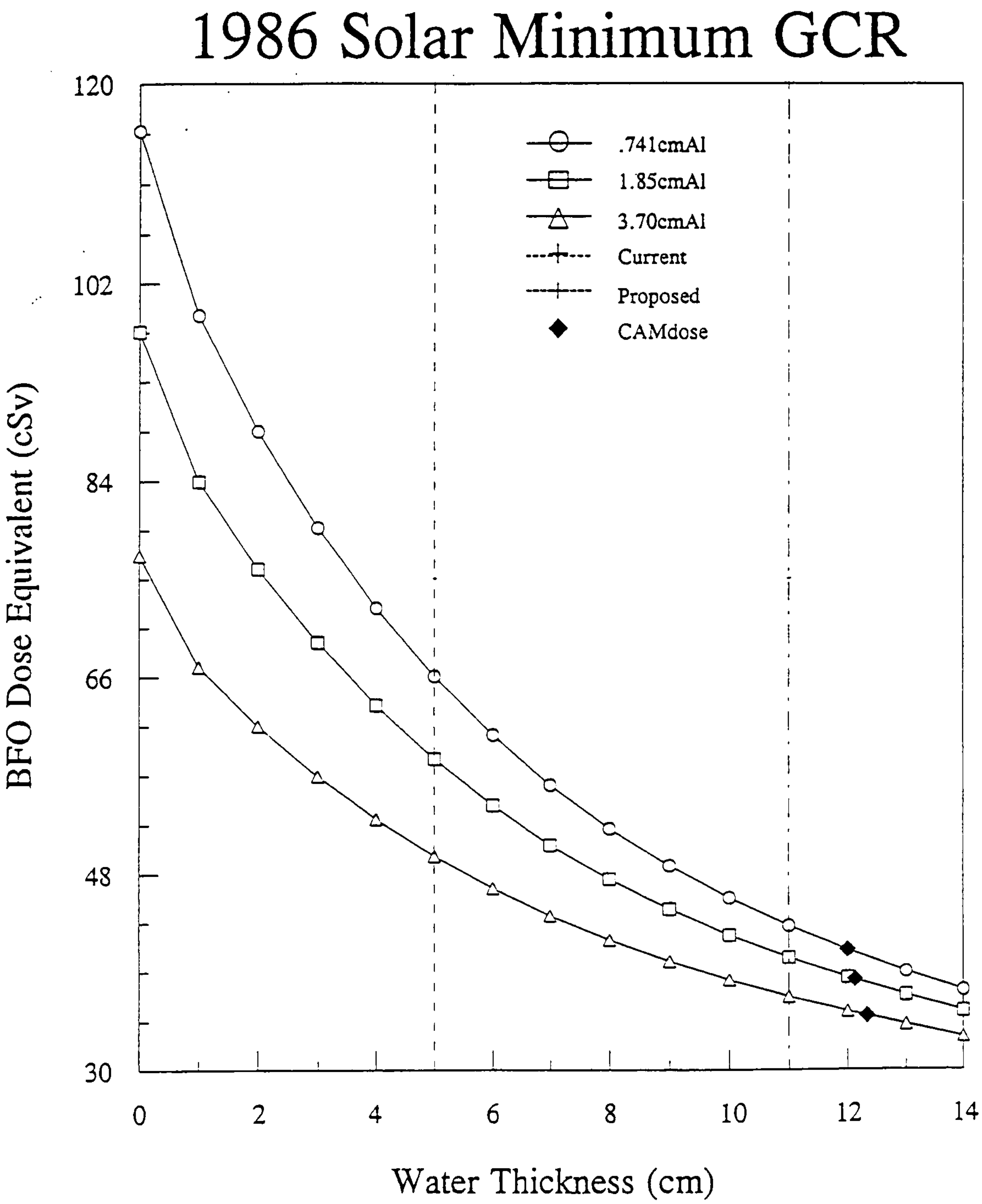

Figure 26. BFO Dose Equivalent Versus Water Depth for 1986 Solar Minimum GCR

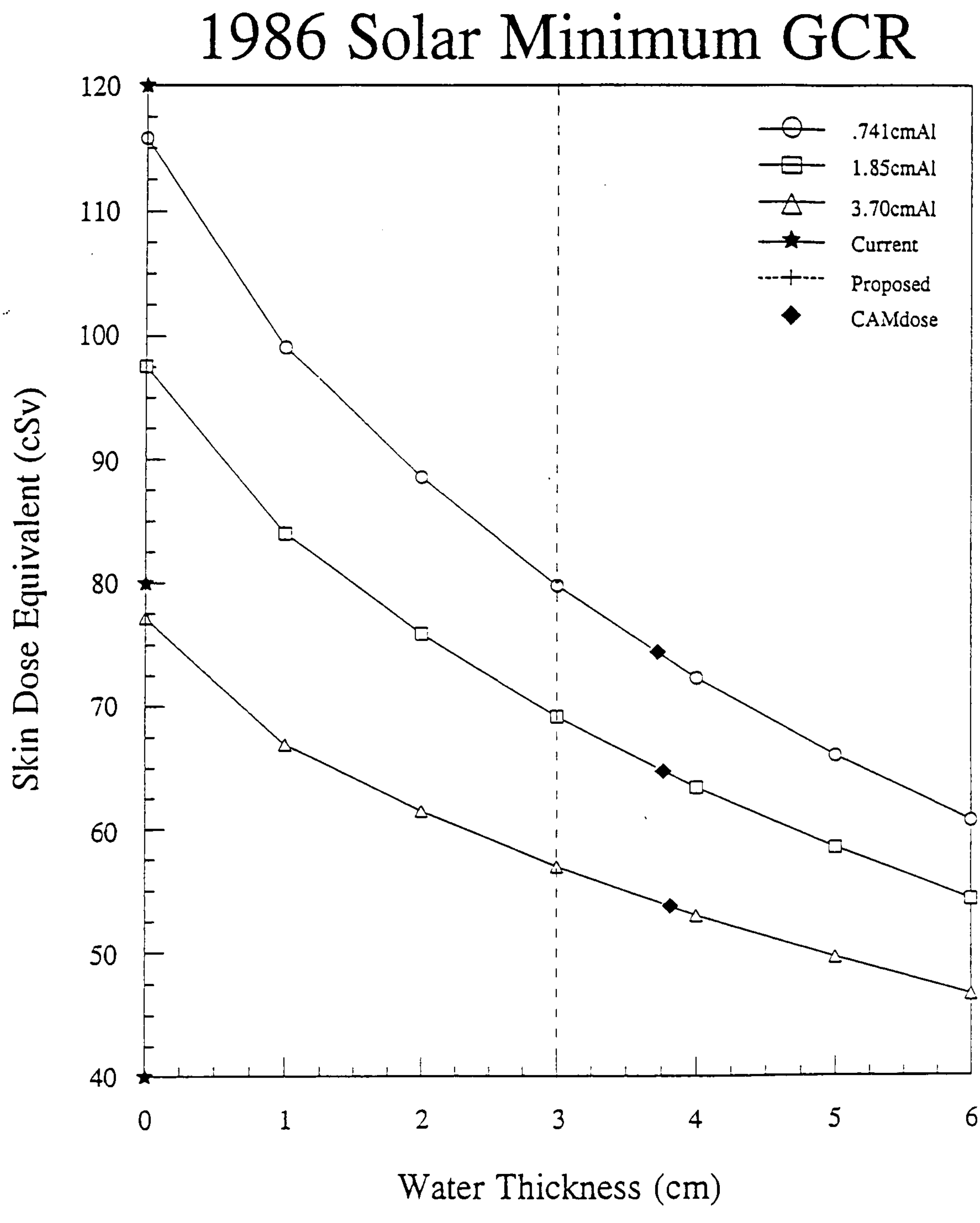

Figure 27. Skin Dose Equivalent Versus Water Depth for 1986 Solar Minimum GCR

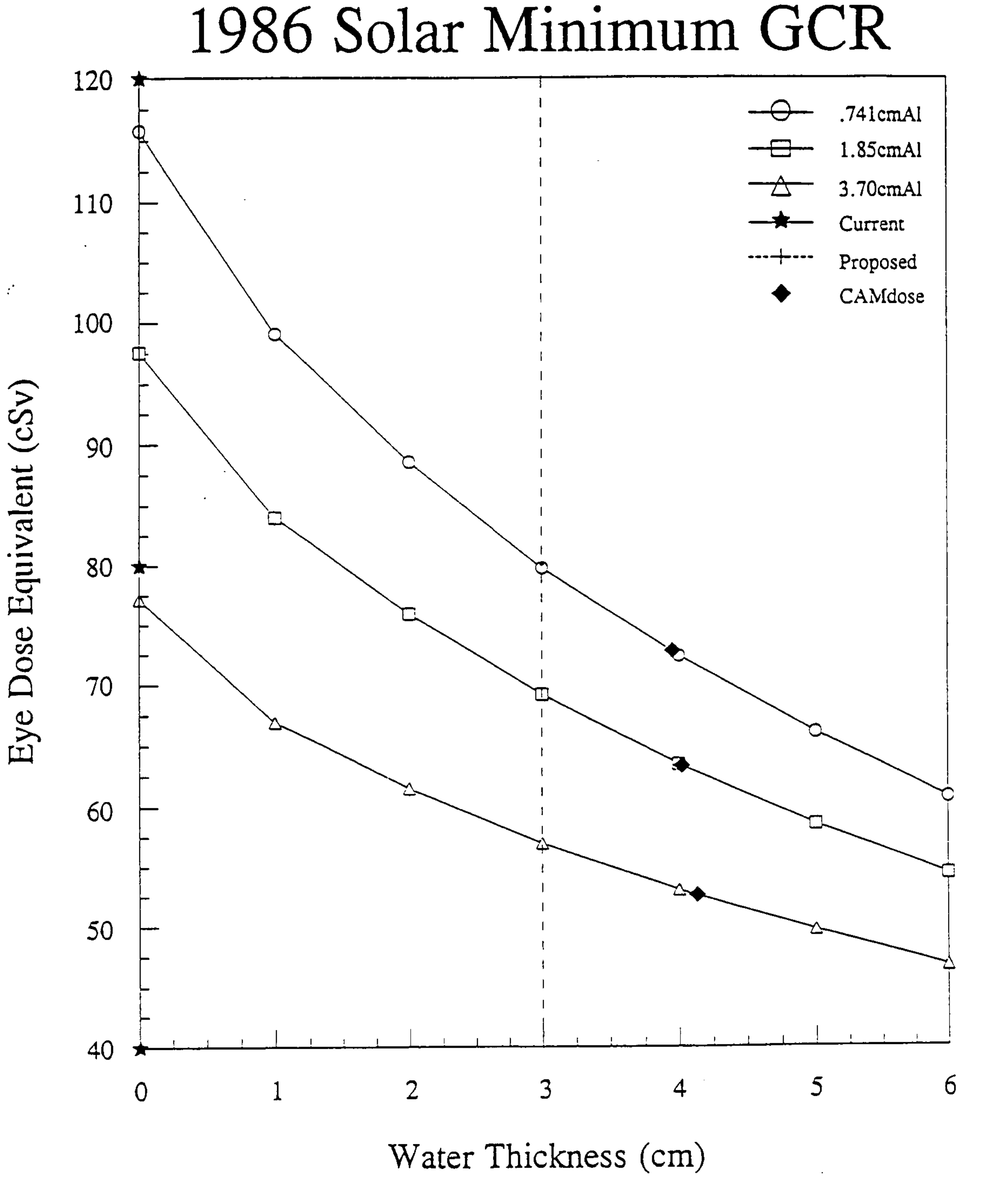

Figure 28. Eye Dose Equivalent Versus Water Depth for 1986 Solar Minimum GCR

equivalent sphere radius is at 3 cm of water. The revised approximations for this GCR data are all conservative and far more accurate than the 0 cm and 5 cm radius equivalent sphere approximations as evidenced in Tables 7 - 9 which show the percent differences from the old approximations to the CAM values and percent difference from the new approximation to the CAM values. It is also important to note that HZETRN provides more information than that used in this study. Values of dose, dose equivalent, and LET versus water thickness for each iteration can be utilized from the HZETRN output.

The shape of these curves is governed by the way particles interact with the aluminum shield material and the slab of water. Through the first few centimeters of water, a dramatic decrease in the dose/dose equivalent is seen (note the vertical scale is logarithmic for SPE spectra). Low energy particles are removed very effectively in these first few centimeters. Also, the probability of fragment production from high energy particles is low due to the small amount of material traversed. As more and more material is traversed, the curve begins to flatten out. Again the cause is twofold. First the particles of highest energy in the spectrum are still not being significantly attenuated. Second, the probability that a fragmentation event from these high energy particles will occur increases with material thickness. These last two effects are also demonstrated by the convergence of the three curves after traversing large amounts of material. This effect is noted in GCR data also, but a much "flatter" curve is found because this radiation has many high energy particles which traverse the shield with little or no attenuation.

