Overview of Integrated Space Radiation Protection Program

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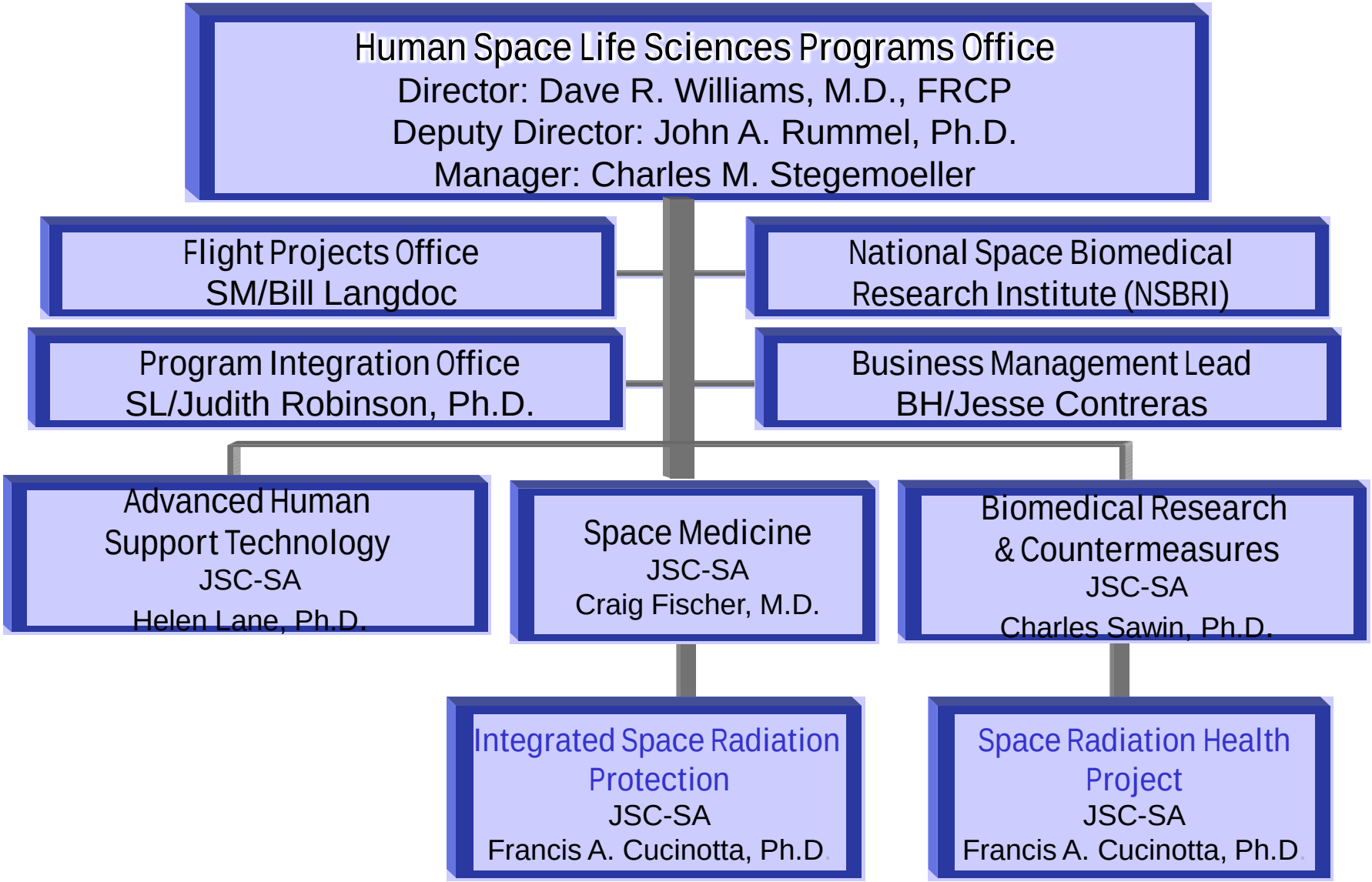
Introduction

