# Safety-

## 1) Radiation Effects to Humans

**Important Factor to the Health of Humans ---**

***Dose Equivalent = The biological effect on specific organs from all radiation expressed on a common scale***

***Dose equivalent = Absorbed Dose (D) x Quality Factor (Q)***

**Absorbed Dose =*The Energy imparted to matter by ionizing radiation per unit mass of irradiated material at the point of interest***

**Units => Gray (Gy)**
**=> Rad (ergs/g)**

**1 Gy = 1 joule/kg=10,000 ergs/g**
**= 100 Rad**

**1 Rad = 0.01 Gy = 10 mGy=100 ergs/g**

**Note : 1 Roentgen (R) is defined as the amount of radiation ( X ray or gammas) that creates**
**$2.58 \times 10^{-4}$ coulomb /kg of air**

**1 R ( 0.1-3 MeV) ≈ 0.87 rad in air**
**≈ 0.98 rad in soft tissue**

# Radiation Effects to Humans

**Dose Equivalence = Absorbed Dose • Quality Factor**

| *Absorbed Dose (AD)* | *Quality Factor (QF)* |
|---|---|
| " Energy Imparted to Matter by Ionizing Radiation per Unit Mass of Irradiated Material." | "Relates the Absorbed Dose to the Biological Effects and is Dependent on the Linear Energy Transfer (LET) of Ionizing Radiation." |
| Rad = 100 ergs/gram<br><br>Gray = 100 Rads | QF — LET in $H_2O$ (keV/$\mu$)<br>1 — <3.5<br>2 — 7<br>5 — 23<br>10 — 53<br>20 — 175 |

**Rem = Rad • QF**
**(SI Units) Sievert = Gray • QF**

# RECOMMENDED QUALITY FACTOR VALUES

| QF | Type of Radiation |
|---|---|
| 1 | X-rays, gamma rays, electrons, positrons. |
| 10 | Neutrons (fast), protons, and singly charged particles of rest mass greater than 1 amu of unknown energy. |
| 20 | Alpha particles, multiply charged particles, and particles of unknown charge and/or unknown energy. |
| [WHEN NEUTRON ENERGY SPECTRUM IS KNOWN] | |
| 2 | thermal neutrons |
| 2.5 | 0.01 MeV neutrons |
| 7.5 | 0.1 MeV neutrons |
| 11 | 0.5 MeV neutrons |
| 11 | 1.0 MeV neutrons |
| 6.5 | 10 MeV neutrons |

dose equivalent (rem) = absorbed dose (rad) × quality factor (QF)

× modifying factor . (*N*)