Table 7. GCR Percent Differences for BFO Dose/Dose Equivalent

	1970 - 1971 Solar Maximum			1977 Solar Minimum			1986 - 1987 Solar Minimum			1989 Solar Maximum		
Aluminum Thickness (g/cm^2)	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**
5 cm Dose (cGy)	6	6	6	18	18	17	18	18	17	5	5	5
11 cm Dose (cGy)	6	6	6	16	16	16	16	16	16	4	4	4
CAM Dose (cGy)	6	6	6	16	16	16	16	16	16	4	4	4
% Difference: 5 cm to CAM	9	9	9	11	11	10	11	11	10	9	9	9
% Difference: 11 cm to CAM	2	2	2	3	3	3	3	3	3	2	2	2
5 cm Dose Equivalent (cSv)	24	22	19	66	58	50	66	58	50	19	17	15
11 cm Dose Equivalent (cSv)	16	16	14	43	40	37	43	40	37	13	12	11
CAM Dose Equivalent (cSv)	15	15	14	41	38	35	41	38	35	12	11	10
% Difference: 5 cm to CAM	58	52	43	61	53	42	61	53	42	57	51	43
% Difference: 11 cm to CAM	6	6	5	5	5	5	5	5	5	7	6	5

Table 8. GCR Percent Differences for Skin Dose/Dose Equivalent

	1970 - 1971 Solar Maximum			1977 Solar Minimum			1986 - 1987 Solar Minimum			1989 Solar Maximum		
Aluminum Thickness (g/cm^2)	2	5	10	2	5	10	2	5	10	2	5	10
0 cm Dose (cGy)	7	7	7	21	21	20	21	21	20	5	6	6
3 cm Dose (cGy)	6	6	6	19	18	18	19	18	18	5	5	5
CAM Dose (cGy)	6	6	6	18	18	18	18	18	18	5	5	5
% Difference: 0 cm to CAM	13	14	13	15	15	14	15	15	14	12	14	14
% Difference: 3 cm to CAM	1	1	1	2	2	2	2	2	2	1	1	1
0 cm Dose Equivalent (cSv)	39	35	30	115	98	77	115	98	77	30	27	23
3 cm Dose Equivalent (cSv)	28	26	22	80	69	57	80	69	57	22	20	17
CAM Dose Equivalent (cSv)	26	24	20	74	65	54	74	65	54	20	18	16
% Difference: 0 cm to CAM	50	48	46	56	51	44	56	51	44	49	47	42
% Difference: 3 cm to CAM	10	8	9	7	7	6	7	7	6	11	9	7

Table 9. GCR Percent Differences for Eye Dose/Dose Equivalent

	1970 - 1971 Solar Maximum			1977 Solar Minimum			1986 - 1987 Solar Minimum			1989 Solar Maximum		
Aluminum Thickness (g/cm^2)	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**	**2**	**5**	**10**
0 cm Dose (cGy)	7	7	7	21	21	20	21	21	20	5	6	6
3 cm Dose (cGy)	6	6	6	19	18	18	19	18	18	5	5	5
CAM Dose (cGy)	6	6	6	18	18	18	18	18	18	5	5	5
% Difference: 0 cm to CAM	14	15	15	16	16	15	16	16	15	14	15	15
% Difference: 3 cm to CAM	2	2	2	3	3	3	3	3	3	2	2	2
0 cm Dose Equivalent (cSv)	39	35	30	115	98	77	115	98	77	30	27	23
3 cm Dose Equivalent (cSv)	28	26	22	80	69	57	80	69	57	22	20	17
CAM Dose Equivalent (cSv)	26	23	20	73	63	53	73	63	53	20	18	16
% Difference: 0 cm to CAM	52	50	46	59	54	47	59	54	47	51	49	45
% Difference: 3 cm to CAM	11	10	9	10	9	8	10	9	8	13	10	9

VI. Recommendations for Future Work

Radiation Dose Limits for Interplanetary Missions

At present, no dose limits exist for missions outside the earth's magnetosphere. It is clear from other studies that if the limits for near-earth orbit are used, such a mission might not be possible. The weight of the spacecraft would be too heavy for present propulsion schemes, or, if shielding configurations for near-earth orbit spacecraft were used, the recommended dose limits would be far exceeded before the spacecraft reached Mars. Dose limits for deep space missions must be established before any other detailed planning can occur. Once these limits exist, criteria for spacecraft design can be implemented. Such criteria would be based on simple models, such as the one in this study.

Need for More Reliable Solar Particle Event Prediction Capability

As noted by Smart and Shea[7] there is no reliable way to predict solar particle events because they can occur at any time during the solar cycle. Also, even after the detection of the onset of an event, there is no reliable way to predict the size or duration of the event. Through ongoing study of the solar cycle, such predictions may become possible. In addition, onboard detection equipment capable of distinguishing between solar particles and particles of different origin would benefit the crew by giving early warning of an event.

Need for Additional Work to Complete the Proposed Equivalent Sphere Model

While much work was performed in this study obtaining the proposed 9-cm radius equivalent sphere model, much more work would be required before it could be accepted as a standard model. LET distributions in the CAM and the equivalent sphere models need to be examined. To be used for preliminary design studies, a revision of the models for all the critical organs would be necessary. NASA also has a Computerized Anatomical Female(CAF) model, that would need to be used in a similar type of study to ensure the results of this study are appropriate. Finally, if some new spacecraft material were used, or the thickness of aluminum shield was significantly changed, the proposed model would have to be tested to reflect those changes.

VII. Conclusion

If interplanetary missions are going to be planned, hazards to the crew from all sources must be evaluated to determine that the benefit gained by the mission offsets the risk taken by the crew. Solar particle events are one example of the overall space radiation hazard that the crew might face. Since these events cannot be predicted, planning must be based on past events with additional safeguards for the theoretical worst case event. The use of simple models, such as tissue-equivalent spheres, speeds up the preliminary design process by giving criteria necessary for the spacecraft to meet certain guidelines. Therefore it is important that these models be as accurate as possible while still retaining their speed and ease of use. In this study we demonstrated the need for revision of the 5 cm sphere model used for BFO dose. The differences found between the dose given by that model and a detailed body geometry model could result in significant shield weight penalty in the preliminary design stage. The use of our proposed 9 cm model would still be significantly faster than a detailed body geometry study even with the speed of today's computers. It was shown to be much closer to the actual dose values yet still conservative in every case tested.

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APPENDIX

The following pages provide data from the BRYNTRN computer code required to do any further study of the solar particle events presented in this thesis. This information is included because of the excessive amount of time that would be required to repeat the calculations. If any questions arise in regard to interpretation of this data, please refer to reference 4 or feel free to contact the author.

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.192E+03	0.602E-03	0.304E+01	0.505E-01	0.195E+03
1.00	0.000E+00	0.113E+03	0.781E-03	0.319E+01	0.435E-01	0.116E+03
2.00	0.000E+00	0.787E+02	0.940E-03	0.328E+01	0.394E-01	0.821E+02
3.00	0.000E+00	0.601E+02	0.108E-02	0.327E+01	0.366E-01	0.634E+02
4.00	0.000E+00	0.488E+02	0.122E-02	0.324E+01	0.345E-01	0.521E+02
5.00	0.000E+00	0.415E+02	0.134E-02	0.320E+01	0.329E-01	0.448E+02
6.00	0.000E+00	0.365E+02	0.146E-02	0.316E+01	0.316E-01	0.397E+02
7.00	0.000E+00	0.329E+02	0.156E-02	0.311E+01	0.305E-01	0.360E+02
8.00	0.000E+00	0.302E+02	0.167E-02	0.307E+01	0.296E-01	0.333E+02
9.00	0.000E+00	0.281E+02	0.176E-02	0.303E+01	0.287E-01	0.312E+02
10.00	0.000E+00	0.265E+02	0.185E-02	0.298E+01	0.280E-01	0.295E+02
11.00	0.000E+00	0.251E+02	0.194E-02	0.294E+01	0.272E-01	0.281E+02
12.00	0.000E+00	0.240E+02	0.202E-02	0.290E+01	0.266E-01	0.269E+02
13.00	0.000E+00	0.230E+02	0.210E-02	0.286E+01	0.260E-01	0.259E+02
14.00	0.000E+00	0.222E+02	0.217E-02	0.282E+01	0.254E-01	0.250E+02

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.277E+03	0.127E-01	0.304E+02	0.998E+00	0.309E+03
1.00	0.000E+00	0.143E+03	0.164E-01	0.199E+02	0.850E+00	0.164E+03
2.00	0.000E+00	0.969E+02	0.197E-01	0.185E+02	0.762E+00	0.116E+03
3.00	0.000E+00	0.721E+02	0.226E-01	0.175E+02	0.704E+00	0.903E+02
4.00	0.000E+00	0.574E+02	0.253E-01	0.168E+02	0.661E+00	0.749E+02
5.00	0.000E+00	0.480E+02	0.279E-01	0.162E+02	0.628E+00	0.649E+02
6.00	0.000E+00	0.417E+02	0.302E-01	0.157E+02	0.602E+00	0.581E+02
7.00	0.000E+00	0.372E+02	0.324E-01	0.153E+02	0.579E+00	0.532E+02
8.00	0.000E+00	0.339E+02	0.345E-01	0.150E+02	0.560E+00	0.495E+02
9.00	0.000E+00	0.314E+02	0.365E-01	0.147E+02	0.543E+00	0.467E+02
10.00	0.000E+00	0.294E+02	0.383E-01	0.144E+02	0.528E+00	0.444E+02
11.00	0.000E+00	0.278E+02	0.401E-01	0.141E+02	0.514E+00	0.425E+02
12.00	0.000E+00	0.265E+02	0.417E-01	0.139E+02	0.501E+00	0.409E+02
13.00	0.000E+00	0.254E+02	0.433E-01	0.137E+02	0.489E+00	0.396E+02
14.00	0.000E+00	0.244E+02	0.447E-01	0.135E+02	0.478E+00	0.384E+02

A1. February 1956 SPE with 2 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.7817E+09	0.1074E+08	0.2665E+08	0.1958E+07
1.00	0.0000E+00	0.5789E+09	0.1435E+08	0.2927E+08	0.3276E+07
2.00	0.0000E+00	0.4733E+09	0.1724E+08	0.3135E+08	0.3819E+07
3.00	0.0000E+00	0.4083E+09	0.1972E+08	0.3312E+08	0.4108E+07
4.00	0.0000E+00	0.3646E+09	0.2195E+08	0.3468E+08	0.4280E+07
5.00	0.0000E+00	0.3330E+09	0.2398E+08	0.3610E+08	0.4388E+07
6.00	0.0000E+00	0.3090E+09	0.2584E+08	0.3740E+08	0.4455E+07
7.00	0.0000E+00	0.2899E+09	0.2755E+08	0.3861E+08	0.4494E+07
8.00	0.0000E+00	0.2742E+09	0.2913E+08	0.3973E+08	0.4513E+07
9.00	0.0000E+00	0.2609E+09	0.3059E+08	0.4078E+08	0.4518E+07
10.00	0.0000E+00	0.2494E+09	0.3193E+08	0.4175E+08	0.4510E+07
11.00	0.0000E+00	0.2392E+09	0.3316E+08	0.4266E+08	0.4494E+07
12.00	0.0000E+00	0.2300E+09	0.3430E+08	0.4351E+08	0.4470E+07
13.00	0.0000E+00	0.2217E+09	0.3534E+08	0.4431E+08	0.4441E+07
14.00	0.0000E+00	0.2140E+09	0.3630E+08	0.4504E+08	0.4407E+07

A1. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.742E+02	0.124E-02	0.244E+01	0.383E-01	0.767E+02
1.00	0.000E+00	0.563E+02	0.135E-02	0.282E+01	0.358E-01	0.591E+02
2.00	0.000E+00	0.463E+02	0.146E-02	0.298E+01	0.339E-01	0.493E+02
3.00	0.000E+00	0.397E+02	0.157E-02	0.303E+01	0.324E-01	0.428E+02
4.00	0.000E+00	0.352E+02	0.167E-02	0.304E+01	0.312E-01	0.383E+02
5.00	0.000E+00	0.319E+02	0.177E-02	0.302E+01	0.301E-01	0.350E+02
6.00	0.000E+00	0.294E+02	0.186E-02	0.300E+01	0.292E-01	0.325E+02
7.00	0.000E+00	0.275E+02	0.194E-02	0.297E+01	0.284E-01	0.305E+02
8.00	0.000E+00	0.259E+02	0.203E-02	0.294E+01	0.276E-01	0.289E+02
9.00	0.000E+00	0.247E+02	0.210E-02	0.290E+01	0.269E-01	0.276E+02
10.00	0.000E+00	0.236E+02	0.218E-02	0.287E+01	0.263E-01	0.265E+02
11.00	0.000E+00	0.227E+02	0.225E-02	0.283E+01	0.257E-01	0.255E+02
12.00	0.000E+00	0.219E+02	0.231E-02	0.279E+01	0.251E-01	0.247E+02
13.00	0.000E+00	0.211E+02	0.238E-02	0.276E+01	0.246E-01	0.239E+02
14.00	0.000E+00	0.205E+02	0.243E-02	0.272E+01	0.240E-01	0.232E+02

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.965E+02	0.259E-01	0.208E+02	0.740E+00	0.118E+03
1.00	0.000E+00	0.671E+02	0.282E-01	0.165E+02	0.687E+00	0.844E+02
2.00	0.000E+00	0.541E+02	0.305E-01	0.163E+02	0.648E+00	0.711E+02
3.00	0.000E+00	0.458E+02	0.327E-01	0.159E+02	0.617E+00	0.623E+02
4.00	0.000E+00	0.401E+02	0.347E-01	0.155E+02	0.592E+00	0.562E+02
5.00	0.000E+00	0.360E+02	0.367E-01	0.152E+02	0.571E+00	0.518E+02
6.00	0.000E+00	0.330E+02	0.385E-01	0.149E+02	0.553E+00	0.485E+02
7.00	0.000E+00	0.307E+02	0.403E-01	0.146E+02	0.536E+00	0.458E+02
8.00	0.000E+00	0.288E+02	0.419E-01	0.143E+02	0.522E+00	0.437E+02
9.00	0.000E+00	0.273E+02	0.435E-01	0.141E+02	0.508E+00	0.420E+02
10.00	0.000E+00	0.261E+02	0.450E-01	0.139E+02	0.496E+00	0.405E+02
11.00	0.000E+00	0.250E+02	0.464E-01	0.136E+02	0.484E+00	0.392E+02
12.00	0.000E+00	0.241E+02	0.477E-01	0.134E+02	0.473E+00	0.380E+02
13.00	0.000E+00	0.233E+02	0.489E-01	0.132E+02	0.462E+00	0.370E+02
14.00	0.000E+00	0.225E+02	0.501E-01	0.130E+02	0.452E+00	0.360E+02

A2. February 1956 SPE with 5 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.4525E+09	0.1750E+08	0.4700E+08	0.2126E+07
1.00	0.0000E+00	0.3931E+09	0.1985E+08	0.4580E+08	0.3201E+07
2.00	0.0000E+00	0.3534E+09	0.2205E+08	0.4528E+08	0.3692E+07
3.00	0.0000E+00	0.3244E+09	0.2403E+08	0.4514E+08	0.3969E+07
4.00	0.0000E+00	0.3021E+09	0.2585E+08	0.4523E+08	0.4138E+07
5.00	0.0000E+00	0.2843E+09	0.2752E+08	0.4547E+08	0.4245E+07
6.00	0.0000E+00	0.2694E+09	0.2906E+08	0.4580E+08	0.4311E+07
7.00	0.0000E+00	0.2567E+09	0.3047E+08	0.4620E+08	0.4349E+07
8.00	0.0000E+00	0.2457E+09	0.3178E+08	0.4663E+08	0.4367E+07
9.00	0.0000E+00	0.2358E+09	0.3298E+08	0.4708E+08	0.4370E+07
10.00	0.0000E+00	0.2270E+09	0.3408E+08	0.4753E+08	0.4362E+07
11.00	0.0000E+00	0.2189E+09	0.3510E+08	0.4798E+08	0.4346E+07
12.00	0.0000E+00	0.2114E+09	0.3603E+08	0.4842E+08	0.4322E+07
13.00	0.0000E+00	0.2044E+09	0.3689E+08	0.4884E+08	0.4292E+07
14.00	0.0000E+00	0.1979E+09	0.3767E+08	0.4924E+08	0.4259E+07