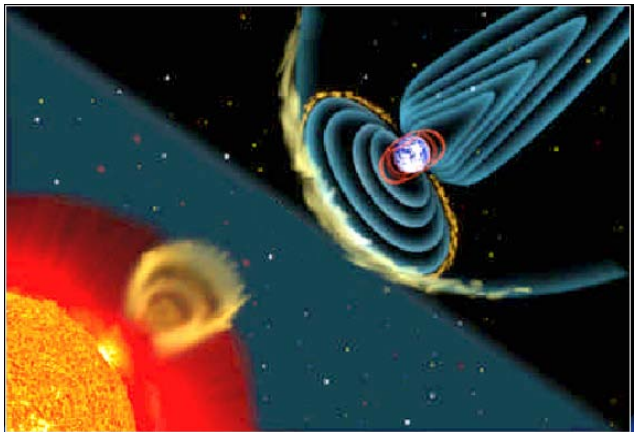
- The National Council on Radiation Protection and Measurements (NCRP) is a non-profit corporation chartered by Congress in 1964 to collect information and provide recommendations of all areas of radiation protection and measurements
- NASA has received guidance from the NCRP on radiation risks, dose limits and research directions several times in the past
  - **NCRP Report No. 98 provides recommendations used by NASA as basis for its current legal dose limits in low Earth Orbit (LEO)**
  - **NCRP Report No. 132 to be published in FY 2000 will provide new guidance on risks in LEO**
- In July of 1999 NASA requested the NCRP to perform a review and produce a formal report on:
  - **Implementation of the Principle of As Low as Reasonable Achievable in Space Flight (ALARA) in Space flight**
  - **Methods used to monitor and record Astronaut radiation exposures**
- Today's Meeting is the initial gathering of NCRP Scientific Committee 46-15 tasked to produce this new report