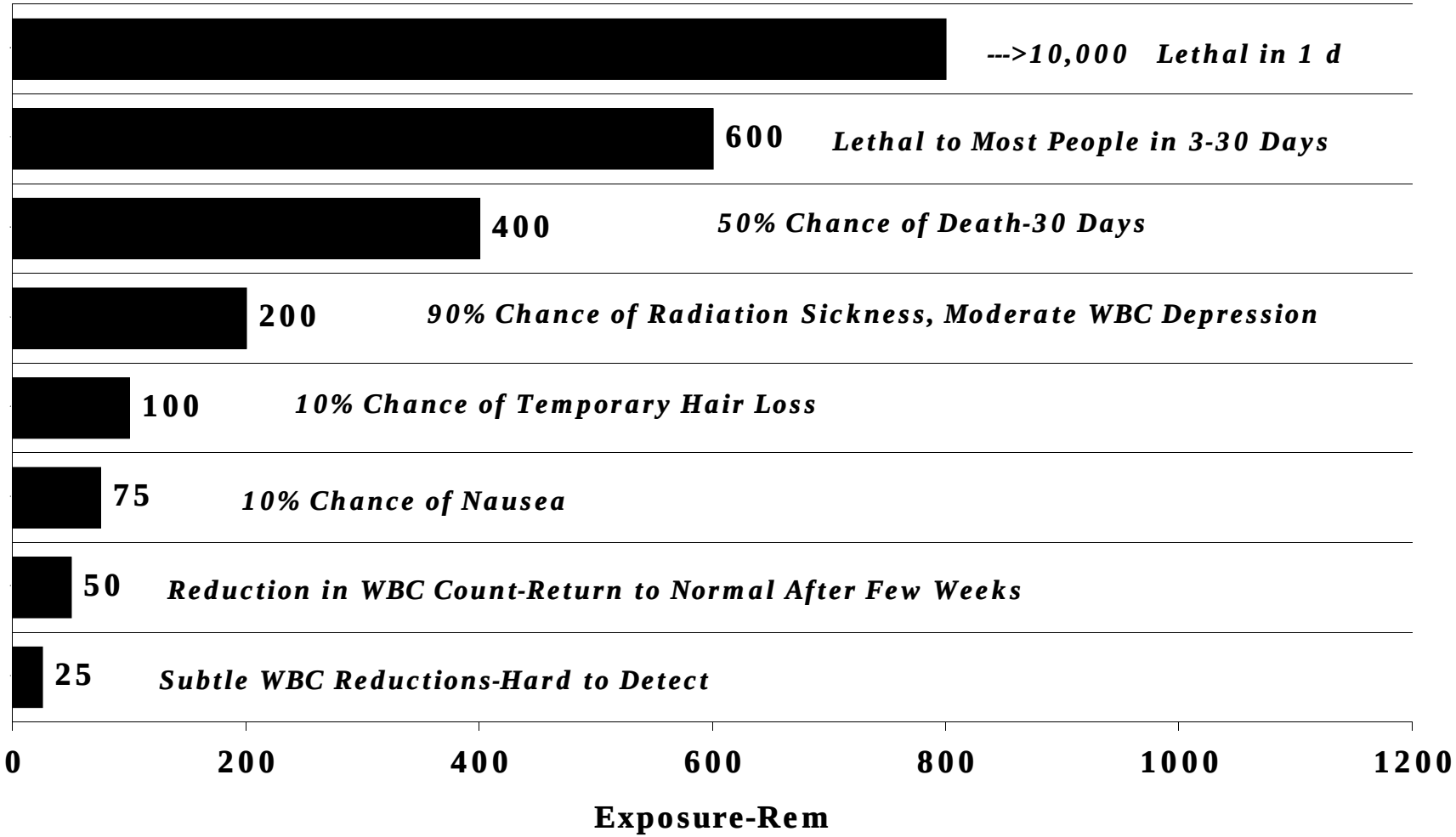
# PERMISSIBLE OCCUPATIONAL WORKER EXPOSURE LEVELS

| Type of Radiation Exposure | Exposure Period | Maximum Possible Dose Equivalent (rem) | (mSv) |
|---|---|---|---|
| Wholebody, head and trunk, gonads, lens of the eye, red bone marrow, active blood forming organs | Year | 5 | 50 |
| | Calendar quarter (13 weeks) | 3 | 30 |
| Unlimited areas of the skin, except hands and forearms; other organs, tissues, and organ systems, except bone | Year | 15 | 150 |
| | Calendar quarter | 5 | 50 |
| Bone and forearms | Year | 30 | 300 |
| | Calendar quarter | 10 | 100 |
| Hands and feet | Year | 75 | 750 |
| | Calendar quarter | 25 | 250 |

# CURRENTLY PERMISSIBLE EXPOSURE STANDARDS FOR THE GENERAL PUBLIC

| Type of Radiation Exposure | Annual Maximum Permissible Dose Equivalent | | | |
|---|---|---|---|---|
| | Based on Dose to Individuals At Points Of Maximum Probable Exposure | | Based on Average Dose To a Suitable Sample Of the Exposed Population | |
| | (rem) | (mSv) | (rem) | (mSv) |
| Wholebody, gonads, or bone marrow | 0.5 | 5 | 0.17 | 1.7 |
| Other organs | 1.5 | 15 | 0.50 | 5.0 |

## Acute Radiation Effects From Whole Body Exposure to Gamma Radiation



# EFFECTS TO THE BODY FROM LOCALIZED EXPOSURE TO X AND GAMMA RADIATION

| Organ of Body | Acute Irradiation Level (rem) | (sievert) | Acute and Delayed Biological Effects |
|---|---|---|---|
| SKIN | 300 | 3.0 | Erythema or "sunburn" effect noticeable. |
| | 1500 | 15.0 | Raw, moist skin surface where irradiated. |
| | 5000–7000 | 50–70 | Ulceration, slow healing, possible skin cancer |
| GONADS | 50 | 0.5 | Brief functional sterility in males only. |
| | 250 | 2.5 | Sterility for 1 to 2 years in both male and female. |
| | 600 | 6.0 | Permanent sterility. |
| EYE | 200 | 2.0 | Change in optic lens opacity. |
| | 600 | 6.0 | Clinically significant cataract. |
| FETUS | 10–20 | 0.1–0.2 | Significant probability of malformation, if irradiation occurs in first 3 months of pregnancy. |