A2. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.365E+02	0.203E-02	0.209E+01	0.312E-01	0.387E+02
1.00	0.000E+00	0.324E+02	0.209E-02	0.253E+01	0.301E-01	0.349E+02
2.00	0.000E+00	0.297E+02	0.215E-02	0.271E+01	0.291E-01	0.325E+02
3.00	0.000E+00	0.277E+02	0.222E-02	0.278E+01	0.283E-01	0.305E+02
4.00	0.000E+00	0.261E+02	0.228E-02	0.281E+01	0.276E-01	0.289E+02
5.00	0.000E+00	0.248E+02	0.235E-02	0.281E+01	0.269E-01	0.276E+02
6.00	0.000E+00	0.237E+02	0.241E-02	0.280E+01	0.262E-01	0.265E+02
7.00	0.000E+00	0.227E+02	0.246E-02	0.278E+01	0.256E-01	0.255E+02
8.00	0.000E+00	0.219E+02	0.252E-02	0.275E+01	0.250E-01	0.247E+02
9.00	0.000E+00	0.212E+02	0.257E-02	0.272E+01	0.245E-01	0.239E+02
10.00	0.000E+00	0.205E+02	0.262E-02	0.269E+01	0.240E-01	0.232E+02
11.00	0.000E+00	0.199E+02	0.267E-02	0.266E+01	0.234E-01	0.226E+02
12.00	0.000E+00	0.194E+02	0.272E-02	0.263E+01	0.230E-01	0.220E+02
13.00	0.000E+00	0.189E+02	0.276E-02	0.259E+01	0.225E-01	0.215E+02
14.00	0.000E+00	0.184E+02	0.280E-02	0.256E+01	0.220E-01	0.210E+02

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.439E+02	0.423E-01	0.165E+02	0.592E+00	0.610E+02
1.00	0.000E+00	0.367E+02	0.434E-01	0.145E+02	0.570E+00	0.517E+02
2.00	0.000E+00	0.334E+02	0.447E-01	0.146E+02	0.552E+00	0.486E+02
3.00	0.000E+00	0.309E+02	0.460E-01	0.144E+02	0.535E+00	0.460E+02
4.00	0.000E+00	0.290E+02	0.473E-01	0.143E+02	0.520E+00	0.439E+02
5.00	0.000E+00	0.275E+02	0.486E-01	0.141E+02	0.507E+00	0.421E+02
6.00	0.000E+00	0.262E+02	0.498E-01	0.139E+02	0.494E+00	0.406E+02
7.00	0.000E+00	0.251E+02	0.509E-01	0.137E+02	0.482E+00	0.393E+02
8.00	0.000E+00	0.241E+02	0.520E-01	0.135E+02	0.471E+00	0.381E+02
9.00	0.000E+00	0.233E+02	0.531E-01	0.133E+02	0.461E+00	0.371E+02
10.00	0.000E+00	0.225E+02	0.541E-01	0.131E+02	0.451E+00	0.361E+02
11.00	0.000E+00	0.219E+02	0.550E-01	0.129E+02	0.441E+00	0.353E+02
12.00	0.000E+00	0.213E+02	0.559E-01	0.127E+02	0.432E+00	0.344E+02
13.00	0.000E+00	0.207E+02	0.567E-01	0.125E+02	0.423E+00	0.337E+02
14.00	0.000E+00	0.202E+02	0.575E-01	0.123E+02	0.414E+00	0.330E+02

A3. February 1956 SPE with 10 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.3054E+09	0.2491E+08	0.6741E+08	0.2144E+07
1.00	0.0000E+00	0.2863E+09	0.2644E+08	0.6346E+08	0.3077E+07
2.00	0.0000E+00	0.2709E+09	0.2799E+08	0.6082E+08	0.3519E+07
3.00	0.0000E+00	0.2579E+09	0.2941E+08	0.5899E+08	0.3772E+07
4.00	0.0000E+00	0.2466E+09	0.3073E+08	0.5768E+08	0.3928E+07
5.00	0.0000E+00	0.2366E+09	0.3194E+08	0.5674E+08	0.4025E+07
6.00	0.0000E+00	0.2276E+09	0.3305E+08	0.5606E+08	0.4085E+07
7.00	0.0000E+00	0.2194E+09	0.3407E+08	0.5558E+08	0.4118E+07
8.00	0.0000E+00	0.2119E+09	0.3501E+08	0.5523E+08	0.4133E+07
9.00	0.0000E+00	0.2049E+09	0.3587E+08	0.5499E+08	0.4133E+07
10.00	0.0000E+00	0.1984E+09	0.3667E+08	0.5483E+08	0.4124E+07
11.00	0.0000E+00	0.1922E+09	0.3739E+08	0.5473E+08	0.4106E+07
12.00	0.0000E+00	0.1864E+09	0.3805E+08	0.5466E+08	0.4082E+07
13.00	0.0000E+00	0.1809E+09	0.3866E+08	0.5462E+08	0.4053E+07
14.00	0.0000E+00	0.1756E+09	0.3920E+08	0.5460E+08	0.4019E+07

A3. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.462E+03	0.877E-03	0.435E+01	0.655E-01	0.466E+03
1.00	0.000E+00	0.209E+03	0.996E-03	0.360E+01	0.497E-01	0.213E+03
2.00	0.000E+00	0.134E+03	0.109E-02	0.340E+01	0.417E-01	0.138E+03
3.00	0.000E+00	0.101E+03	0.116E-02	0.318E+01	0.365E-01	0.104E+03
4.00	0.000E+00	0.817E+02	0.122E-02	0.297E+01	0.325E-01	0.847E+02
5.00	0.000E+00	0.691E+02	0.127E-02	0.276E+01	0.294E-01	0.719E+02
6.00	0.000E+00	0.600E+02	0.132E-02	0.257E+01	0.267E-01	0.626E+02
7.00	0.000E+00	0.529E+02	0.135E-02	0.240E+01	0.244E-01	0.553E+02
8.00	0.000E+00	0.471E+02	0.138E-02	0.224E+01	0.224E-01	0.493E+02
9.00	0.000E+00	0.423E+02	0.140E-02	0.209E+01	0.206E-01	0.444E+02
10.00	0.000E+00	0.382E+02	0.142E-02	0.195E+01	0.190E-01	0.402E+02
11.00	0.000E+00	0.347E+02	0.143E-02	0.183E+01	0.176E-01	0.365E+02
12.00	0.000E+00	0.316E+02	0.143E-02	0.171E+01	0.163E-01	0.333E+02
13.00	0.000E+00	0.289E+02	0.144E-02	0.160E+01	0.151E-01	0.305E+02
14.00	0.000E+00	0.265E+02	0.144E-02	0.150E+01	0.140E-01	0.280E+02

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.729E+03	0.189E-01	0.469E+02	0.138E+01	0.777E+03
1.00	0.000E+00	0.275E+03	0.215E-01	0.231E+02	0.104E+01	0.299E+03
2.00	0.000E+00	0.167E+03	0.234E-01	0.196E+02	0.870E+00	0.188E+03
3.00	0.000E+00	0.121E+03	0.250E-01	0.174E+02	0.759E+00	0.139E+03
4.00	0.000E+00	0.963E+02	0.263E-01	0.157E+02	0.676E+00	0.113E+03
5.00	0.000E+00	0.806E+02	0.273E-01	0.143E+02	0.609E+00	0.955E+02
6.00	0.000E+00	0.694E+02	0.282E-01	0.132E+02	0.553E+00	0.831E+02
7.00	0.000E+00	0.608E+02	0.289E-01	0.122E+02	0.505E+00	0.735E+02
8.00	0.000E+00	0.540E+02	0.295E-01	0.113E+02	0.462E+00	0.657E+02
9.00	0.000E+00	0.483E+02	0.299E-01	0.105E+02	0.425E+00	0.593E+02
10.00	0.000E+00	0.436E+02	0.302E-01	0.977E+01	0.392E+00	0.537E+02
11.00	0.000E+00	0.395E+02	0.304E-01	0.912E+01	0.362E+00	0.490E+02
12.00	0.000E+00	0.359E+02	0.306E-01	0.854E+01	0.335E+00	0.448E+02
13.00	0.000E+00	0.328E+02	0.307E-01	0.801E+01	0.311E+00	0.411E+02
14.00	0.000E+00	0.300E+02	0.307E-01	0.752E+01	0.289E+00	0.379E+02

A4. November 1960 SPE with 2 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.1389E+10	0.1222E+08	0.6308E+08	0.2532E+07
1.00	0.0000E+00	0.8571E+09	0.1471E+08	0.6049E+08	0.3601E+07
2.00	0.0000E+00	0.6497E+09	0.1623E+08	0.5782E+08	0.3846E+07
3.00	0.0000E+00	0.5356E+09	0.1720E+08	0.5546E+08	0.3847E+07
4.00	0.0000E+00	0.4598E+09	0.1784E+08	0.5339E+08	0.3743E+07
5.00	0.0000E+00	0.4035E+09	0.1818E+08	0.5155E+08	0.3589E+07
6.00	0.0000E+00	0.3588E+09	0.1831E+08	0.4991E+08	0.3415E+07
7.00	0.0000E+00	0.3219E+09	0.1828E+08	0.4840E+08	0.3234E+07
8.00	0.0000E+00	0.2907E+09	0.1812E+08	0.4701E+08	0.3055E+07
9.00	0.0000E+00	0.2637E+09	0.1787E+08	0.4570E+08	0.2881E+07
10.00	0.0000E+00	0.2402E+09	0.1755E+08	0.4447E+08	0.2715E+07
11.00	0.0000E+00	0.2195E+09	0.1718E+08	0.4329E+08	0.2558E+07
12.00	0.0000E+00	0.2012E+09	0.1677E+08	0.4215E+08	0.2409E+07
13.00	0.0000E+00	0.1848E+09	0.1634E+08	0.4106E+08	0.2269E+07
14.00	0.0000E+00	0.1701E+09	0.1589E+08	0.4000E+08	0.2137E+07

A4. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.125E+03	0.138E-02	0.256E+01	0.398E-01	0.128E+03
1.00	0.000E+00	0.941E+02	0.141E-02	0.270E+01	0.350E-01	0.968E+02
2.00	0.000E+00	0.772E+02	0.144E-02	0.269E+01	0.314E-01	0.800E+02
3.00	0.000E+00	0.658E+02	0.146E-02	0.258E+01	0.284E-01	0.685E+02
4.00	0.000E+00	0.574E+02	0.148E-02	0.244E+01	0.258E-01	0.599E+02
5.00	0.000E+00	0.508E+02	0.150E-02	0.230E+01	0.236E-01	0.531E+02
6.00	0.000E+00	0.453E+02	0.152E-02	0.216E+01	0.217E-01	0.475E+02
7.00	0.000E+00	0.408E+02	0.153E-02	0.202E+01	0.200E-01	0.428E+02
8.00	0.000E+00	0.369E+02	0.153E-02	0.189E+01	0.184E-01	0.388E+02
9.00	0.000E+00	0.335E+02	0.153E-02	0.178E+01	0.170E-01	0.353E+02
10.00	0.000E+00	0.306E+02	0.153E-02	0.167E+01	0.158E-01	0.322E+02
11.00	0.000E+00	0.280E+02	0.153E-02	0.156E+01	0.147E-01	0.295E+02
12.00	0.000E+00	0.257E+02	0.152E-02	0.147E+01	0.136E-01	0.271E+02
13.00	0.000E+00	0.236E+02	0.152E-02	0.138E+01	0.127E-01	0.250E+02
14.00	0.000E+00	0.218E+02	0.151E-02	0.130E+01	0.118E-01	0.231E+02

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.164E+03	0.297E-01	0.233E+02	0.830E+00	0.188E+03
1.00	0.000E+00	0.113E+03	0.303E-01	0.161E+02	0.728E+00	0.129E+03
2.00	0.000E+00	0.908E+02	0.308E-01	0.150E+02	0.651E+00	0.106E+03
3.00	0.000E+00	0.766E+02	0.314E-01	0.138E+02	0.588E+00	0.910E+02
4.00	0.000E+00	0.663E+02	0.318E-01	0.128E+02	0.535E+00	0.796E+02
5.00	0.000E+00	0.584E+02	0.322E-01	0.118E+02	0.488E+00	0.707E+02
6.00	0.000E+00	0.519E+02	0.324E-01	0.110E+02	0.448E+00	0.634E+02
7.00	0.000E+00	0.466E+02	0.326E-01	0.103E+02	0.412E+00	0.573E+02
8.00	0.000E+00	0.420E+02	0.327E-01	0.957E+01	0.380E+00	0.520E+02
9.00	0.000E+00	0.381E+02	0.328E-01	0.895E+01	0.352E+00	0.475E+02
10.00	0.000E+00	0.347E+02	0.327E-01	0.839E+01	0.326E+00	0.435E+02
11.00	0.000E+00	0.317E+02	0.326E-01	0.787E+01	0.302E+00	0.399E+02
12.00	0.000E+00	0.291E+02	0.325E-01	0.740E+01	0.281E+00	0.368E+02
13.00	0.000E+00	0.267E+02	0.323E-01	0.696E+01	0.261E+00	0.340E+02
14.00	0.000E+00	0.246E+02	0.321E-01	0.656E+01	0.243E+00	0.315E+02

A5. November 1960 SPE with 5 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.6126E+09	0.1523E+08	0.8281E+08	0.2144E+07
1.00	0.0000E+00	0.5093E+09	0.1649E+08	0.7472E+08	0.3022E+07
2.00	0.0000E+00	0.4400E+09	0.1725E+08	0.6876E+08	0.3245E+07
3.00	0.0000E+00	0.3876E+09	0.1764E+08	0.6411E+08	0.3254E+07
4.00	0.0000E+00	0.3456E+09	0.1781E+08	0.6033E+08	0.3171E+07
5.00	0.0000E+00	0.3106E+09	0.1780E+08	0.5717E+08	0.3046E+07
6.00	0.0000E+00	0.2809E+09	0.1766E+08	0.5446E+08	0.2903E+07
7.00	0.0000E+00	0.2551E+09	0.1743E+08	0.5209E+08	0.2755E+07
8.00	0.0000E+00	0.2326E+09	0.1712E+08	0.4998E+08	0.2608E+07
9.00	0.0000E+00	0.2127E+09	0.1676E+08	0.4808E+08	0.2465E+07
10.00	0.0000E+00	0.1951E+09	0.1637E+08	0.4634E+08	0.2328E+07
11.00	0.0000E+00	0.1793E+09	0.1595E+08	0.4475E+08	0.2198E+07
12.00	0.0000E+00	0.1651E+09	0.1550E+08	0.4326E+08	0.2074E+07
13.00	0.0000E+00	0.1523E+09	0.1505E+08	0.4187E+08	0.1958E+07
14.00	0.0000E+00	0.1408E+09	0.1460E+08	0.4056E+08	0.1848E+07