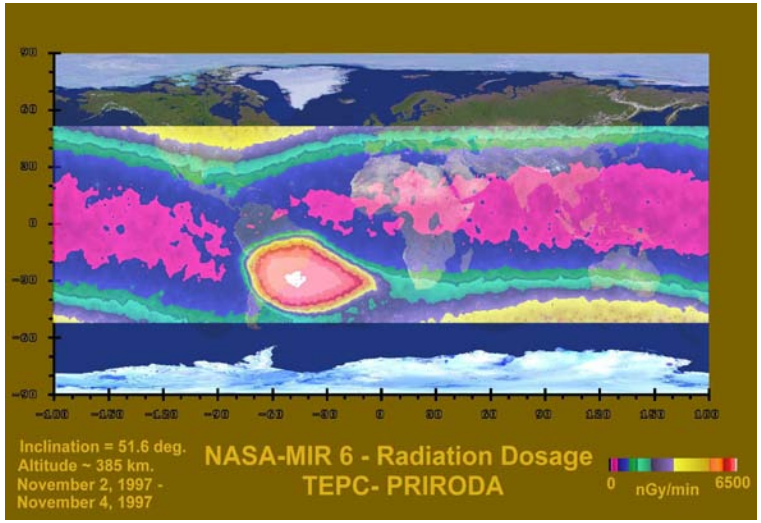
HSLSPO Organization

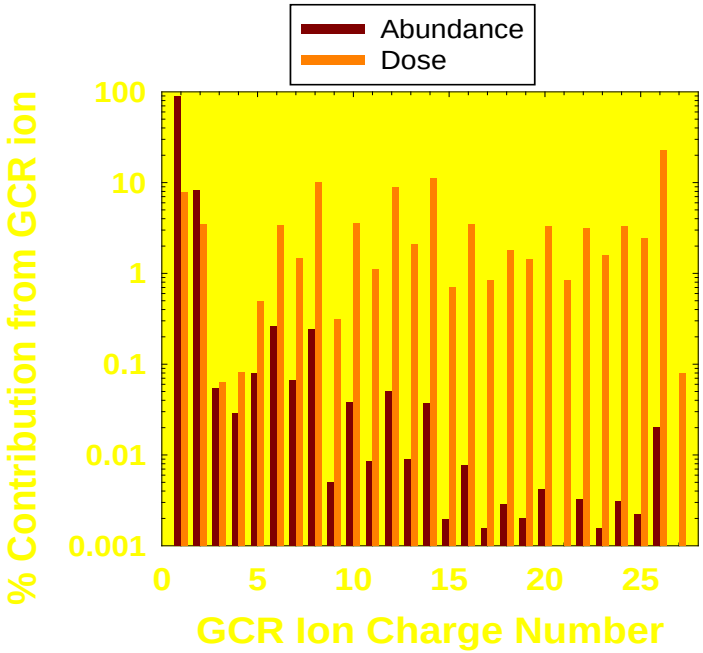


Space Radiation Environment

- **Galactic Cosmic Rays (GCR):**
  - highly penetrating protons and heavy ions of extra-solar origin
  - large amounts of secondary radiation
  - largest doses occur during minimum solar activity in an 11 year solar cycle
- **Trapped Radiation in South Atlantic:**
  - medium energy protons and electrons
  - effectively mitigated by shielding
- **Solar Particle Events (SPE):**
  - medium to high energy protons
  - occur during maximum solar activity