# Risk of Illness

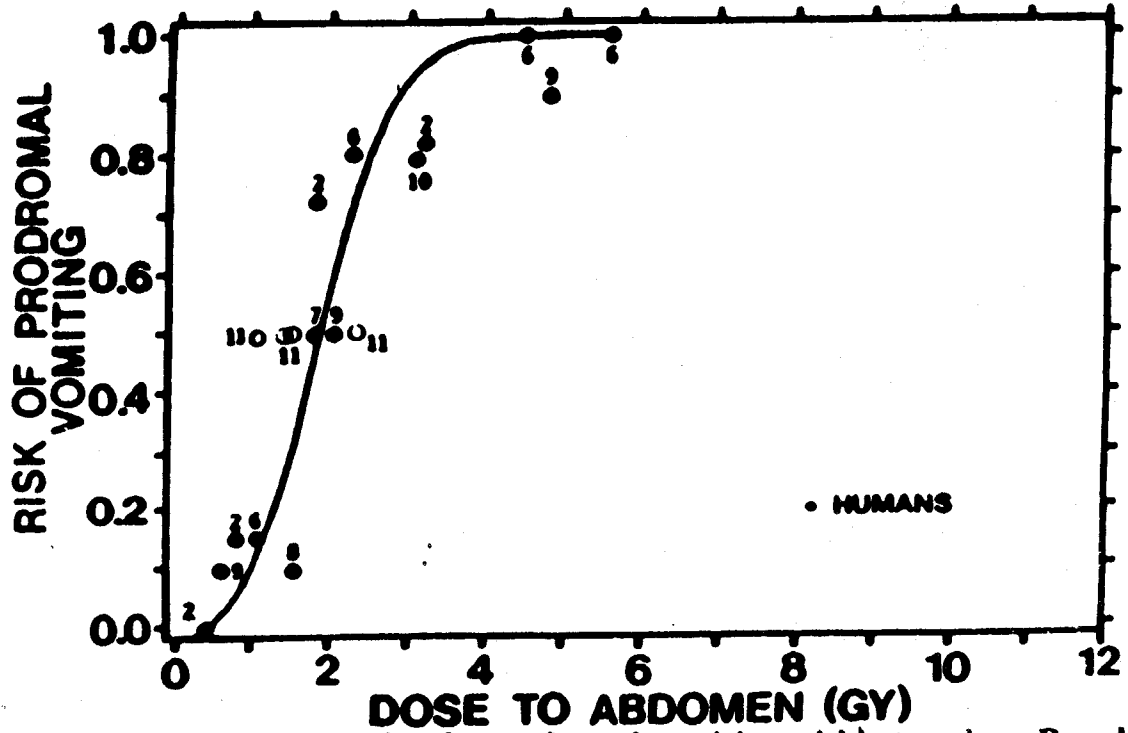
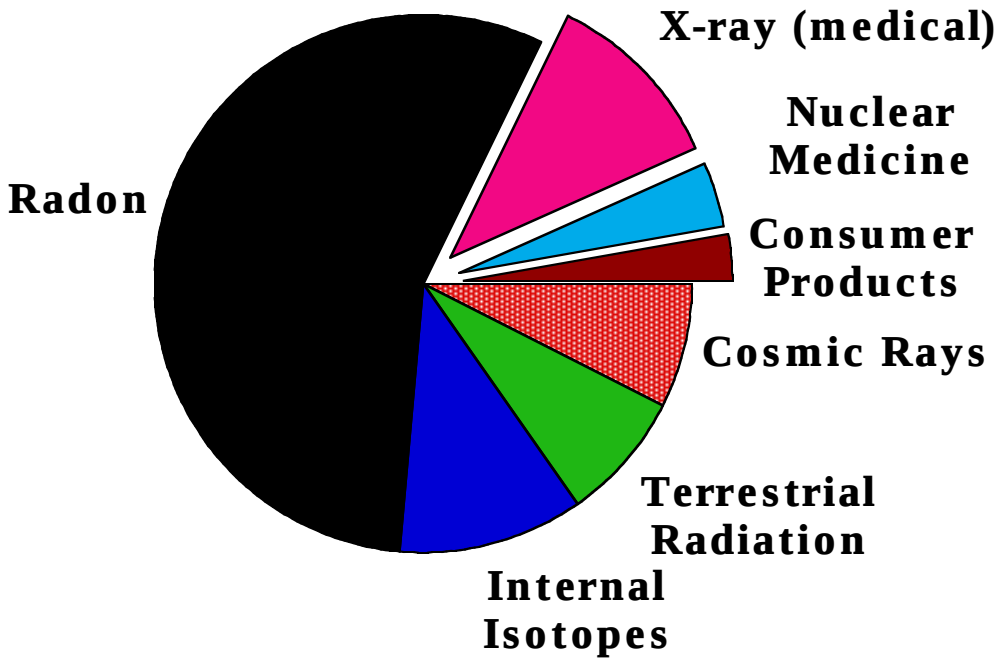