A5. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.594E+02	0.182E-02	0.175E+01	0.260E-01	0.612E+02
1.00	0.000E+00	0.516E+02	0.178E-02	0.196E+01	0.237E-01	0.535E+02
2.00	0.000E+00	0.459E+02	0.176E-02	0.198E+01	0.218E-01	0.479E+02
3.00	0.000E+00	0.412E+02	0.174E-02	0.192E+01	0.200E-01	0.431E+02
4.00	0.000E+00	0.372E+02	0.173E-02	0.184E+01	0.185E-01	0.390E+02
5.00	0.000E+00	0.338E+02	0.171E-02	0.174E+01	0.171E-01	0.355E+02
6.00	0.000E+00	0.308E+02	0.170E-02	0.165E+01	0.158E-01	0.324E+02
7.00	0.000E+00	0.281E+02	0.168E-02	0.155E+01	0.147E-01	0.297E+02
8.00	0.000E+00	0.258E+02	0.167E-02	0.146E+01	0.137E-01	0.273E+02
9.00	0.000E+00	0.237E+02	0.165E-02	0.138E+01	0.127E-01	0.251E+02
10.00	0.000E+00	0.219E+02	0.163E-02	0.130E+01	0.118E-01	0.232E+02
11.00	0.000E+00	0.202E+02	0.161E-02	0.123E+01	0.111E-01	0.214E+02
12.00	0.000E+00	0.187E+02	0.159E-02	0.116E+01	0.103E-01	0.198E+02
13.00	0.000E+00	0.173E+02	0.157E-02	0.110E+01	0.965E-02	0.184E+02
14.00	0.000E+00	0.160E+02	0.155E-02	0.104E+01	0.903E-02	0.171E+02

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.721E+02	0.390E-01	0.148E+02	0.538E+00	0.875E+02
1.00	0.000E+00	0.594E+02	0.382E-01	0.114E+02	0.491E+00	0.714E+02
2.00	0.000E+00	0.526E+02	0.377E-01	0.109E+02	0.450E+00	0.640E+02
3.00	0.000E+00	0.471E+02	0.373E-01	0.102E+02	0.414E+00	0.578E+02
4.00	0.000E+00	0.424E+02	0.370E-01	0.962E+01	0.382E+00	0.525E+02
5.00	0.000E+00	0.384E+02	0.366E-01	0.903E+01	0.353E+00	0.479E+02
6.00	0.000E+00	0.350E+02	0.363E-01	0.847E+01	0.326E+00	0.438E+02
7.00	0.000E+00	0.320E+02	0.359E-01	0.796E+01	0.303E+00	0.403E+02
8.00	0.000E+00	0.293E+02	0.356E-01	0.749E+01	0.281E+00	0.371E+02
9.00	0.000E+00	0.269E+02	0.352E-01	0.705E+01	0.262E+00	0.342E+02
10.00	0.000E+00	0.248E+02	0.348E-01	0.665E+01	0.244E+00	0.317E+02
11.00	0.000E+00	0.228E+02	0.344E-01	0.627E+01	0.227E+00	0.294E+02
12.00	0.000E+00	0.211E+02	0.339E-01	0.593E+01	0.212E+00	0.273E+02
13.00	0.000E+00	0.195E+02	0.335E-01	0.560E+01	0.198E+00	0.254E+02
14.00	0.000E+00	0.181E+02	0.330E-01	0.530E+01	0.185E+00	0.236E+02

A6. November 1960 SPE with 10 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.3517E+09	0.1654E+08	0.9302E+08	0.1716E+07
1.00	0.0000E+00	0.3146E+09	0.1681E+08	0.8272E+08	0.2322E+07
2.00	0.0000E+00	0.2838E+09	0.1687E+08	0.7507E+08	0.2479E+07
3.00	0.0000E+00	0.2574E+09	0.1677E+08	0.6907E+08	0.2487E+07
4.00	0.0000E+00	0.2345E+09	0.1656E+08	0.6419E+08	0.2430E+07
5.00	0.0000E+00	0.2143E+09	0.1628E+08	0.6012E+08	0.2341E+07
6.00	0.0000E+00	0.1964E+09	0.1594E+08	0.5666E+08	0.2239E+07
7.00	0.0000E+00	0.1804E+09	0.1556E+08	0.5366E+08	0.2133E+07
8.00	0.0000E+00	0.1661E+09	0.1515E+08	0.5102E+08	0.2026E+07
9.00	0.0000E+00	0.1531E+09	0.1473E+08	0.4868E+08	0.1922E+07
10.00	0.0000E+00	0.1415E+09	0.1430E+08	0.4657E+08	0.1821E+07
11.00	0.0000E+00	0.1309E+09	0.1387E+08	0.4466E+08	0.1725E+07
12.00	0.0000E+00	0.1213E+09	0.1343E+08	0.4291E+08	0.1634E+07
13.00	0.0000E+00	0.1125E+09	0.1299E+08	0.4129E+08	0.1547E+07
14.00	0.0000E+00	0.1045E+09	0.1256E+08	0.3979E+08	0.1465E+07

A6. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.181E+04	0.231E-02	0.151E+02	0.194E+00	0.183E+04
1.00	0.000E+00	0.957E+03	0.257E-02	0.952E+01	0.123E+00	0.967E+03
2.00	0.000E+00	0.587E+03	0.268E-02	0.718E+01	0.840E-01	0.594E+03
3.00	0.000E+00	0.383E+03	0.270E-02	0.538E+01	0.594E-01	0.389E+03
4.00	0.000E+00	0.262E+03	0.266E-02	0.407E+01	0.431E-01	0.266E+03
5.00	0.000E+00	0.185E+03	0.260E-02	0.312E+01	0.320E-01	0.188E+03
6.00	0.000E+00	0.133E+03	0.252E-02	0.243E+01	0.241E-01	0.136E+03
7.00	0.000E+00	0.980E+02	0.242E-02	0.191E+01	0.184E-01	0.999E+02
8.00	0.000E+00	0.731E+02	0.232E-02	0.153E+01	0.142E-01	0.747E+02
9.00	0.000E+00	0.553E+02	0.222E-02	0.123E+01	0.111E-01	0.566E+02
10.00	0.000E+00	0.423E+02	0.212E-02	0.101E+01	0.868E-02	0.434E+02
11.00	0.000E+00	0.327E+02	0.202E-02	0.831E+00	0.687E-02	0.336E+02
12.00	0.000E+00	0.255E+02	0.193E-02	0.694E+00	0.547E-02	0.262E+02
13.00	0.000E+00	0.201E+02	0.183E-02	0.584E+00	0.439E-02	0.207E+02
14.00	0.000E+00	0.159E+02	0.174E-02	0.497E+00	0.353E-02	0.164E+02
15.00	0.000E+00	0.127E+02	0.166E-02	0.426E+00	0.286E-02	0.131E+02
16.00	0.000E+00	0.102E+02	0.158E-02	0.369E+00	0.233E-02	0.105E+02
17.00	0.000E+00	0.821E+01	0.150E-02	0.322E+00	0.190E-02	0.853E+01
18.00	0.000E+00	0.666E+01	0.143E-02	0.283E+00	0.156E-02	0.695E+01
20.00	0.000E+00	0.445E+01	0.129E-02	0.225E+00	0.106E-02	0.468E+01

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.270E+04	0.502E-01	0.169E+03	0.418E+01	0.288E+04
1.00	0.000E+00	0.127E+04	0.558E-01	0.671E+02	0.266E+01	0.134E+04
2.00	0.000E+00	0.765E+03	0.581E-01	0.467E+02	0.181E+01	0.813E+03
3.00	0.000E+00	0.492E+03	0.585E-01	0.337E+02	0.128E+01	0.528E+03
4.00	0.000E+00	0.333E+03	0.578E-01	0.251E+02	0.928E+00	0.359E+03
5.00	0.000E+00	0.233E+03	0.564E-01	0.192E+02	0.687E+00	0.253E+03
6.00	0.000E+00	0.167E+03	0.546E-01	0.150E+02	0.517E+00	0.183E+03
7.00	0.000E+00	0.122E+03	0.526E-01	0.119E+02	0.395E+00	0.135E+03
8.00	0.000E+00	0.909E+02	0.504E-01	0.962E+01	0.304E+00	0.101E+03
9.00	0.000E+00	0.685E+02	0.482E-01	0.790E+01	0.237E+00	0.767E+02
10.00	0.000E+00	0.523E+02	0.460E-01	0.658E+01	0.186E+00	0.591E+02
11.00	0.000E+00	0.403E+02	0.439E-01	0.556E+01	0.147E+00	0.461E+02
12.00	0.000E+00	0.314E+02	0.418E-01	0.474E+01	0.117E+00	0.363E+02
13.00	0.000E+00	0.246E+02	0.397E-01	0.410E+01	0.939E-01	0.289E+02
14.00	0.000E+00	0.195E+02	0.378E-01	0.357E+01	0.756E-01	0.232E+02
15.00	0.000E+00	0.155E+02	0.359E-01	0.314E+01	0.612E-01	0.188E+02
16.00	0.000E+00	0.125E+02	0.342E-01	0.279E+01	0.497E-01	0.153E+02
17.00	0.000E+00	0.101E+02	0.325E-01	0.249E+01	0.406E-01	0.126E+02
18.00	0.000E+00	0.818E+01	0.309E-01	0.224E+01	0.333E-01	0.105E+02
20.00	0.000E+00	0.549E+01	0.279E-01	0.185E+01	0.226E-01	0.738E+01

A7. August 1972 SPE with 2 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.5163E+10	0.3580E+08	0.1752E+09	0.8362E+07
1.00	0.0000E+00	0.3040E+10	0.3690E+08	0.1723E+09	0.8678E+07
2.00	0.0000E+00	0.1966E+10	0.3243E+08	0.1647E+09	0.7097E+07
3.00	0.0000E+00	0.1337E+10	0.2724E+08	0.1553E+09	0.5548E+07
4.00	0.0000E+00	0.9416E+09	0.2269E+08	0.1453E+09	0.4300E+07
5.00	0.0000E+00	0.6800E+09	0.1879E+08	0.1354E+09	0.3343E+07
6.00	0.0000E+00	0.5007E+09	0.1554E+08	0.1259E+09	0.2616E+07
7.00	0.0000E+00	0.3744E+09	0.1287E+08	0.1169E+09	0.2065E+07
8.00	0.0000E+00	0.2837E+09	0.1069E+08	0.1085E+09	0.1645E+07
9.00	0.0000E+00	0.2173E+09	0.8917E+07	0.1007E+09	0.1321E+07
10.00	0.0000E+00	0.1681E+09	0.7466E+07	0.9347E+08	0.1071E+07
11.00	0.0000E+00	0.1311E+09	0.6278E+07	0.8684E+08	0.8746E+06
12.00	0.0000E+00	0.1031E+09	0.5303E+07	0.8074E+08	0.7201E+06
13.00	0.0000E+00	0.8157E+08	0.4500E+07	0.7513E+08	0.5974E+06
14.00	0.0000E+00	0.6494E+08	0.3836E+07	0.6997E+08	0.4994E+06
15.00	0.0000E+00	0.5198E+08	0.3285E+07	0.6522E+08	0.4206E+06
16.00	0.0000E+00	0.4181E+08	0.2827E+07	0.6085E+08	0.3568E+06
17.00	0.0000E+00	0.3378E+08	0.2445E+07	0.5682E+08	0.3048E+06
18.00	0.0000E+00	0.2741E+08	0.2124E+07	0.5310E+08	0.2623E+06
20.00	0.0000E+00	0.1825E+08	0.1626E+07	0.4649E+08	0.2012E+06

A7. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.532E+03	0.337E-02	0.633E+01	0.752E-01	0.538E+03
1.00	0.000E+00	0.341E+03	0.324E-02	0.452E+01	0.534E-01	0.345E+03
2.00	0.000E+00	0.234E+03	0.311E-02	0.360E+01	0.389E-01	0.237E+03
3.00	0.000E+00	0.165E+03	0.297E-02	0.283E+01	0.290E-01	0.168E+03
4.00	0.000E+00	0.120E+03	0.284E-02	0.223E+01	0.219E-01	0.122E+03
5.00	0.000E+00	0.886E+02	0.270E-02	0.178E+01	0.168E-01	0.904E+02
6.00	0.000E+00	0.664E+02	0.257E-02	0.143E+01	0.130E-01	0.679E+02
7.00	0.000E+00	0.504E+02	0.244E-02	0.116E+01	0.102E-01	0.516E+02
8.00	0.000E+00	0.387E+02	0.232E-02	0.954E+00	0.799E-02	0.397E+02
9.00	0.000E+00	0.300E+02	0.220E-02	0.793E+00	0.634E-02	0.308E+02
10.00	0.000E+00	0.235E+02	0.208E-02	0.665E+00	0.506E-02	0.241E+02
11.00	0.000E+00	0.185E+02	0.198E-02	0.564E+00	0.406E-02	0.191E+02
12.00	0.000E+00	0.147E+02	0.188E-02	0.482E+00	0.328E-02	0.152E+02
13.00	0.000E+00	0.117E+02	0.178E-02	0.416E+00	0.266E-02	0.122E+02
14.00	0.000E+00	0.944E+01	0.169E-02	0.362E+00	0.216E-02	0.981E+01
15.00	0.000E+00	0.763E+01	0.160E-02	0.317E+00	0.177E-02	0.796E+01
16.00	0.000E+00	0.621E+01	0.152E-02	0.280E+00	0.145E-02	0.649E+01
17.00	0.000E+00	0.507E+01	0.144E-02	0.249E+00	0.120E-02	0.533E+01
18.00	0.000E+00	0.417E+01	0.137E-02	0.223E+00	0.988E-03	0.439E+01
20.00	0.000E+00	0.285E+01	0.124E-02	0.184E+00	0.682E-03	0.304E+01

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.742E+03	0.732E-01	0.625E+02	0.162E+01	0.807E+03
1.00	0.000E+00	0.437E+03	0.704E-01	0.301E+02	0.115E+01	0.469E+03
2.00	0.000E+00	0.297E+03	0.675E-01	0.229E+02	0.837E+00	0.321E+03
3.00	0.000E+00	0.208E+03	0.646E-01	0.177E+02	0.623E+00	0.227E+03
4.00	0.000E+00	0.150E+03	0.616E-01	0.140E+02	0.471E+00	0.165E+03
5.00	0.000E+00	0.110E+03	0.586E-01	0.112E+02	0.360E+00	0.122E+03
6.00	0.000E+00	0.825E+02	0.557E-01	0.916E+01	0.279E+00	0.920E+02
7.00	0.000E+00	0.624E+02	0.529E-01	0.759E+01	0.218E+00	0.703E+02
8.00	0.000E+00	0.478E+02	0.502E-01	0.637E+01	0.171E+00	0.544E+02
9.00	0.000E+00	0.370E+02	0.476E-01	0.541E+01	0.136E+00	0.426E+02
10.00	0.000E+00	0.289E+02	0.452E-01	0.465E+01	0.108E+00	0.337E+02
11.00	0.000E+00	0.227E+02	0.428E-01	0.404E+01	0.869E-01	0.269E+02
12.00	0.000E+00	0.180E+02	0.406E-01	0.355E+01	0.701E-01	0.217E+02
13.00	0.000E+00	0.144E+02	0.385E-01	0.314E+01	0.568E-01	0.176E+02
14.00	0.000E+00	0.116E+02	0.366E-01	0.280E+01	0.462E-01	0.145E+02
15.00	0.000E+00	0.938E+01	0.347E-01	0.251E+01	0.378E-01	0.120E+02
16.00	0.000E+00	0.764E+01	0.329E-01	0.227E+01	0.310E-01	0.997E+01
17.00	0.000E+00	0.625E+01	0.313E-01	0.206E+01	0.255E-01	0.837E+01
18.00	0.000E+00	0.515E+01	0.297E-01	0.188E+01	0.211E-01	0.708E+01
20.00	0.000E+00	0.354E+01	0.268E-01	0.159E+01	0.146E-01	0.518E+01