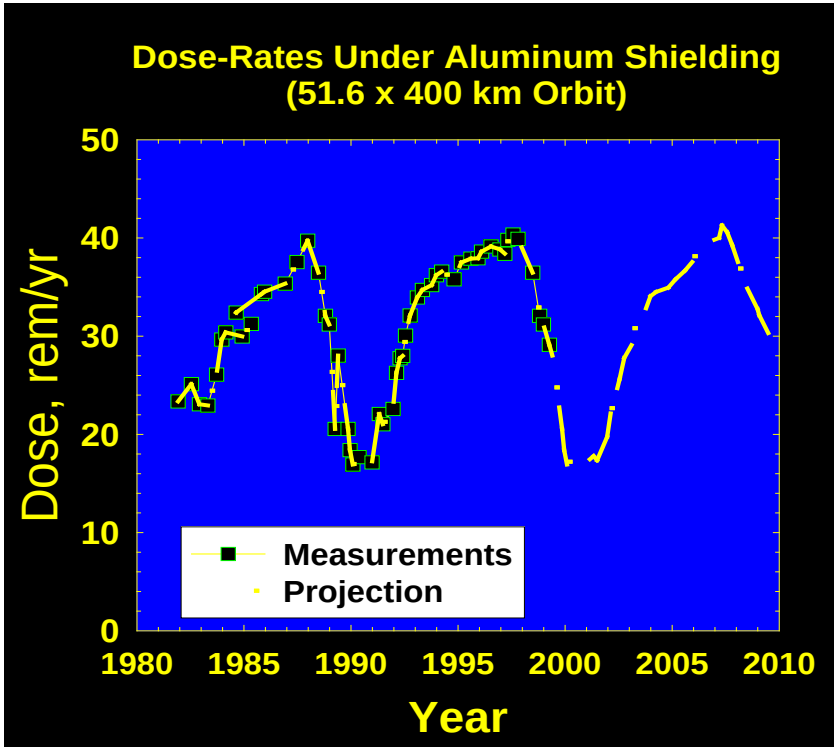




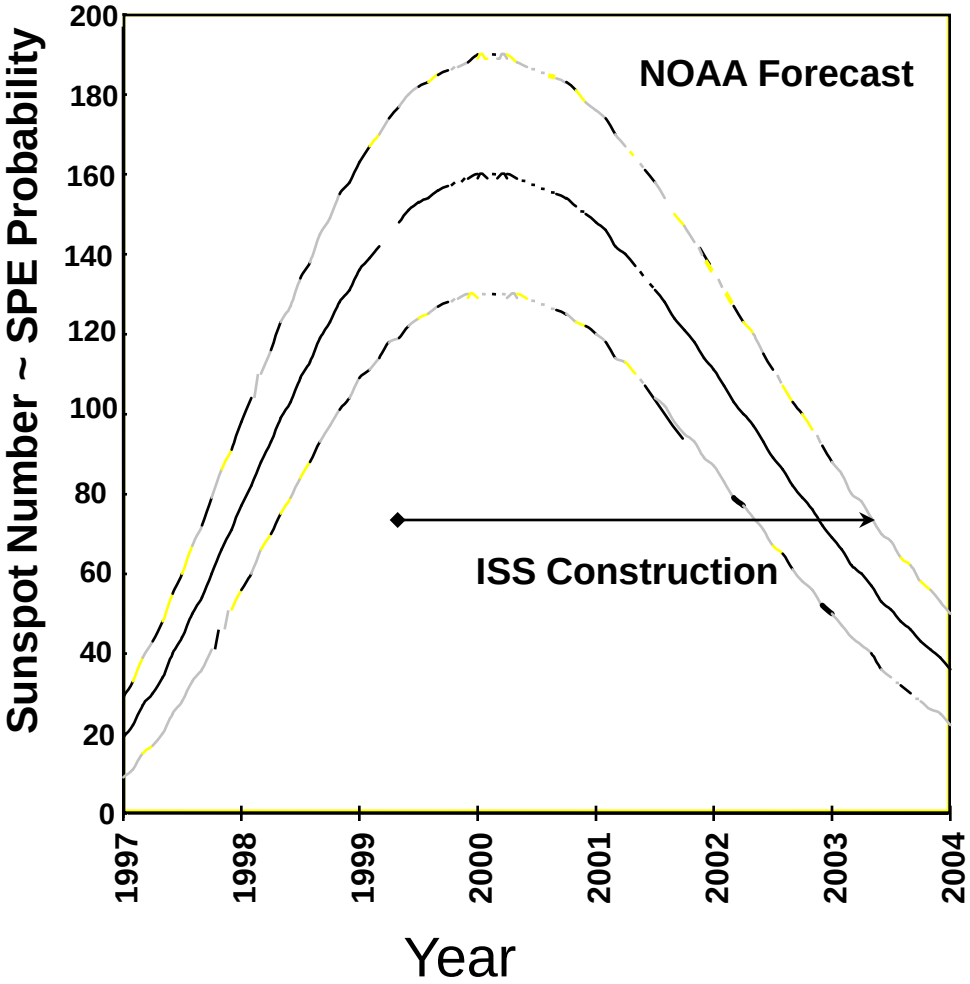


Solar Cycle Effects and Radiation

- Solar Magnetic field modulates radiation dose at Earth:
  - –Solar Minimum: weak magnetic effects; highest GCR/ trapped radiation doses
  - –Solar Maximum: strong magnetic effects and highest SPE probability; lowest GCR/ trapped radiation doses



Estimates of High SPE Period



Models and Dosimetry on Mir Station

Comparisons of Calculations to Active Measurements on Mir-18

	GCR			Trapped Protons			Total		
	Dose mGy/day	Dose Eq. mSv/day	Q	Dose mGy/day	Dose Eq. mSv/day	Q	Dose mGy/day	Dose Eq. mSv/day	Q
TEPC	0.142	0.461	3.2	0.153	0.298	1.9	0.295	0.759	2.6
HZETRN	0.141	0.526	3.7	0.140	0.219	1.6	0.281	0.745	2.7

Comparisons of Calculations to Measurements for Fraction of dicentrics in lymphocytes from Mir-18 Crew Member

Shielding	Model	GCR	Trapped p+	*Total*
Naussica	LET	2.20×10^{-3}	2.19×10^{-3}	4.39×10^{-3}
Naussica	Track	2.78×10^{-3}	2.66×10^{-3}	5.44×10^{-3}
Lyulin	LET	2.23×10^{-3}	2.46×10^{-3}	4.69×10^{-3}
Lyulin	Track	2.76×10^{-3}	3.02×10^{-3}	5.78×10^{-3}
Mir-18-Crew Member	Biodos.			$6.4(\pm 2) \times 10^{-3}$