**Fig. 5.7 Dose-effect relationship for prodromal vomiting within two days. Based on information provided in the Reactor Safety Study (NRC, 1975) with additional data from Lushbaugh (1982), based on 2,000 patients given therapeutic total-body irradiation. The median effective doses given by the open circles, #11, represent from left to right anorexia, nausea, fatigue, vomiting, and diarrhea. Origin of other data: 2, NAS/NRC (1967), accident exposure cases; 6, accident exposure cases (Thoma and Wald, 1959; updated); 7, therapy patients (Thomas, *et al.*, 1975; 1977); 8, Rongelap fallout cases, protracted 50-hour exposure (NAS/NRC, 1967); 9, half the difference between normal arithmetical and log-normal values given in NAS/NRC (1967); 10, Toronto-therapy cases (11/14) with Gravol pretreatment (from Evans *et al.*, 1985).**

# Average Annual Radiation Dose to Average U. S. Citizen




**0.35 Rem/y**

# TYPICAL NASA MISSION SCENARIOS

- 3 YR MARS MISSION
  - 1 YR ON SURFACE
- 90 DAY LUNAR MISSION
  - 86 DAYS ON SURFACE
- 15 DAY LEO-TO-GEO SORTIE
- 90 DAY LEO LOW INCLINATION ORBIT
  - 450 km, 28.5° INCLINATION
- 90 DAY LEO MEDIUM INCLINATION ORBIT
  - 450 km, 57° INCLINATION
- 90 DAY LEO POLAR ORBIT
  - 450 km, 90° INCLINATION

# Radiation Environment in Space

- ***Geomagnetically Trapped Particles***

  **-Inner Zone (<2.8 Earth radii), Protons & Electrons**
  **-Outer Zone (2.8-12 Earth radii), Electrons & Protons**
  **-Intensities Vary Slowly from Solar Activity, Magnetic Storms, & Solar Cycles**

- ***Galactic Cosmic Rays (GCR)***

  **-87% Protons, 12% He Ions, 1% HZE (high Z & energy ions)**
  **-HZE is a Major GCR Dose Contributor**
  **-Intensities Vary with Solar Wind, Magnetic Field, & Solar Cycles**

- ***Solar Particle Events (SPE)***

  **-Sporadic Large Solar Emissions of Protons, He, & Heavier Ions**
  **-Wide Variations in Intensity & Duration**
  **-Ave. Time from Detection to Arrival ≈ 15 h (range of 0.25-60 h)**

# ESTIMATED NATURAL RADIATION DOSES* FOR TYPICAL MISSION SCENARIOS

| MISSION | DURATION | RADIATION SOURCE | DOSE EQUIVALENT (mSv) TO THE BFO |
|---|---|---|---|
| MARS | 2 YR FLIGHT(1)<br>1 YR SURFACE(2)<br><br>3 YR TOTAL | PROTONS, ELECTRONS, GCR<br>GCR | 900<br>100<br><br>1000 100 Rem |
| LUNAR | 4 DAY FLIGHT(1)<br>86 DAY SURFACE<br><br>90 DAY TOTAL | PROTONS, ELECTRONS, GCR<br>GCR | 45<br>35<br><br>80 |
| GEO SORTIE, 0° | 15 DAY(1) | TRAPPED ELECTRONS, GCR | 60 |
| LEO, 28.5° | 90 DAY(1) | TRAPPED PROTONS, GCR | 110 |
| LEO, 57° | 90 DAY(1) | TRAPPED PROTONS, GCR | 70 |
| LEO, 90° | 90 DAY(1) | TRAPPED PROTONS, GCR | 70 |