A8. August 1972 SPE with 5 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.1762E+10	0.2574E+08	0.2414E+09	0.4600E+07
1.00	0.0000E+00	0.1196E+10	0.2334E+08	0.2135E+09	0.4499E+07
2.00	0.0000E+00	0.8456E+09	0.1995E+08	0.1909E+09	0.3735E+07
3.00	0.0000E+00	0.6132E+09	0.1674E+08	0.1720E+09	0.2993E+07
4.00	0.0000E+00	0.4535E+09	0.1402E+08	0.1558E+09	0.2382E+07
5.00	0.0000E+00	0.3404E+09	0.1173E+08	0.1416E+09	0.1898E+07
6.00	0.0000E+00	0.2587E+09	0.9813E+07	0.1291E+09	0.1522E+07
7.00	0.0000E+00	0.1988E+09	0.8232E+07	0.1181E+09	0.1229E+07
8.00	0.0000E+00	0.1542E+09	0.6929E+07	0.1083E+09	0.1000E+07
9.00	0.0000E+00	0.1205E+09	0.5854E+07	0.9958E+08	0.8208E+06
10.00	0.0000E+00	0.9495E+08	0.4967E+07	0.9174E+08	0.6788E+06
11.00	0.0000E+00	0.7527E+08	0.4232E+07	0.8468E+08	0.5658E+06
12.00	0.0000E+00	0.6002E+08	0.3623E+07	0.7832E+08	0.4751E+06
13.00	0.0000E+00	0.4812E+08	0.3115E+07	0.7255E+08	0.4020E+06
14.00	0.0000E+00	0.3876E+08	0.2692E+07	0.6732E+08	0.3426E+06
15.00	0.0000E+00	0.3136E+08	0.2337E+07	0.6256E+08	0.2941E+06
16.00	0.0000E+00	0.2547E+08	0.2038E+07	0.5822E+08	0.2543E+06
17.00	0.0000E+00	0.2077E+08	0.1787E+07	0.5424E+08	0.2214E+06
18.00	0.0000E+00	0.1699E+08	0.1574E+07	0.5061E+08	0.1942E+06
20.00	0.0000E+00	0.1148E+08	0.1239E+07	0.4420E+08	0.1543E+06

A8. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.129E+03	0.355E-02	0.208E+01	0.227E-01	0.131E+03
1.00	0.000E+00	0.924E+02	0.328E-02	0.167E+01	0.173E-01	0.941E+02
2.00	0.000E+00	0.687E+02	0.305E-02	0.141E+01	0.133E-01	0.702E+02
3.00	0.000E+00	0.519E+02	0.286E-02	0.118E+01	0.104E-01	0.531E+02
4.00	0.000E+00	0.398E+02	0.268E-02	0.977E+00	0.816E-02	0.407E+02
5.00	0.000E+00	0.308E+02	0.252E-02	0.816E+00	0.646E-02	0.316E+02
6.00	0.000E+00	0.240E+02	0.237E-02	0.688E+00	0.515E-02	0.247E+02
7.00	0.000E+00	0.189E+02	0.223E-02	0.584E+00	0.413E-02	0.195E+02
8.00	0.000E+00	0.150E+02	0.211E-02	0.501E+00	0.333E-02	0.155E+02
9.00	0.000E+00	0.120E+02	0.199E-02	0.433E+00	0.270E-02	0.124E+02
10.00	0.000E+00	0.963E+01	0.188E-02	0.378E+00	0.220E-02	0.100E+02
11.00	0.000E+00	0.778E+01	0.178E-02	0.332E+00	0.179E-02	0.812E+01
12.00	0.000E+00	0.632E+01	0.168E-02	0.294E+00	0.147E-02	0.662E+01
13.00	0.000E+00	0.517E+01	0.159E-02	0.262E+00	0.121E-02	0.543E+01
14.00	0.000E+00	0.424E+01	0.151E-02	0.235E+00	0.100E-02	0.448E+01
15.00	0.000E+00	0.350E+01	0.143E-02	0.212E+00	0.830E-03	0.372E+01
16.00	0.000E+00	0.290E+01	0.136E-02	0.192E+00	0.690E-03	0.310E+01
17.00	0.000E+00	0.242E+01	0.129E-02	0.175E+00	0.576E-03	0.260E+01
18.00	0.000E+00	0.202E+01	0.122E-02	0.161E+00	0.482E-03	0.219E+01
20.00	0.000E+00	0.144E+01	0.110E-02	0.137E+00	0.340E-03	0.158E+01

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.173E+03	0.771E-01	0.195E+02	0.487E+00	0.193E+03
1.00	0.000E+00	0.116E+03	0.712E-01	0.115E+02	0.371E+00	0.127E+03
2.00	0.000E+00	0.855E+02	0.662E-01	0.948E+01	0.286E+00	0.954E+02
3.00	0.000E+00	0.643E+02	0.620E-01	0.790E+01	0.223E+00	0.725E+02
4.00	0.000E+00	0.491E+02	0.581E-01	0.666E+01	0.175E+00	0.560E+02
5.00	0.000E+00	0.379E+02	0.546E-01	0.567E+01	0.138E+00	0.438E+02
6.00	0.000E+00	0.296E+02	0.514E-01	0.489E+01	0.110E+00	0.346E+02
7.00	0.000E+00	0.233E+02	0.484E-01	0.426E+01	0.884E-01	0.277E+02
8.00	0.000E+00	0.184E+02	0.456E-01	0.374E+01	0.713E-01	0.223E+02
9.00	0.000E+00	0.147E+02	0.431E-01	0.332E+01	0.577E-01	0.181E+02
10.00	0.000E+00	0.118E+02	0.407E-01	0.296E+01	0.470E-01	0.149E+02
11.00	0.000E+00	0.958E+01	0.385E-01	0.267E+01	0.384E-01	0.123E+02
12.00	0.000E+00	0.779E+01	0.364E-01	0.241E+01	0.315E-01	0.103E+02
13.00	0.000E+00	0.638E+01	0.345E-01	0.220E+01	0.259E-01	0.864E+01
14.00	0.000E+00	0.525E+01	0.326E-01	0.201E+01	0.214E-01	0.731E+01
15.00	0.000E+00	0.435E+01	0.309E-01	0.185E+01	0.177E-01	0.624E+01
16.00	0.000E+00	0.362E+01	0.293E-01	0.170E+01	0.147E-01	0.536E+01
17.00	0.000E+00	0.303E+01	0.278E-01	0.158E+01	0.123E-01	0.464E+01
18.00	0.000E+00	0.254E+01	0.264E-01	0.146E+01	0.103E-01	0.404E+01
20.00	0.000E+00	0.183E+01	0.239E-01	0.127E+01	0.725E-02	0.313E+01

A9. August 1972 SPE with 10 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.4772E+09	0.1211E+08	0.2428E+09	0.1670E+07
1.00	0.0000E+00	0.3533E+09	0.1080E+08	0.2090E+09	0.1685E+07
2.00	0.0000E+00	0.2670E+09	0.9281E+07	0.1829E+09	0.1457E+07
3.00	0.0000E+00	0.2044E+09	0.7899E+07	0.1620E+09	0.1215E+07
4.00	0.0000E+00	0.1581E+09	0.6735E+07	0.1446E+09	0.1005E+07
5.00	0.0000E+00	0.1234E+09	0.5742E+07	0.1300E+09	0.8311E+06
6.00	0.0000E+00	0.9707E+08	0.4903E+07	0.1174E+09	0.6903E+06
7.00	0.0000E+00	0.7686E+08	0.4199E+07	0.1066E+09	0.5769E+06
8.00	0.0000E+00	0.6122E+08	0.3610E+07	0.9714E+08	0.4855E+06
9.00	0.0000E+00	0.4903E+08	0.3115E+07	0.8882E+08	0.4115E+06
10.00	0.0000E+00	0.3945E+08	0.2700E+07	0.8146E+08	0.3514E+06
11.00	0.0000E+00	0.3189E+08	0.2350E+07	0.7492E+08	0.3023E+06
12.00	0.0000E+00	0.2589E+08	0.2056E+07	0.6908E+08	0.2619E+06
13.00	0.0000E+00	0.2109E+08	0.1806E+07	0.6383E+08	0.2284E+06
14.00	0.0000E+00	0.1725E+08	0.1595E+07	0.5911E+08	0.2007E+06
15.00	0.0000E+00	0.1415E+08	0.1415E+07	0.5484E+08	0.1774E+06
16.00	0.0000E+00	0.1164E+08	0.1261E+07	0.5097E+08	0.1579E+06
17.00	0.0000E+00	0.9609E+07	0.1129E+07	0.4744E+08	0.1414E+06
18.00	0.0000E+00	0.7951E+07	0.1016E+07	0.4422E+08	0.1274E+06
20.00	0.0000E+00	0.5485E+07	0.8333E+06	0.3858E+08	0.1064E+06

A9. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.326E+03	0.471E-03	0.215E+01	0.244E-01	0.328E+03
1.00	0.000E+00	0.127E+03	0.468E-03	0.105E+01	0.131E-01	0.128E+03
2.00	0.000E+00	0.658E+02	0.451E-03	0.709E+00	0.810E-02	0.665E+02
3.00	0.000E+00	0.386E+02	0.429E-03	0.503E+00	0.542E-02	0.391E+02
4.00	0.000E+00	0.245E+02	0.405E-03	0.371E+00	0.382E-02	0.249E+02
5.00	0.000E+00	0.165E+02	0.382E-03	0.282E+00	0.280E-02	0.168E+02
6.00	0.000E+00	0.115E+02	0.359E-03	0.221E+00	0.210E-02	0.118E+02
7.00	0.000E+00	0.834E+01	0.338E-03	0.176E+00	0.161E-02	0.851E+01
8.00	0.000E+00	0.617E+01	0.317E-03	0.143E+00	0.126E-02	0.632E+01
9.00	0.000E+00	0.466E+01	0.298E-03	0.118E+00	0.998E-03	0.478E+01
10.00	0.000E+00	0.359E+01	0.280E-03	0.990E-01	0.801E-03	0.369E+01
11.00	0.000E+00	0.280E+01	0.263E-03	0.839E-01	0.649E-03	0.289E+01
12.00	0.000E+00	0.222E+01	0.248E-03	0.718E-01	0.532E-03	0.229E+01
13.00	0.000E+00	0.177E+01	0.233E-03	0.621E-01	0.439E-03	0.184E+01
14.00	0.000E+00	0.143E+01	0.219E-03	0.542E-01	0.365E-03	0.149E+01

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.532E+03	0.103E-01	0.246E+02	0.528E+00	0.557E+03
1.00	0.000E+00	0.177E+03	0.102E-01	0.763E+01	0.282E+00	0.185E+03
2.00	0.000E+00	0.886E+02	0.980E-02	0.477E+01	0.174E+00	0.936E+02
3.00	0.000E+00	0.507E+02	0.932E-02	0.326E+01	0.117E+00	0.541E+02
4.00	0.000E+00	0.317E+02	0.881E-02	0.237E+01	0.822E-01	0.342E+02
5.00	0.000E+00	0.210E+02	0.830E-02	0.180E+01	0.600E-01	0.229E+02
6.00	0.000E+00	0.146E+02	0.780E-02	0.141E+01	0.450E-01	0.160E+02
7.00	0.000E+00	0.104E+02	0.733E-02	0.114E+01	0.345E-01	0.116E+02
8.00	0.000E+00	0.768E+01	0.689E-02	0.939E+00	0.269E-01	0.865E+01
9.00	0.000E+00	0.577E+01	0.647E-02	0.789E+00	0.213E-01	0.659E+01
10.00	0.000E+00	0.442E+01	0.608E-02	0.673E+00	0.171E-01	0.512E+01
11.00	0.000E+00	0.344E+01	0.571E-02	0.581E+00	0.139E-01	0.404E+01
12.00	0.000E+00	0.271E+01	0.537E-02	0.508E+00	0.113E-01	0.324E+01
13.00	0.000E+00	0.217E+01	0.505E-02	0.448E+00	0.934E-02	0.263E+01
14.00	0.000E+00	0.175E+01	0.476E-02	0.399E+00	0.776E-02	0.216E+01

A10. August 1989 SPE with 2 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.7655E+09	0.4358E+07	0.4450E+08	0.1091E+07
1.00	0.0000E+00	0.3559E+09	0.3847E+07	0.3998E+08	0.9051E+06
2.00	0.0000E+00	0.2021E+09	0.3099E+07	0.3562E+08	0.6732E+06
3.00	0.0000E+00	0.1269E+09	0.2476E+07	0.3174E+08	0.5024E+06
4.00	0.0000E+00	0.8499E+08	0.2011E+07	0.2835E+08	0.3819E+06
5.00	0.0000E+00	0.5956E+08	0.1650E+07	0.2539E+08	0.2958E+06
6.00	0.0000E+00	0.4314E+08	0.1367E+07	0.2282E+08	0.2331E+06
7.00	0.0000E+00	0.3207E+08	0.1143E+07	0.2058E+08	0.1867E+06
8.00	0.0000E+00	0.2435E+08	0.9646E+06	0.1860E+08	0.1516E+06
9.00	0.0000E+00	0.1881E+08	0.8206E+06	0.1687E+08	0.1247E+06
10.00	0.0000E+00	0.1474E+08	0.7032E+06	0.1534E+08	0.1037E+06
11.00	0.0000E+00	0.1170E+08	0.6068E+06	0.1398E+08	0.8710E+05
12.00	0.0000E+00	0.9393E+07	0.5269E+06	0.1277E+08	0.7380E+05
13.00	0.0000E+00	0.7611E+07	0.4600E+06	0.1170E+08	0.6304E+05
14.00	0.0000E+00	0.6220E+07	0.4038E+06	0.1073E+08	0.5425E+05