External Guidance Obtained by NASA

Current Guidance:	NASA response:
NCRP Report 98: Guidance on Radiation Received in Space Activities (1989)	NASA adopted recommendations; basis of current legal radiation limits.
International Commission on Radiation Protection (ICRP) Report: Recommendations of the ICRP on Radiological Protection (1990)	New definition of Quality Factor as a function of LET probably will be incorporated into revised NCRP guidelines
NAS/NCR Report: Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies (1996)	Ground-based facility (BAF) started (expected commissioning date: April 2002); JSC appointed as Lead Center for expanded research program
Aerospace Safety Advisory Panel (ASAP) Annual Safety Report (1998)	Operational radiation (ALARA) levels being set to 20 rem as recommended; development of local shielding and EVA suit testing program

Guidance in Progress:	Expected NASA Response:
NCRP Report 132 : Guidance on Radiation Received in Space Activities-Revision (in press)	Review of current legal radiation limits
NAS Report, Space Environments and the International Space Station (in press)	Improve EVA ground and flight rules; establish Integrated Space Radiation Protection Office
NCRP Committee 1-4, Extrapolation of Risks from Non-human Experimental Systems to Humans	Review research solicitations; review integration of radiobiology research into risk prediction
NCRP Committee 1-7, Information Needed to Make Radiation Protection Recommendations for Travel Beyond Low-Earth Orbit	Development of radiation limits for exploration of solar system planetary bodies
NCRP Committee 46-15, Radiation Protection Methods in Space: Operations, Dosimetry and ALARA	Improved implementation of ALARA on ISS; establish flight rules and international agreements on radiation dosimetry on ISS

Risks and Dose Limits

Risks

- Deterministic Effects include acute radiation sickness, damage to central nervous system (CNS), or cataracts; occur only above dose thresholds
  - ***Acceptable risk*: Zero; dose limits ensure threshold not exceeded**
- Stochastic effects include cancer, hereditary effects, or neurological disorders; occur with probability proportional to dose
  - ***Acceptable risk:* dose limits ensure less than 3% probability of excess cancer death; ALARA Principle is used to stay well below limits**
    - » **Limit of 3% excess cancer deaths originates from comparisons to other occupational injuries**
    - » **Dose to risk conversion highly dependent on age and sex**
  - **Health risks from stochastic effects continue after mission completion**

Risk Acceptability

- NASA sponsored NCRP Symposium, "Acceptability of Risk from Radiation -- Application to Human Space Flight" (1996) included Astronaut participation and advocated continued use of ALARA,
  - "no magic formula" but "process of negotiation that integrates … social, technical and economic factors," weighing risks and benefits
- Improvements in Occupational Safety since 1970's suggests an acceptability risk of 1% be used unless clear benefit to society is shown

Occupational Risks since Apollo/Skylab

- ***Occupational Injury*:** Large improvements in occupational safety have occurred:
  - *Deaths per 10,000 workers per year*:*

Occupation	***1977***	***1987***	***1997***
Agriculture	***5.4***	***4.9***	***2.3***
Mining	***6.3***	***3.8***	***2.5***
Construction	***5.7***	***3.5***	***1.4***
Transportation	***3.1***	***2.8***	***1.2***
Manufacturing	***0.9***	***0.6***	***0.3***
Government	***1.1***	***0.8***	***0.2***
All	***1.4***	***1.0***	***0.4***

** Source National Safety Council*

- ***Radiation Risk*:** Epidemiology analysis of Atomic-bomb data estimates large increases in risk:
  - *Probability of life-time excess cancer mortality for average worker with exposure of 1 Sv:*

Year	**Total***
1970	***1 %***
1989	***2 %***
1999	***4 %***

***Sources NAS (1970), NCRP (1989), and NCRP (1999)*

Radiation Doses and Risks

- ***Deterministic Effects:*** Threshold doses for 50% of population following acute exposures:

Effect	Effective Dose (Sv)
Blood count changes	0.2-0.5
Vomiting/ nausea	1.0
Death:	
Minimal Care	3.2-3.6
Medical treatment	4.8-5.4
Autologous bone marrow transplant	11.0
Permanent Sterility:	
Males	3.5
Females	2.5
Cataracts	2.0-5.0

– **Threshold doses increase by factor of 2-3 for low dose-rate exposures**

Radiation Doses and Risks- continued

- ***Central Nervous System Damage:*** The 1996 NAS/NRC Report, "Radiation Hazards to Crews on Interplanetary Missions" has noted a large concern for damage to non-renewable cell systems, especially CNS, from HZE ions:
  - **Late degenerative damage to neurons and behavioral changes including accelerated aging seen in lower species models**
  - **Insufficient information to extrapolate to humans for determining risks for Mars Mission**
- ***Hereditary Effects:*** NAS estimates of probability that radiation will increase genetic defects:
  - Radiation-induced rate for chronic exposure of 1 Sv:

1st generation **$0.15\text{-}0.4 \times 10^{-2}$**

All generations **$1.09\text{-}2.12 \times 10^{-2}$**

(Background rate: $3.6\text{-}4.6 \times 10^{-2}$)

  - **Risks include dominant gene mutations and chromosomal diseases**

- ***Risks to the Embryo and Fetus*:** Risks for malformation and retardation are high with most sensitive period between 8 and 25 week
  - **Probability of retardation for chronic exposure of 0.2 Sv is 8%**

Radiation Doses and Risk-continued

- ***Cancer*:** Probability of radiation induced cancer is highly dependent on sex, age at exposure, and tissue type
  - NCRP estimates of percent probability of excess cancer for chronic exposure of 0.2 Sv in one year:

Age	35		45		55	
Sex	M	F	M	F	M	F
Mortality:						
Solid Cancers	0.38	0.68	0.26	0.48	0.20	0.32
Leukemia	0.13	0.05	0.08	0.06	0.06	0.04
Total(%):	0.51	0.73	0.34	0.54	0.26	0.36
Morbidity:						
Solid Cancers	0.78	1.42	0.42	1.20	0.32	0.76
Leukemia	0.09	0.06	0.10	0.12	0.08	0.06
Total (%):	0.87	1.48	0.52	1.32	0.40	0.82

  - Risks to Females are higher due to breast and ovarian cancer; higher incidence in lung
  - Risks decrease with age due to higher background rate of cancer; long latency of cancer; and due to changes in target cell populations with age

Radiation Workers Exposure Limits

- **NASA uses NCRP recommended dose limits:**
  - 30 day and 1 year prevent acute effects
  - Career limit age/sex dependent for risk of 3% excess cancer mortality
- Short-term limits distinct from terrestrial workers due to exposure patterns
- Career limits and radiation workers:
  - Astronauts: 1-5 missions in 15 years
  - Terrestrial: daily over 30 years
- **Annual Terrestrial Exposures:**

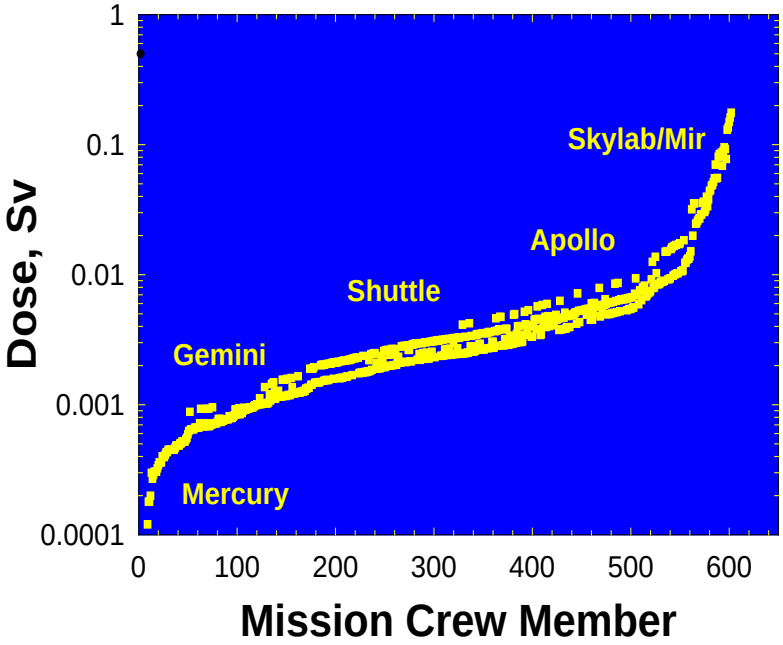
Exposure	Dose, Sv	Dose-rate
Chest x-ray	*0.0001*	*High*
Atomic bomb survivor	*0-2*	*High*
Airline pilots	*0.001-0.04*	*Low*
Nuclear power workers	*0.001-0.04*	*Low*
Cancer therapy	*10-80*	*High*