* SOLAR PARTICLE EVENTS (SPE) NOT INCLUDED
(1) WITH SPACECRAFT SHIELD OF 2 g/cm² ALUMINUM
(2) MARS ATMOSPHERE SHIELD OF 10 g/cm² $CO_2$

10m Sv = 1 Rem

Blood Forming Organs

# DEFINITIONS

## CAREER LIMITS

Based on a uniform whole body exposure lifetime absolute excess risk of 3 percent for the later or delayed effects of carcinogenesis and genetic damage

## SHORT-TERM LIMITS

Based on acute specific organ exposures (BFO, Eye, Skin) that do not produce any acute or delayed non-cancer effects

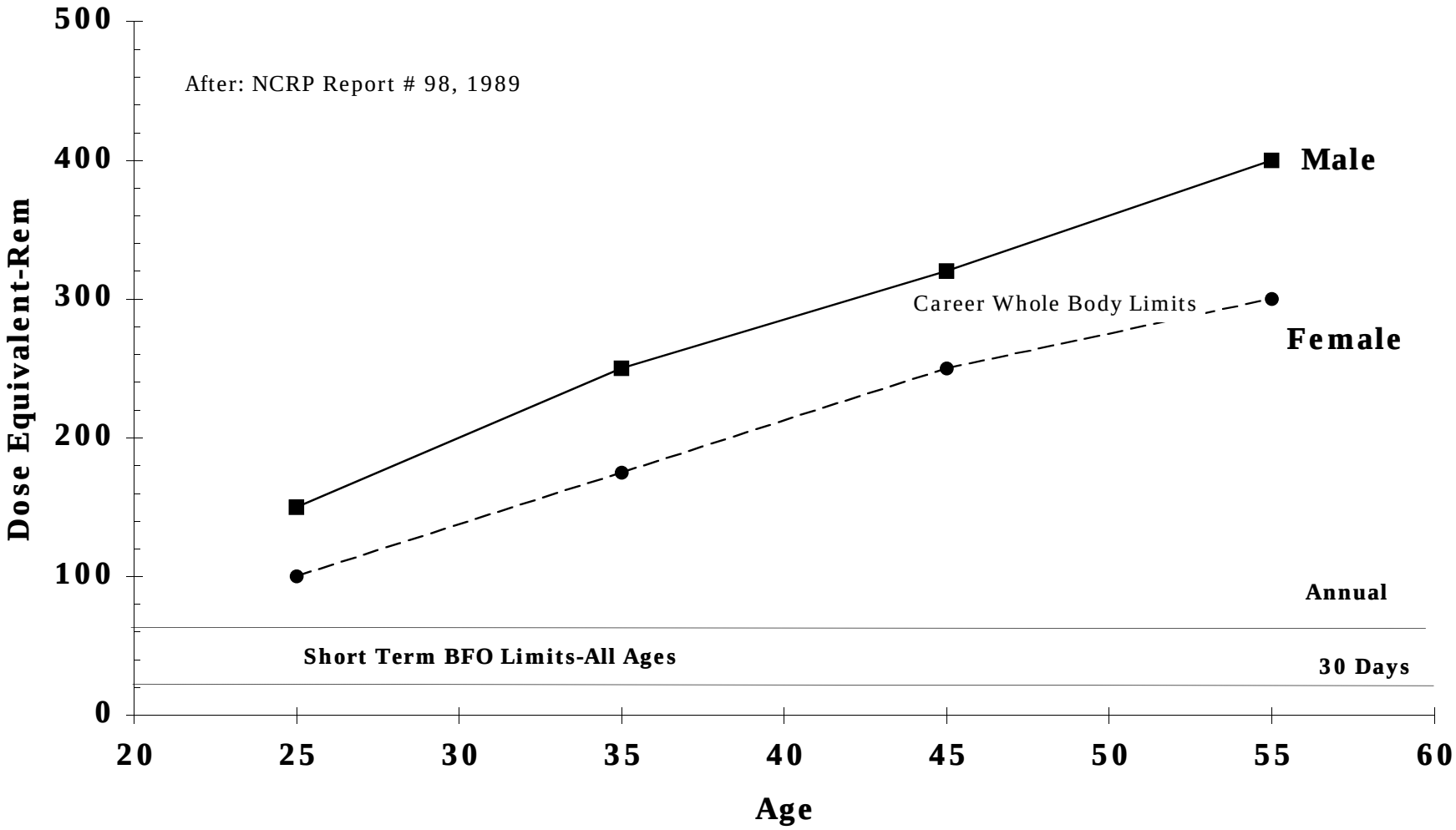
**TABLE 1 Proposed NASA Radiation Dose-Equivalent Limits (mSv) for Exposure of Spaceflight Crewmembers to Natural Sources of Radiation**