A10. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.579E+02	0.561E-03	0.633E+00	0.713E-02	0.585E+02
1.00	0.000E+00	0.335E+02	0.513E-03	0.422E+00	0.483E-02	0.339E+02
2.00	0.000E+00	0.215E+02	0.473E-03	0.329E+00	0.344E-02	0.219E+02
3.00	0.000E+00	0.146E+02	0.438E-03	0.257E+00	0.253E-02	0.149E+02
4.00	0.000E+00	0.103E+02	0.406E-03	0.204E+00	0.192E-02	0.105E+02
5.00	0.000E+00	0.752E+01	0.378E-03	0.165E+00	0.148E-02	0.768E+01
6.00	0.000E+00	0.560E+01	0.352E-03	0.135E+00	0.116E-02	0.574E+01
7.00	0.000E+00	0.426E+01	0.329E-03	0.113E+00	0.923E-03	0.437E+01
8.00	0.000E+00	0.329E+01	0.307E-03	0.949E-01	0.743E-03	0.339E+01
9.00	0.000E+00	0.258E+01	0.287E-03	0.809E-01	0.605E-03	0.266E+01
10.00	0.000E+00	0.205E+01	0.269E-03	0.697E-01	0.496E-03	0.212E+01
11.00	0.000E+00	0.165E+01	0.252E-03	0.606E-01	0.411E-03	0.171E+01
12.00	0.000E+00	0.134E+01	0.237E-03	0.531E-01	0.342E-03	0.139E+01
13.00	0.000E+00	0.109E+01	0.223E-03	0.469E-01	0.287E-03	0.114E+01
14.00	0.000E+00	0.902E+00	0.209E-03	0.416E-01	0.242E-03	0.944E+00

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.837E+02	0.122E-01	0.636E+01	0.154E+00	0.902E+02
1.00	0.000E+00	0.439E+02	0.112E-01	0.290E+01	0.104E+00	0.469E+02
2.00	0.000E+00	0.278E+02	0.103E-01	0.217E+01	0.738E-01	0.300E+02
3.00	0.000E+00	0.186E+02	0.951E-02	0.167E+01	0.543E-01	0.203E+02
4.00	0.000E+00	0.130E+02	0.883E-02	0.133E+01	0.410E-01	0.144E+02
5.00	0.000E+00	0.940E+01	0.821E-02	0.109E+01	0.316E-01	0.105E+02
6.00	0.000E+00	0.696E+01	0.765E-02	0.906E+00	0.248E-01	0.790E+01
7.00	0.000E+00	0.527E+01	0.714E-02	0.767E+00	0.197E-01	0.606E+01
8.00	0.000E+00	0.405E+01	0.667E-02	0.660E+00	0.159E-01	0.474E+01
9.00	0.000E+00	0.317E+01	0.624E-02	0.574E+00	0.129E-01	0.376E+01
10.00	0.000E+00	0.251E+01	0.584E-02	0.504E+00	0.106E-01	0.303E+01
11.00	0.000E+00	0.201E+01	0.547E-02	0.447E+00	0.874E-02	0.247E+01
12.00	0.000E+00	0.163E+01	0.514E-02	0.400E+00	0.728E-02	0.204E+01
13.00	0.000E+00	0.133E+01	0.483E-02	0.360E+00	0.610E-02	0.170E+01
14.00	0.000E+00	0.110E+01	0.454E-02	0.325E+00	0.514E-02	0.143E+01

A11. August 1989 SPE with 5 g/cm^{2}Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.1768E+09	0.2401E+07	0.4949E+08	0.4382E+06
1.00	0.0000E+00	0.1116E+09	0.2106E+07	0.4211E+08	0.4057E+06
2.00	0.0000E+00	0.7554E+08	0.1766E+07	0.3641E+08	0.3309E+06
3.00	0.0000E+00	0.5340E+08	0.1473E+07	0.3182E+08	0.2649E+06
4.00	0.0000E+00	0.3899E+08	0.1239E+07	0.2804E+08	0.2128E+06
5.00	0.0000E+00	0.2918E+08	0.1049E+07	0.2486E+08	0.1724E+06
6.00	0.0000E+00	0.2227E+08	0.8926E+06	0.2217E+08	0.1412E+06
7.00	0.0000E+00	0.1728E+08	0.7647E+06	0.1986E+08	0.1169E+06
8.00	0.0000E+00	0.1360E+08	0.6592E+06	0.1786E+08	0.9775E+05
9.00	0.0000E+00	0.1083E+08	0.5716E+06	0.1613E+08	0.8250E+05
10.00	0.0000E+00	0.8722E+07	0.4985E+06	0.1461E+08	0.7023E+05
11.00	0.0000E+00	0.7087E+07	0.4370E+06	0.1328E+08	0.6026E+05
12.00	0.0000E+00	0.5805E+07	0.3850E+06	0.1210E+08	0.5207E+05
13.00	0.0000E+00	0.4790E+07	0.3407E+06	0.1106E+08	0.4530E+05
14.00	0.0000E+00	0.3979E+07	0.3028E+06	0.1012E+08	0.3965E+05

A11. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.112E+02	0.530E-03	0.191E+00	0.198E-02	0.114E+02
1.00	0.000E+00	0.786E+01	0.476E-03	0.156E+00	0.152E-02	0.802E+01
2.00	0.000E+00	0.581E+01	0.433E-03	0.134E+00	0.119E-02	0.594E+01
3.00	0.000E+00	0.439E+01	0.397E-03	0.114E+00	0.942E-03	0.450E+01
4.00	0.000E+00	0.338E+01	0.365E-03	0.973E-01	0.757E-03	0.348E+01
5.00	0.000E+00	0.265E+01	0.338E-03	0.834E-01	0.615E-03	0.273E+01
6.00	0.000E+00	0.210E+01	0.314E-03	0.721E-01	0.504E-03	0.217E+01
7.00	0.000E+00	0.168E+01	0.292E-03	0.628E-01	0.417E-03	0.175E+01
8.00	0.000E+00	0.136E+01	0.272E-03	0.552E-01	0.347E-03	0.142E+01
9.00	0.000E+00	0.111E+01	0.254E-03	0.488E-01	0.291E-03	0.116E+01
10.00	0.000E+00	0.918E+00	0.237E-03	0.434E-01	0.245E-03	0.962E+00
11.00	0.000E+00	0.763E+00	0.222E-03	0.389E-01	0.207E-03	0.802E+00
12.00	0.000E+00	0.638E+00	0.208E-03	0.350E-01	0.177E-03	0.673E+00
13.00	0.000E+00	0.537E+00	0.195E-03	0.316E-01	0.151E-03	0.568E+00
14.00	0.000E+00	0.454E+00	0.184E-03	0.287E-01	0.130E-03	0.483E+00

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.151E+02	0.115E-01	0.183E+01	0.425E-01	0.170E+02
1.00	0.000E+00	0.987E+01	0.103E-01	0.112E+01	0.325E-01	0.110E+02
2.00	0.000E+00	0.723E+01	0.940E-02	0.942E+00	0.254E-01	0.821E+01
3.00	0.000E+00	0.543E+01	0.862E-02	0.803E+00	0.201E-01	0.626E+01
4.00	0.000E+00	0.417E+01	0.794E-02	0.693E+00	0.162E-01	0.488E+01
5.00	0.000E+00	0.325E+01	0.734E-02	0.604E+00	0.131E-01	0.388E+01
6.00	0.000E+00	0.257E+01	0.681E-02	0.532E+00	0.107E-01	0.312E+01
7.00	0.000E+00	0.206E+01	0.633E-02	0.473E+00	0.887E-02	0.255E+01
8.00	0.000E+00	0.166E+01	0.589E-02	0.423E+00	0.738E-02	0.210E+01
9.00	0.000E+00	0.136E+01	0.550E-02	0.381E+00	0.618E-02	0.175E+01
10.00	0.000E+00	0.112E+01	0.514E-02	0.346E+00	0.520E-02	0.148E+01
11.00	0.000E+00	0.931E+00	0.482E-02	0.315E+00	0.440E-02	0.125E+01
12.00	0.000E+00	0.779E+00	0.451E-02	0.288E+00	0.375E-02	0.107E+01
13.00	0.000E+00	0.656E+00	0.424E-02	0.264E+00	0.320E-02	0.927E+00
14.00	0.000E+00	0.556E+00	0.398E-02	0.243E+00	0.275E-02	0.806E+00

A12. August 1989 SPE with 10 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.4113E+08	0.1070E+07	0.4440E+08	0.1483E+06
1.00	0.0000E+00	0.3031E+08	0.9704E+06	0.3743E+08	0.1518E+06
2.00	0.0000E+00	0.2298E+08	0.8474E+06	0.3214E+08	0.1340E+06
3.00	0.0000E+00	0.1776E+08	0.7357E+06	0.2793E+08	0.1147E+06
4.00	0.0000E+00	0.1394E+08	0.6416E+06	0.2450E+08	0.9747E+05
5.00	0.0000E+00	0.1108E+08	0.5608E+06	0.2165E+08	0.8298E+05
6.00	0.0000E+00	0.8902E+07	0.4918E+06	0.1924E+08	0.7099E+05
7.00	0.0000E+00	0.7221E+07	0.4330E+06	0.1719E+08	0.6111E+05
8.00	0.0000E+00	0.5907E+07	0.3827E+06	0.1544E+08	0.5294E+05
9.00	0.0000E+00	0.4869E+07	0.3396E+06	0.1391E+08	0.4615E+05
10.00	0.0000E+00	0.4040E+07	0.3025E+06	0.1259E+08	0.4047E+05
11.00	0.0000E+00	0.3372E+07	0.2705E+06	0.1143E+08	0.3569E+05
12.00	0.0000E+00	0.2830E+07	0.2428E+06	0.1040E+08	0.3164E+05
13.00	0.0000E+00	0.2387E+07	0.2187E+06	0.9497E+07	0.2819E+05
14.00	0.0000E+00	0.2023E+07	0.1976E+06	0.8692E+07	0.2523E+05

A12. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.303E+03	0.474E-03	0.286E+01	0.407E-01	0.306E+03
1.00	0.000E+00	0.164E+03	0.545E-03	0.217E+01	0.292E-01	0.167E+03
2.00	0.000E+00	0.108E+03	0.590E-03	0.188E+01	0.226E-01	0.110E+03
3.00	0.000E+00	0.769E+02	0.620E-03	0.160E+01	0.181E-01	0.785E+02
4.00	0.000E+00	0.578E+02	0.638E-03	0.138E+01	0.150E-01	0.592E+02
5.00	0.000E+00	0.451E+02	0.648E-03	0.119E+01	0.126E-01	0.463E+02
6.00	0.000E+00	0.360E+02	0.652E-03	0.104E+01	0.107E-01	0.371E+02
7.00	0.000E+00	0.294E+02	0.652E-03	0.918E+00	0.923E-02	0.303E+02
8.00	0.000E+00	0.244E+02	0.649E-03	0.813E+00	0.803E-02	0.252E+02
9.00	0.000E+00	0.205E+02	0.643E-03	0.725E+00	0.703E-02	0.212E+02
10.00	0.000E+00	0.174E+02	0.635E-03	0.650E+00	0.620E-02	0.181E+02
11.00	0.000E+00	0.149E+02	0.625E-03	0.585E+00	0.550E-02	0.155E+02
12.00	0.000E+00	0.129E+02	0.615E-03	0.529E+00	0.491E-02	0.134E+02
13.00	0.000E+00	0.112E+02	0.603E-03	0.481E+00	0.439E-02	0.117E+02
14.00	0.000E+00	0.984E+01	0.591E-03	0.438E+00	0.395E-02	0.103E+02

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.452E+03	0.103E-01	0.314E+02	0.871E+00	0.484E+03
1.00	0.000E+00	0.214E+03	0.118E-01	0.146E+02	0.623E+00	0.229E+03
2.00	0.000E+00	0.137E+03	0.128E-01	0.114E+02	0.480E+00	0.148E+03
3.00	0.000E+00	0.955E+02	0.134E-01	0.929E+01	0.384E+00	0.105E+03
4.00	0.000E+00	0.708E+02	0.138E-01	0.775E+01	0.316E+00	0.789E+02
5.00	0.000E+00	0.546E+02	0.140E-01	0.659E+01	0.265E+00	0.614E+02
6.00	0.000E+00	0.433E+02	0.141E-01	0.569E+01	0.226E+00	0.492E+02
7.00	0.000E+00	0.351E+02	0.141E-01	0.497E+01	0.194E+00	0.403E+02
8.00	0.000E+00	0.289E+02	0.140E-01	0.438E+01	0.169E+00	0.335E+02
9.00	0.000E+00	0.242E+02	0.138E-01	0.390E+01	0.148E+00	0.283E+02
10.00	0.000E+00	0.205E+02	0.137E-01	0.349E+01	0.130E+00	0.241E+02
11.00	0.000E+00	0.175E+02	0.134E-01	0.314E+01	0.115E+00	0.208E+02
12.00	0.000E+00	0.151E+02	0.132E-01	0.285E+01	0.103E+00	0.180E+02
13.00	0.000E+00	0.131E+02	0.130E-01	0.259E+01	0.917E-01	0.158E+02
14.00	0.000E+00	0.114E+02	0.127E-01	0.237E+01	0.824E-01	0.139E+02

A13. September 1989 SPE with 2 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.9411E+09	0.7575E+07	0.3355E+08	0.1655E+07
1.00	0.0000E+00	0.6002E+09	0.8688E+07	0.3324E+08	0.2097E+07
2.00	0.0000E+00	0.4301E+09	0.8725E+07	0.3232E+08	0.2008E+07
3.00	0.0000E+00	0.3268E+09	0.8407E+07	0.3116E+08	0.1821E+07
4.00	0.0000E+00	0.2579E+09	0.8002E+07	0.2990E+08	0.1627E+07
5.00	0.0000E+00	0.2089E+09	0.7556E+07	0.2862E+08	0.1448E+07
6.00	0.0000E+00	0.1725E+09	0.7106E+07	0.2736E+08	0.1291E+07
7.00	0.0000E+00	0.1446E+09	0.6671E+07	0.2612E+08	0.1154E+07
8.00	0.0000E+00	0.1227E+09	0.6259E+07	0.2494E+08	0.1035E+07
9.00	0.0000E+00	0.1052E+09	0.5873E+07	0.2381E+08	0.9323E+06
10.00	0.0000E+00	0.9094E+08	0.5513E+07	0.2273E+08	0.8425E+06
11.00	0.0000E+00	0.7920E+08	0.5178E+07	0.2170E+08	0.7639E+06
12.00	0.0000E+00	0.6941E+08	0.4867E+07	0.2072E+08	0.6948E+06
13.00	0.0000E+00	0.6117E+08	0.4578E+07	0.1979E+08	0.6337E+06
14.00	0.0000E+00	0.5417E+08	0.4309E+07	0.1891E+08	0.5795E+06