- **Dose Limits (Sv):**

Period	NASA	Ground-workers
30-day	*0.25*	*-*
1 year	*0.5*	*0.05*
Career	*1-4**	*Age x 0.01 Sv*

**Age and sex dependent*

- **Astronaut Mission Exposures**



New NCRP Recommendations

Doses Received in Individual Programs

Program	Average* Altitude	Inclination	Dose* (cSv)	Dose-rate* (cSv/day)
Gemini	454 km (1370 km)	30	0.053 (0.47)	0.087 (0.47)
Apollo	-	-	1.22 (3.3)	0.13 (0.39)
Skylab	381 (435)	50	7.2 (17.0)	0.12 (0.21)
STS Alt > 450 km	570	28.5	2.65 (7.8)	0.32 (0.77)
STS Alt.< 450 km	337	28.5	0.21 (0.71)	0.023 (0.04)
STS/Mir	341 (355)	51.6	9.9 (14.0)	0.072 (0.10)
ISS	350-450	51.6	10-20 (4-6 months)	0.06-0.12

*Maximum value in parenthesis

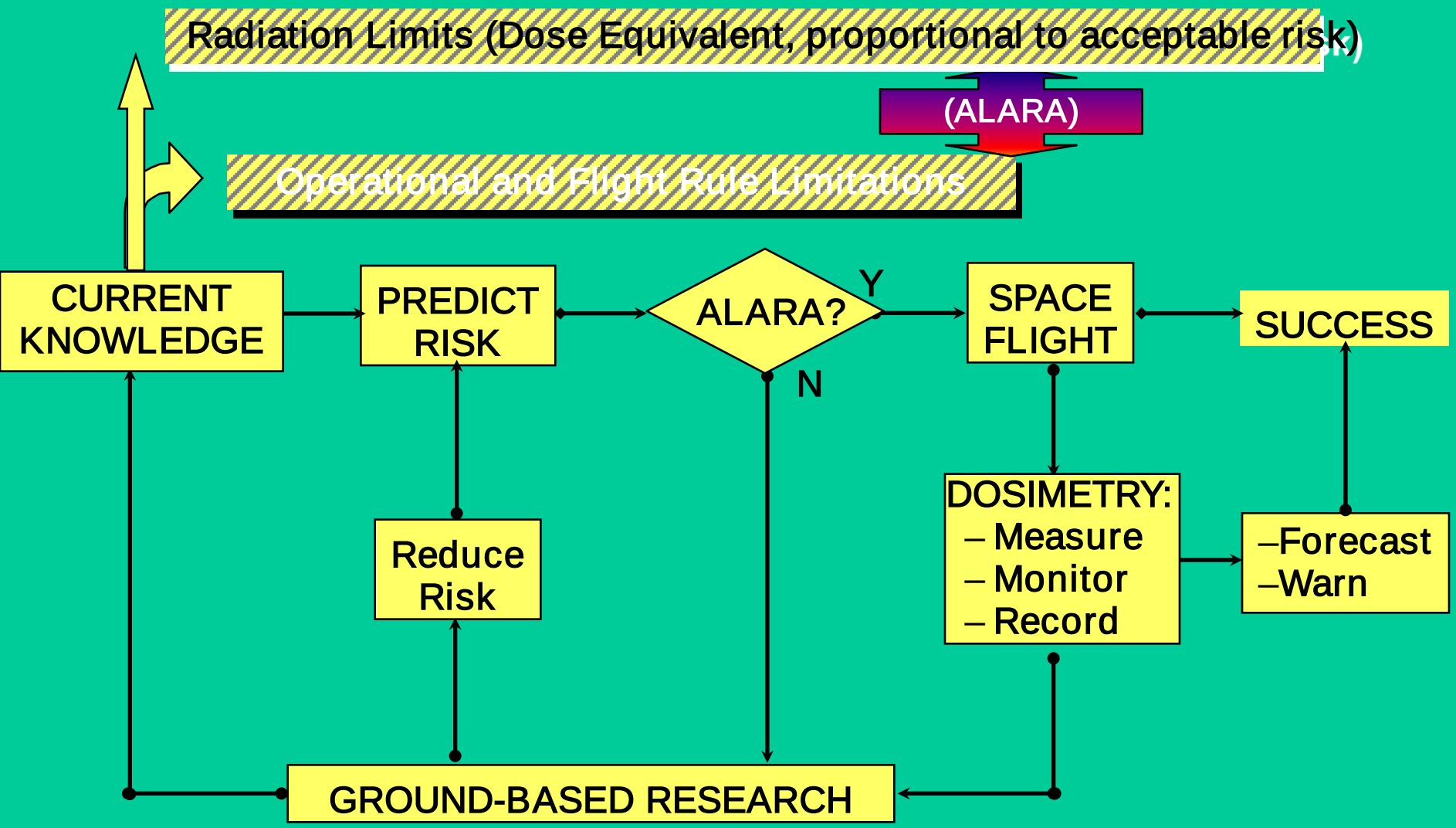
Exposure Sources In NASA Programs

Source	DOSE FROM TIME PERIOD-				
	1957-1969	**1970-1979**	**1980-1989**	**1990-1999**	**Total**
Space					
Total	20	111	42	273	**446 cSv**
Ave. Dose	0.46	4.0	0.26	0.734	**0.738**
Diag. X-rays					
Total*	141	179	52	15	**387**
Ave. Dose	0.095	0.082	0.027	0.007	**0.05**
Research**					
Total	6	12	8	2	**28**
Ave. Dose	0.059	0.018	0.158	0.014	**0.029**
Air –Flight	20	32	50	75	**180**
Background	15	25	35	55	**130**