| Time Period | Blood Forming Organs | Lens of Eye | Skin |
|---|---|---|---|
| 30 Days | 250 | 1000 | 1500 |
| Annual | 500 | 2000 | 3000 |
| Career | See Table 2 | 4000 | 6000 |

**TABLE 2 Proposed NASA Standard for Career Wholebody Dose-Equivalent Limits Based on a Lifetime Excess Risk of Cancer Mortality of 3 percent**

| Age (Years) | Female (Sv) | Male (Sv) |
|---|---|---|
| 25 | 1.0 | 1.5 |
| 35 | 1.75 | 2.5 |
| 45 | 2.5 | 3.2 |
| 55 | 3.0 | 4.0 |

**The Recommended Career Dose Limits for Space Activities Depend on Gender and Age**



# RADIATION EXPOSURE LIMITS

## Recommended for Spaceflight Crewmembers

| Constraint | Primary Reference Risk* rem [Sv] | Ancillary Reference Risks: Bone Marrow** (Dose Equivalent at 5 cm) rem [Sv] | Skin (Dose Equivalent at 0.1 mm) rem [Sv] | Ocular Lens (Dose Equivalent at 3 mm) rem [Sv] | Testes (Dose Equivalent at 3 cm) rem [Sv] |
|---|---|---|---|---|---|
| 1 year average daily dose | | 0.2 [0.002] | 0.6 [0.006] | 0.3 [0.003] | 0.1 [0.001] |
| 30 day maximum | | 25 [0.25] | 75 [0.75] | 37 [0.37] | 13 [0.13] |
| Quarterly maximum*** | | 34 [0.34] | 105 [1.05] | 52 [0.52] | 18 [0.18] |
| Yearly maximum | | 75 [0.75] | 225 [2.25] | 112 [1.12] | 38 [0.38] |
| Career limit | 400 [4.0] | 400 [4.0] | 1200 [12.0] | 600 [6.0] | 200 [2.0] |

* Dose equivalent at 5 cm depth in tissue

** Wholebody exposure

*** May be permitted for two consecutive quarters followed by 6 months of restriction from further exposure to maintain yearly limit and includes all occupational exposures

# PUBLISHED SOVIET MAX PERMISSIBLE DOSE LEVELS (1982)

| T, MONTHS | MPD, REM | |
|---|---|---|
| 1 | 50 | US=25 |
| 2 | 65 | |
| 3 | 80 | |
| 4 | 90 | |
| 5 | 100 | |
| 6 | 110 | |
| 8 | 125 | |
| 10 | 140 | |
| 12 | 150 | US= 75 |