A13. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.998E+02	0.749E-03	0.152E+01	0.210E-01	0.101E+03
1.00	0.000E+00	0.703E+02	0.748E-03	0.136E+01	0.170E-01	0.717E+02
2.00	0.000E+00	0.533E+02	0.746E-03	0.124E+01	0.141E-01	0.545E+02
3.00	0.000E+00	0.418E+02	0.742E-03	0.110E+01	0.119E-01	0.429E+02
4.00	0.000E+00	0.336E+02	0.734E-03	0.980E+00	0.102E-01	0.346E+02
5.00	0.000E+00	0.276E+02	0.725E-03	0.870E+00	0.878E-02	0.284E+02
6.00	0.000E+00	0.229E+02	0.714E-03	0.776E+00	0.765E-02	0.237E+02
7.00	0.000E+00	0.193E+02	0.702E-03	0.695E+00	0.672E-02	0.200E+02
8.00	0.000E+00	0.165E+02	0.688E-03	0.625E+00	0.594E-02	0.171E+02
9.00	0.000E+00	0.142E+02	0.674E-03	0.565E+00	0.528E-02	0.147E+02
10.00	0.000E+00	0.123E+02	0.660E-03	0.513E+00	0.471E-02	0.128E+02
11.00	0.000E+00	0.107E+02	0.645E-03	0.467E+00	0.422E-02	0.112E+02
12.00	0.000E+00	0.940E+01	0.629E-03	0.426E+00	0.380E-02	0.984E+01
13.00	0.000E+00	0.830E+01	0.614E-03	0.390E+00	0.343E-02	0.869E+01
14.00	0.000E+00	0.736E+01	0.599E-03	0.359E+00	0.311E-02	0.772E+01

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.134E+03	0.162E-01	0.145E+02	0.446E+00	0.149E+03
1.00	0.000E+00	0.871E+02	0.162E-01	0.849E+01	0.360E+00	0.959E+02
2.00	0.000E+00	0.651E+02	0.161E-01	0.726E+01	0.297E+00	0.726E+02
3.00	0.000E+00	0.505E+02	0.160E-01	0.625E+01	0.250E+00	0.570E+02
4.00	0.000E+00	0.403E+02	0.158E-01	0.544E+01	0.214E+00	0.460E+02
5.00	0.000E+00	0.328E+02	0.156E-01	0.478E+01	0.185E+00	0.378E+02
6.00	0.000E+00	0.272E+02	0.154E-01	0.423E+01	0.161E+00	0.316E+02
7.00	0.000E+00	0.228E+02	0.151E-01	0.378E+01	0.141E+00	0.268E+02
8.00	0.000E+00	0.194E+02	0.148E-01	0.340E+01	0.124E+00	0.229E+02
9.00	0.000E+00	0.166E+02	0.145E-01	0.307E+01	0.110E+00	0.198E+02
10.00	0.000E+00	0.143E+02	0.142E-01	0.279E+01	0.984E-01	0.172E+02
11.00	0.000E+00	0.125E+02	0.139E-01	0.254E+01	0.881E-01	0.151E+02
12.00	0.000E+00	0.109E+02	0.135E-01	0.233E+01	0.792E-01	0.134E+02
13.00	0.000E+00	0.963E+01	0.132E-01	0.214E+01	0.715E-01	0.119E+02
14.00	0.000E+00	0.852E+01	0.129E-01	0.197E+01	0.647E-01	0.106E+02

A14. September 1989 SPE with 5 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.3971E+09	0.7597E+07	0.4741E+08	0.1202E+07
1.00	0.0000E+00	0.3028E+09	0.7687E+07	0.4271E+08	0.1455E+07
2.00	0.0000E+00	0.2404E+09	0.7457E+07	0.3905E+08	0.1416E+07
3.00	0.0000E+00	0.1957E+09	0.7107E+07	0.3604E+08	0.1311E+07
4.00	0.0000E+00	0.1623E+09	0.6737E+07	0.3346E+08	0.1194E+07
5.00	0.0000E+00	0.1366E+09	0.6359E+07	0.3122E+08	0.1081E+07
6.00	0.0000E+00	0.1163E+09	0.5990E+07	0.2923E+08	0.9775E+06
7.00	0.0000E+00	0.9995E+08	0.5636E+07	0.2745E+08	0.8854E+06
8.00	0.0000E+00	0.8661E+08	0.5302E+07	0.2585E+08	0.8037E+06
9.00	0.0000E+00	0.7558E+08	0.4989E+07	0.2440E+08	0.7313E+06
10.00	0.0000E+00	0.6635E+08	0.4696E+07	0.2307E+08	0.6672E+06
11.00	0.0000E+00	0.5856E+08	0.4423E+07	0.2184E+08	0.6101E+06
12.00	0.0000E+00	0.5194E+08	0.4168E+07	0.2072E+08	0.5592E+06
13.00	0.0000E+00	0.4625E+08	0.3930E+07	0.1967E+08	0.5137E+06
14.00	0.0000E+00	0.4135E+08	0.3708E+07	0.1870E+08	0.4729E+06

A14. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.354E+02	0.904E-03	0.774E+00	0.103E-01	0.362E+02
1.00	0.000E+00	0.283E+02	0.866E-03	0.767E+00	0.889E-02	0.291E+02
2.00	0.000E+00	0.234E+02	0.835E-03	0.731E+00	0.773E-02	0.242E+02
3.00	0.000E+00	0.197E+02	0.808E-03	0.675E+00	0.678E-02	0.204E+02
4.00	0.000E+00	0.167E+02	0.783E-03	0.617E+00	0.599E-02	0.174E+02
5.00	0.000E+00	0.144E+02	0.759E-03	0.562E+00	0.532E-02	0.149E+02
6.00	0.000E+00	0.124E+02	0.737E-03	0.513E+00	0.474E-02	0.130E+02
7.00	0.000E+00	0.108E+02	0.716E-03	0.468E+00	0.425E-02	0.113E+02
8.00	0.000E+00	0.950E+01	0.695E-03	0.429E+00	0.382E-02	0.994E+01
9.00	0.000E+00	0.838E+01	0.674E-03	0.393E+00	0.345E-02	0.878E+01
10.00	0.000E+00	0.742E+01	0.655E-03	0.362E+00	0.312E-02	0.779E+01
11.00	0.000E+00	0.661E+01	0.636E-03	0.334E+00	0.283E-02	0.694E+01
12.00	0.000E+00	0.590E+01	0.617E-03	0.308E+00	0.258E-02	0.622E+01
13.00	0.000E+00	0.529E+01	0.600E-03	0.286E+00	0.235E-02	0.558E+01
14.00	0.000E+00	0.476E+01	0.582E-03	0.265E+00	0.215E-02	0.503E+01

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.450E+02	0.195E-01	0.683E+01	0.217E+00	0.520E+02
1.00	0.000E+00	0.338E+02	0.187E-01	0.470E+01	0.187E+00	0.387E+02
2.00	0.000E+00	0.278E+02	0.180E-01	0.425E+01	0.162E+00	0.323E+02
3.00	0.000E+00	0.233E+02	0.174E-01	0.383E+01	0.142E+00	0.272E+02
4.00	0.000E+00	0.197E+02	0.169E-01	0.345E+01	0.125E+00	0.233E+02
5.00	0.000E+00	0.168E+02	0.163E-01	0.313E+01	0.111E+00	0.201E+02
6.00	0.000E+00	0.145E+02	0.159E-01	0.284E+01	0.991E-01	0.175E+02
7.00	0.000E+00	0.126E+02	0.154E-01	0.260E+01	0.887E-01	0.153E+02
8.00	0.000E+00	0.111E+02	0.149E-01	0.238E+01	0.797E-01	0.135E+02
9.00	0.000E+00	0.973E+01	0.145E-01	0.219E+01	0.719E-01	0.120E+02
10.00	0.000E+00	0.861E+01	0.141E-01	0.202E+01	0.650E-01	0.107E+02
11.00	0.000E+00	0.765E+01	0.137E-01	0.187E+01	0.589E-01	0.959E+01
12.00	0.000E+00	0.682E+01	0.132E-01	0.173E+01	0.536E-01	0.862E+01
13.00	0.000E+00	0.611E+01	0.129E-01	0.161E+01	0.488E-01	0.778E+01
14.00	0.000E+00	0.549E+01	0.125E-01	0.150E+01	0.446E-01	0.705E+01

A15. September 1989 SPE with 10 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.1674E+09	0.6098E+07	0.5190E+08	0.7084E+06
1.00	0.0000E+00	0.1396E+09	0.5947E+07	0.4558E+08	0.8677E+06
2.00	0.0000E+00	0.1184E+09	0.5697E+07	0.4077E+08	0.8667E+06
3.00	0.0000E+00	0.1015E+09	0.5413E+07	0.3692E+08	0.8228E+06
4.00	0.0000E+00	0.8781E+08	0.5132E+07	0.3374E+08	0.7662E+06
5.00	0.0000E+00	0.7652E+08	0.4854E+07	0.3105E+08	0.7077E+06
6.00	0.0000E+00	0.6711E+08	0.4585E+07	0.2873E+08	0.6517E+06
7.00	0.0000E+00	0.5918E+08	0.4330E+07	0.2671E+08	0.5998E+06
8.00	0.0000E+00	0.5244E+08	0.4089E+07	0.2493E+08	0.5524E+06
9.00	0.0000E+00	0.4666E+08	0.3862E+07	0.2335E+08	0.5093E+06
10.00	0.0000E+00	0.4169E+08	0.3648E+07	0.2193E+08	0.4702E+06
11.00	0.0000E+00	0.3737E+08	0.3448E+07	0.2065E+08	0.4348E+06
12.00	0.0000E+00	0.3361E+08	0.3261E+07	0.1948E+08	0.4026E+06
13.00	0.0000E+00	0.3031E+08	0.3086E+07	0.1842E+08	0.3734E+06
14.00	0.0000E+00	0.2741E+08	0.2921E+07	0.1745E+08	0.3468E+06

A15. (Continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.918E+03	0.137E-02	0.809E+01	0.111E+00	0.926E+03
1.00	0.000E+00	0.474E+03	0.154E-02	0.573E+01	0.763E-01	0.480E+03
2.00	0.000E+00	0.300E+03	0.163E-02	0.478E+01	0.571E-01	0.305E+03
3.00	0.000E+00	0.208E+03	0.168E-02	0.398E+01	0.447E-01	0.212E+03
4.00	0.000E+00	0.153E+03	0.171E-02	0.334E+01	0.361E-01	0.156E+03
5.00	0.000E+00	0.116E+03	0.171E-02	0.284E+01	0.297E-01	0.119E+03
6.00	0.000E+00	0.913E+02	0.170E-02	0.244E+01	0.249E-01	0.938E+02
7.00	0.000E+00	0.732E+02	0.169E-02	0.211E+01	0.211E-01	0.754E+02
8.00	0.000E+00	0.597E+02	0.166E-02	0.184E+01	0.181E-01	0.616E+02
9.00	0.000E+00	0.494E+02	0.163E-02	0.162E+01	0.156E-01	0.510E+02
10.00	0.000E+00	0.414E+02	0.160E-02	0.144E+01	0.136E-01	0.428E+02
11.00	0.000E+00	0.350E+02	0.156E-02	0.128E+01	0.119E-01	0.363E+02
12.00	0.000E+00	0.298E+02	0.152E-02	0.115E+01	0.105E-01	0.310E+02
13.00	0.000E+00	0.257E+02	0.148E-02	0.103E+01	0.927E-02	0.267E+02
14.00	0.000E+00	0.222E+02	0.144E-02	0.932E+00	0.824E-02	0.232E+02
15.00	0.000E+00	0.194E+02	0.140E-02	0.845E+00	0.735E-02	0.202E+02
16.00	0.000E+00	0.169E+02	0.136E-02	0.769E+00	0.658E-02	0.177E+02
17.00	0.000E+00	0.149E+02	0.132E-02	0.701E+00	0.592E-02	0.156E+02
18.00	0.000E+00	0.132E+02	0.128E-02	0.642E+00	0.533E-02	0.138E+02
20.00	0.000E+00	0.104E+02	0.121E-02	0.543E+00	0.436E-02	0.110E+02

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.139E+04	0.298E-01	0.895E+02	0.237E+01	0.148E+04
1.00	0.000E+00	0.624E+03	0.333E-01	0.390E+02	0.163E+01	0.665E+03
2.00	0.000E+00	0.384E+03	0.353E-01	0.296E+02	0.122E+01	0.415E+03
3.00	0.000E+00	0.261E+03	0.364E-01	0.234E+02	0.952E+00	0.285E+03
4.00	0.000E+00	0.189E+03	0.369E-01	0.191E+02	0.766E+00	0.209E+03
5.00	0.000E+00	0.142E+03	0.370E-01	0.160E+02	0.630E+00	0.159E+03
6.00	0.000E+00	0.111E+03	0.368E-01	0.136E+02	0.526E+00	0.125E+03
7.00	0.000E+00	0.881E+02	0.364E-01	0.117E+02	0.445E+00	0.100E+03
8.00	0.000E+00	0.714E+02	0.358E-01	0.102E+02	0.381E+00	0.820E+02
9.00	0.000E+00	0.588E+02	0.351E-01	0.894E+01	0.329E+00	0.681E+02
10.00	0.000E+00	0.490E+02	0.344E-01	0.792E+01	0.286E+00	0.572E+02
11.00	0.000E+00	0.413E+02	0.336E-01	0.707E+01	0.250E+00	0.486E+02
12.00	0.000E+00	0.351E+02	0.328E-01	0.635E+01	0.220E+00	0.417E+02
13.00	0.000E+00	0.301E+02	0.319E-01	0.573E+01	0.194E+00	0.361E+02
14.00	0.000E+00	0.260E+02	0.310E-01	0.520E+01	0.173E+00	0.314E+02
15.00	0.000E+00	0.226E+02	0.302E-01	0.474E+01	0.154E+00	0.275E+02
16.00	0.000E+00	0.198E+02	0.293E-01	0.433E+01	0.138E+00	0.243E+02
17.00	0.000E+00	0.174E+02	0.285E-01	0.397E+01	0.124E+00	0.215E+02
18.00	0.000E+00	0.153E+02	0.276E-01	0.365E+01	0.111E+00	0.191E+02
20.00	0.000E+00	0.121E+02	0.260E-01	0.312E+01	0.909E-01	0.153E+02

A16. October 1989 SPE with 2 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.2705E+10	0.2048E+08	0.1028E+09	0.4583E+07
1.00	0.0000E+00	0.1648E+10	0.2266E+08	0.9997E+08	0.5446E+07
2.00	0.0000E+00	0.1142E+10	0.2204E+08	0.9560E+08	0.5030E+07
3.00	0.0000E+00	0.8440E+09	0.2066E+08	0.9078E+08	0.4436E+07
4.00	0.0000E+00	0.6504E+09	0.1921E+08	0.8592E+08	0.3870E+07
5.00	0.0000E+00	0.5159E+09	0.1777E+08	0.8119E+08	0.3375E+07
6.00	0.0000E+00	0.4180E+09	0.1640E+08	0.7669E+08	0.2954E+07
7.00	0.0000E+00	0.3444E+09	0.1513E+08	0.7243E+08	0.2598E+07
8.00	0.0000E+00	0.2876E+09	0.1397E+08	0.6842E+08	0.2296E+07
9.00	0.0000E+00	0.2429E+09	0.1292E+08	0.6467E+08	0.2040E+07
10.00	0.0000E+00	0.2071E+09	0.1196E+08	0.6116E+08	0.1820E+07
11.00	0.0000E+00	0.1779E+09	0.1108E+08	0.5788E+08	0.1630E+07
12.00	0.0000E+00	0.1540E+09	0.1029E+08	0.5481E+08	0.1466E+07
13.00	0.0000E+00	0.1341E+09	0.9566E+07	0.5194E+08	0.1323E+07
14.00	0.0000E+00	0.1174E+09	0.8904E+07	0.4925E+08	0.1197E+07
15.00	0.0000E+00	0.1032E+09	0.8299E+07	0.4673E+08	0.1087E+07
16.00	0.0000E+00	0.9120E+08	0.7744E+07	0.4437E+08	0.9899E+06
17.00	0.0000E+00	0.8088E+08	0.7235E+07	0.4215E+08	0.9037E+06
18.00	0.0000E+00	0.7198E+08	0.6767E+07	0.4007E+08	0.8270E+06
20.00	0.0000E+00	0.5755E+08	0.5938E+07	0.3627E+08	0.7003E+06