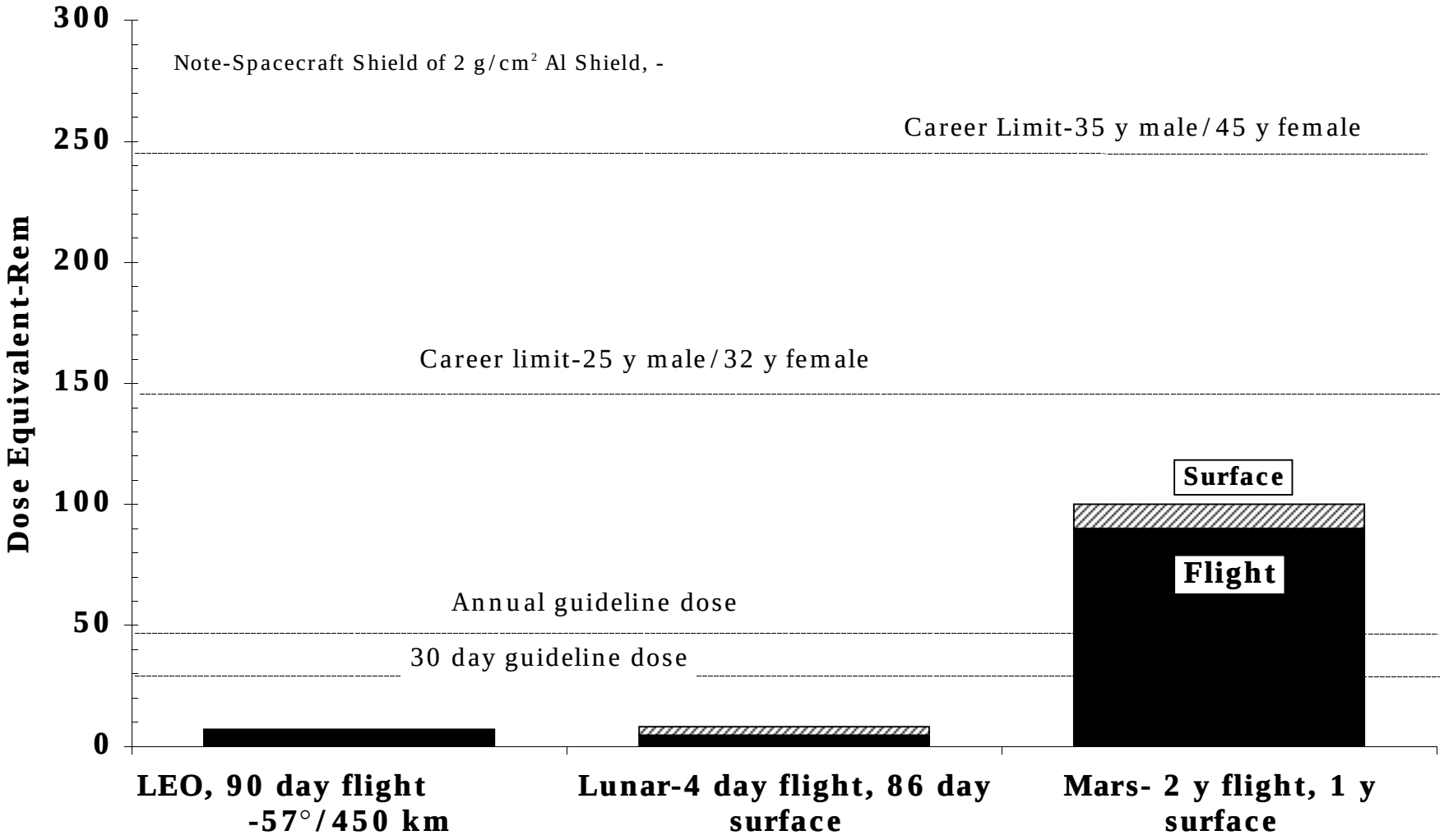
# IMPACT OF SHORT TERM DOSE LIMITS ON NASA MISSION SCENARIOS

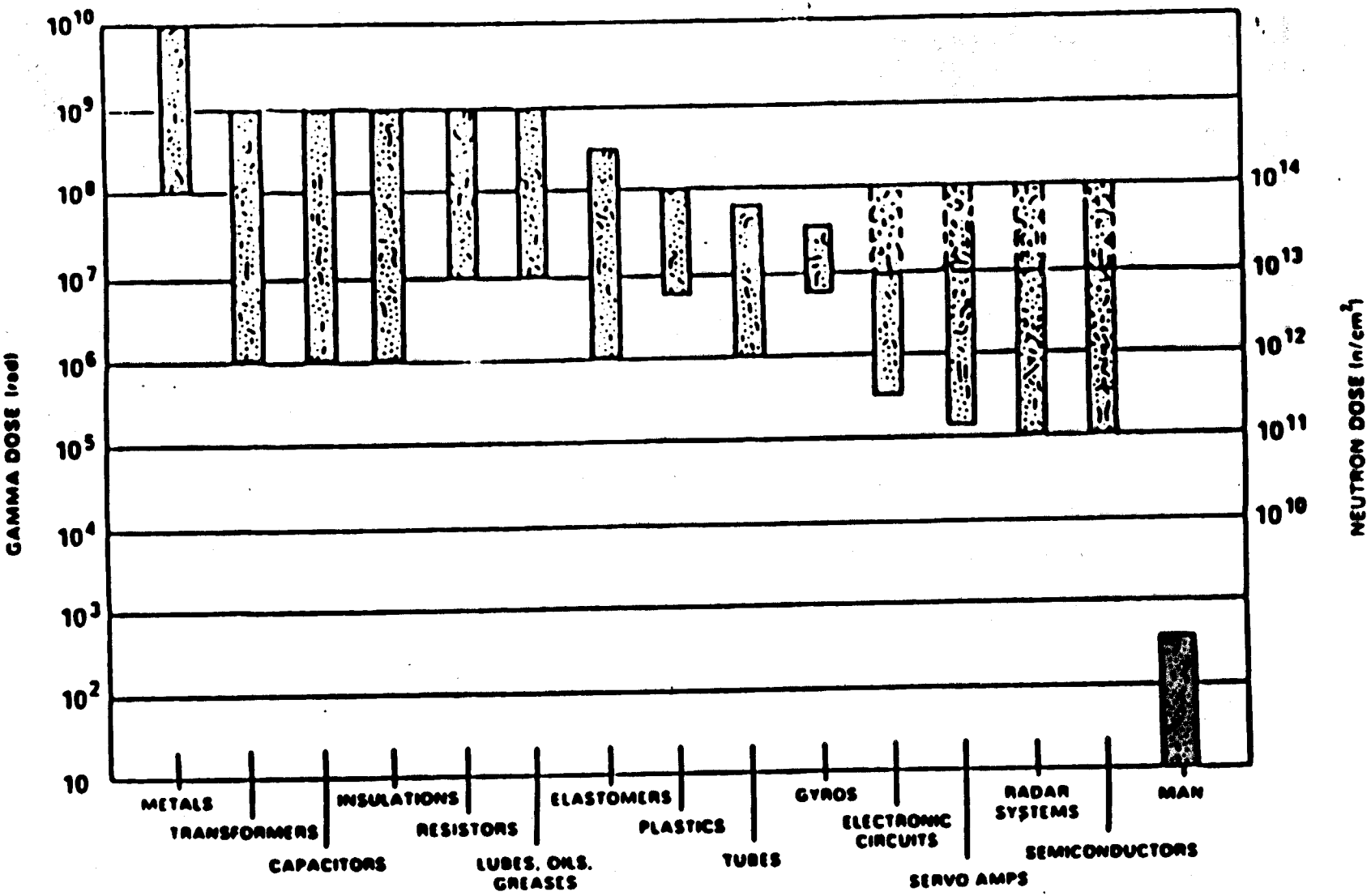
| MISSION | HIGHEST 30 DAY DOSE[1] (rem) | % OF 30 DAY DOSE LIMIT | HIGHEST ANNUAL DOSE[1] (rem) | % OF ANNUAL DOSE LIMIT | IMPACT ON NUCLEAR SOURCES |
|---|---|---|---|---|---|
| 3 YR MARS | | | | | |
| FLIGHT | 14 | 56 | 55 | 110* | YES |
| SURFACE | 11 | 43 | 20 | 40 | NO |
| 90 DAY LUNAR SURFACE | 15 | 60 | 21 | 42 | NO |
| 15 DAY GEO | 26 | 104* | 26 | 52 | YES |
| 90 DAY LEO-28.5° | 4 | 16 | 11 | 22 | NO |
| 90 DAY LEO-57° | 3 | 12 | 8 | 16 | NO |
| 90 DAY LEO-90° | 8 | 30 | 12 | 24 | NO |

* EXCEEDS LIMIT

(1) INCLUDES ALSPE SHIELDED BY 10 g/cm²

**The Anticipated Background Radiation Doses During Space Missions Are Reasonable Except For Mars Missions**






$10^{6}$ n/cm² ≅ 1 rad