A16. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.276E+03	0.206E-02	0.395E+01	0.528E-01	0.280E+03
1.00	0.000E+00	0.189E+03	0.203E-02	0.337E+01	0.416E-01	0.192E+03
2.00	0.000E+00	0.140E+03	0.200E-02	0.300E+01	0.337E-01	0.143E+03
3.00	0.000E+00	0.107E+03	0.196E-02	0.262E+01	0.279E-01	0.110E+03
4.00	0.000E+00	0.847E+02	0.192E-02	0.228E+01	0.235E-01	0.870E+02
5.00	0.000E+00	0.682E+02	0.188E-02	0.200E+01	0.200E-01	0.703E+02
6.00	0.000E+00	0.559E+02	0.183E-02	0.176E+01	0.171E-01	0.577E+02
7.00	0.000E+00	0.464E+02	0.178E-02	0.155E+01	0.148E-01	0.480E+02
8.00	0.000E+00	0.390E+02	0.173E-02	0.138E+01	0.129E-01	0.404E+02
9.00	0.000E+00	0.331E+02	0.168E-02	0.123E+01	0.114E-01	0.343E+02
10.00	0.000E+00	0.283E+02	0.163E-02	0.111E+01	0.100E-01	0.294E+02
11.00	0.000E+00	0.244E+02	0.159E-02	0.100E+01	0.888E-02	0.254E+02
12.00	0.000E+00	0.212E+02	0.154E-02	0.905E+00	0.790E-02	0.221E+02
13.00	0.000E+00	0.185E+02	0.149E-02	0.822E+00	0.706E-02	0.193E+02
14.00	0.000E+00	0.162E+02	0.145E-02	0.749E+00	0.633E-02	0.169E+02
15.00	0.000E+00	0.143E+02	0.140E-02	0.685E+00	0.569E-02	0.150E+02
16.00	0.000E+00	0.126E+02	0.136E-02	0.628E+00	0.513E-02	0.133E+02
17.00	0.000E+00	0.112E+02	0.131E-02	0.577E+00	0.464E-02	0.118E+02
18.00	0.000E+00	0.100E+02	0.127E-02	0.532E+00	0.420E-02	0.105E+02
20.00	0.000E+00	0.803E+01	0.119E-02	0.455E+00	0.347E-02	0.849E+01

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.375E+03	0.447E-01	0.379E+02	0.112E+01	0.414E+03
1.00	0.000E+00	0.236E+03	0.439E-01	0.213E+02	0.884E+00	0.258E+03
2.00	0.000E+00	0.172E+03	0.432E-01	0.178E+02	0.715E+00	0.191E+03
3.00	0.000E+00	0.131E+03	0.424E-01	0.151E+02	0.591E+00	0.146E+03
4.00	0.000E+00	0.102E+03	0.415E-01	0.129E+02	0.496E+00	0.116E+03
5.00	0.000E+00	0.819E+02	0.405E-01	0.112E+02	0.421E+00	0.936E+02
6.00	0.000E+00	0.667E+02	0.395E-01	0.981E+01	0.361E+00	0.770E+02
7.00	0.000E+00	0.552E+02	0.384E-01	0.866E+01	0.313E+00	0.642E+02
8.00	0.000E+00	0.462E+02	0.374E-01	0.770E+01	0.272E+00	0.542E+02
9.00	0.000E+00	0.390E+02	0.363E-01	0.690E+01	0.239E+00	0.462E+02
10.00	0.000E+00	0.333E+02	0.352E-01	0.621E+01	0.210E+00	0.397E+02
11.00	0.000E+00	0.286E+02	0.342E-01	0.562E+01	0.186E+00	0.344E+02
12.00	0.000E+00	0.248E+02	0.331E-01	0.511E+01	0.165E+00	0.301E+02
13.00	0.000E+00	0.216E+02	0.321E-01	0.466E+01	0.148E+00	0.264E+02
14.00	0.000E+00	0.189E+02	0.311E-01	0.427E+01	0.132E+00	0.233E+02
15.00	0.000E+00	0.166E+02	0.301E-01	0.392E+01	0.119E+00	0.207E+02
16.00	0.000E+00	0.147E+02	0.292E-01	0.362E+01	0.107E+00	0.184E+02
17.00	0.000E+00	0.130E+02	0.282E-01	0.334E+01	0.967E-01	0.165E+02
18.00	0.000E+00	0.116E+02	0.273E-01	0.309E+01	0.876E-01	0.148E+02
20.00	0.000E+00	0.930E+01	0.256E-01	0.267E+01	0.723E-01	0.121E+02

A17. October 1989 SPE with 5 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.1046E+10	0.1883E+08	0.1391E+09	0.3059E+07
1.00	0.0000E+00	0.7762E+09	0.1867E+08	0.1239E+09	0.3555E+07
2.00	0.0000E+00	0.6022E+09	0.1774E+08	0.1121E+09	0.3370E+07
3.00	0.0000E+00	0.4804E+09	0.1658E+08	0.1023E+09	0.3054E+07
4.00	0.0000E+00	0.3912E+09	0.1544E+08	0.9400E+08	0.2728E+07
5.00	0.0000E+00	0.3236E+09	0.1434E+08	0.8682E+08	0.2429E+07
6.00	0.0000E+00	0.2712E+09	0.1330E+08	0.8052E+08	0.2164E+07
7.00	0.0000E+00	0.2297E+09	0.1234E+08	0.7492E+08	0.1933E+07
8.00	0.0000E+00	0.1963E+09	0.1145E+08	0.6992E+08	0.1732E+07
9.00	0.0000E+00	0.1691E+09	0.1064E+08	0.6542E+08	0.1557E+07
10.00	0.0000E+00	0.1466E+09	0.9894E+07	0.6134E+08	0.1405E+07
11.00	0.0000E+00	0.1278E+09	0.9212E+07	0.5763E+08	0.1271E+07
12.00	0.0000E+00	0.1121E+09	0.8586E+07	0.5424E+08	0.1153E+07
13.00	0.0000E+00	0.9873E+08	0.8013E+07	0.5113E+08	0.1050E+07
14.00	0.0000E+00	0.8733E+08	0.7486E+07	0.4826E+08	0.9576E+06
15.00	0.0000E+00	0.7754E+08	0.7001E+07	0.4562E+08	0.8757E+06
16.00	0.0000E+00	0.6908E+08	0.6554E+07	0.4317E+08	0.8028E+06
17.00	0.0000E+00	0.6173E+08	0.6142E+07	0.4089E+08	0.7375E+06
18.00	0.0000E+00	0.5533E+08	0.5761E+07	0.3878E+08	0.6789E+06
20.00	0.0000E+00	0.4479E+08	0.5083E+07	0.3497E+08	0.5810E+06

A17. (continued)

DOSE CONTRIBUTIONS, cGy

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.896E+02	0.238E-02	0.185E+01	0.239E-01	0.914E+02
1.00	0.000E+00	0.703E+02	0.225E-02	0.178E+01	0.203E-01	0.721E+02
2.00	0.000E+00	0.572E+02	0.215E-02	0.167E+01	0.174E-01	0.589E+02
3.00	0.000E+00	0.473E+02	0.206E-02	0.152E+01	0.150E-01	0.488E+02
4.00	0.000E+00	0.397E+02	0.198E-02	0.137E+01	0.131E-01	0.410E+02
5.00	0.000E+00	0.336E+02	0.191E-02	0.123E+01	0.115E-01	0.348E+02
6.00	0.000E+00	0.287E+02	0.184E-02	0.111E+01	0.101E-01	0.298E+02
7.00	0.000E+00	0.247E+02	0.177E-02	0.101E+01	0.894E-02	0.257E+02
8.00	0.000E+00	0.214E+02	0.171E-02	0.914E+00	0.795E-02	0.223E+02
9.00	0.000E+00	0.187E+02	0.165E-02	0.831E+00	0.710E-02	0.195E+02
10.00	0.000E+00	0.164E+02	0.159E-02	0.759E+00	0.636E-02	0.171E+02
11.00	0.000E+00	0.144E+02	0.153E-02	0.695E+00	0.572E-02	0.151E+02
12.00	0.000E+00	0.127E+02	0.148E-02	0.637E+00	0.515E-02	0.134E+02
13.00	0.000E+00	0.113E+02	0.143E-02	0.586E+00	0.466E-02	0.119E+02
14.00	0.000E+00	0.101E+02	0.138E-02	0.541E+00	0.422E-02	0.106E+02
15.00	0.000E+00	0.901E+01	0.133E-02	0.500E+00	0.383E-02	0.952E+01
16.00	0.000E+00	0.809E+01	0.129E-02	0.463E+00	0.348E-02	0.855E+01
17.00	0.000E+00	0.727E+01	0.124E-02	0.429E+00	0.318E-02	0.771E+01
18.00	0.000E+00	0.656E+01	0.120E-02	0.399E+00	0.290E-02	0.696E+01
20.00	0.000E+00	0.538E+01	0.112E-02	0.347E+00	0.243E-02	0.573E+01

DOSE EQ. CONTRIBUTIONS, cSv

x	Mono prim.	proton	neut(hi)	light ion	heavy-ion	total
0.00	0.000E+00	0.115E+03	0.515E-01	0.165E+02	0.506E+00	0.132E+03
1.00	0.000E+00	0.846E+02	0.487E-01	0.111E+02	0.428E+00	0.962E+02
2.00	0.000E+00	0.685E+02	0.465E-01	0.989E+01	0.366E+00	0.788E+02
3.00	0.000E+00	0.563E+02	0.445E-01	0.880E+01	0.316E+00	0.655E+02
4.00	0.000E+00	0.470E+02	0.428E-01	0.786E+01	0.275E+00	0.552E+02
5.00	0.000E+00	0.397E+02	0.411E-01	0.706E+01	0.241E+00	0.470E+02
6.00	0.000E+00	0.338E+02	0.396E-01	0.637E+01	0.212E+00	0.404E+02
7.00	0.000E+00	0.290E+02	0.381E-01	0.577E+01	0.188E+00	0.350E+02
8.00	0.000E+00	0.251E+02	0.367E-01	0.525E+01	0.167E+00	0.305E+02
9.00	0.000E+00	0.218E+02	0.354E-01	0.479E+01	0.149E+00	0.268E+02
10.00	0.000E+00	0.191E+02	0.342E-01	0.439E+01	0.133E+00	0.236E+02
11.00	0.000E+00	0.168E+02	0.330E-01	0.404E+01	0.119E+00	0.210E+02
12.00	0.000E+00	0.148E+02	0.318E-01	0.372E+01	0.108E+00	0.187E+02
13.00	0.000E+00	0.131E+02	0.307E-01	0.344E+01	0.972E-01	0.167E+02
14.00	0.000E+00	0.117E+02	0.296E-01	0.319E+01	0.880E-01	0.150E+02
15.00	0.000E+00	0.105E+02	0.286E-01	0.296E+01	0.798E-01	0.135E+02
16.00	0.000E+00	0.938E+01	0.276E-01	0.276E+01	0.726E-01	0.122E+02
17.00	0.000E+00	0.843E+01	0.267E-01	0.257E+01	0.661E-01	0.111E+02
18.00	0.000E+00	0.760E+01	0.258E-01	0.240E+01	0.603E-01	0.101E+02
20.00	0.000E+00	0.622E+01	0.241E-01	0.211E+01	0.505E-01	0.840E+01

A18. October 1989 SPE with 10 g/cm^2 Al

TOTAL FLUENCE, #/cm^2/primary

x	primary	prot(1)	prot(2)	neutron	light ion
0.00	0.0000E+00	0.4047E+09	0.1388E+08	0.1463E+09	0.1660E+07
1.00	0.0000E+00	0.3316E+09	0.1338E+08	0.1275E+09	0.1978E+07
2.00	0.0000E+00	0.2767E+09	0.1264E+08	0.1131E+09	0.1939E+07
3.00	0.0000E+00	0.2337E+09	0.1184E+08	0.1016E+09	0.1812E+07
4.00	0.0000E+00	0.1993E+09	0.1109E+08	0.9206E+08	0.1663E+07
5.00	0.0000E+00	0.1714E+09	0.1036E+08	0.8403E+08	0.1516E+07
6.00	0.0000E+00	0.1484E+09	0.9671E+07	0.7715E+08	0.1379E+07
7.00	0.0000E+00	0.1293E+09	0.9030E+07	0.7117E+08	0.1255E+07
8.00	0.0000E+00	0.1133E+09	0.8436E+07	0.6592E+08	0.1144E+07
9.00	0.0000E+00	0.9971E+08	0.7886E+07	0.6128E+08	0.1044E+07
10.00	0.0000E+00	0.8813E+08	0.7377E+07	0.5714E+08	0.9553E+06
11.00	0.0000E+00	0.7820E+08	0.6908E+07	0.5343E+08	0.8756E+06
12.00	0.0000E+00	0.6963E+08	0.6473E+07	0.5007E+08	0.8041E+06
13.00	0.0000E+00	0.6220E+08	0.6072E+07	0.4703E+08	0.7399E+06
14.00	0.0000E+00	0.5572E+08	0.5700E+07	0.4426E+08	0.6820E+06
15.00	0.0000E+00	0.5005E+08	0.5355E+07	0.4172E+08	0.6298E+06
16.00	0.0000E+00	0.4507E+08	0.5036E+07	0.3939E+08	0.5826E+06
17.00	0.0000E+00	0.4068E+08	0.4739E+07	0.3724E+08	0.5399E+06
18.00	0.0000E+00	0.3680E+08	0.4464E+07	0.3526E+08	0.5011E+06
20.00	0.0000E+00	0.3028E+08	0.3968E+07	0.3171E+08	0.4352E+06

A18. (continued)

VITA

William Maxson was born in Banner Elk, North Carolina on February 25, 1972. After attending a succession of schools, he graduated from Morristown-Hamblen East High School in June, 1990. He entered Carson-Newman College the following fall and graduated in May, 1994 with Bachelor of Arts degrees in Physics and Chemistry. Later he entered the Master of Science degree program in Nuclear Engineering with Radiological Safety emphasis in June, 1995 at The University of Tennessee. While in Knoxville, he also worked as a graduate student assistant in the University Radiological Safety Office and received a Master of Science Degree in December, 1996.