Total Dose	**202 cSv**	**359 cSv**	**187 cSv**	**420 cSv**	**1,168 cSv**

***Carter Administration Directive led to significant reductions in doses from Diagnostic X-rays**

****JSC Improved protocols led to large reduction in dose from isotopes in early 1990's**

Radiation Protection Model



History of Radiation Dosimetry in NASA Programs

	Area Dosimetry		Crew Dosimetry	
Program	**Active**	**Passive**	**Active**	**Passive**
Mercury	None	None	None	TLD*
Gemini	None	None	None	TLD
Apollo	None	Plastic track (Cellulose Nirate)	None	TLD, PTD* (cellulose nitrate), BioD.
Skylab	None	TLD, Plastic	None	TLD, PTD (cellulose nitrate)
STS	None	TLD	None	TLD, PTD (CR-39)
STS-Mir	TEPC Particle Telescopes	TLD/Plastic Track (CR-39)	None	TLD PTD (CR-39) Bio.D.
ISS	TEPC Particle Telescopes	TLD/Plastic Track (CR-39)	Silicon Chip Detector	TLD Bio.D.

* TLD= Thermoluminescence detector; PTD= plastic track detector

ISS Radiation Monitoring System

Key

EV-CPDS: ***Extra-Vehicular Charged Particle Spectrometer***

IV-CPDS: ***Intra-Vehicular Charged Particle Spectrometer***

TEPC: ***Tissue Equivalent Proportional Counter***

RAM: ***Radiation Area Monitors*** **(TLDs)**

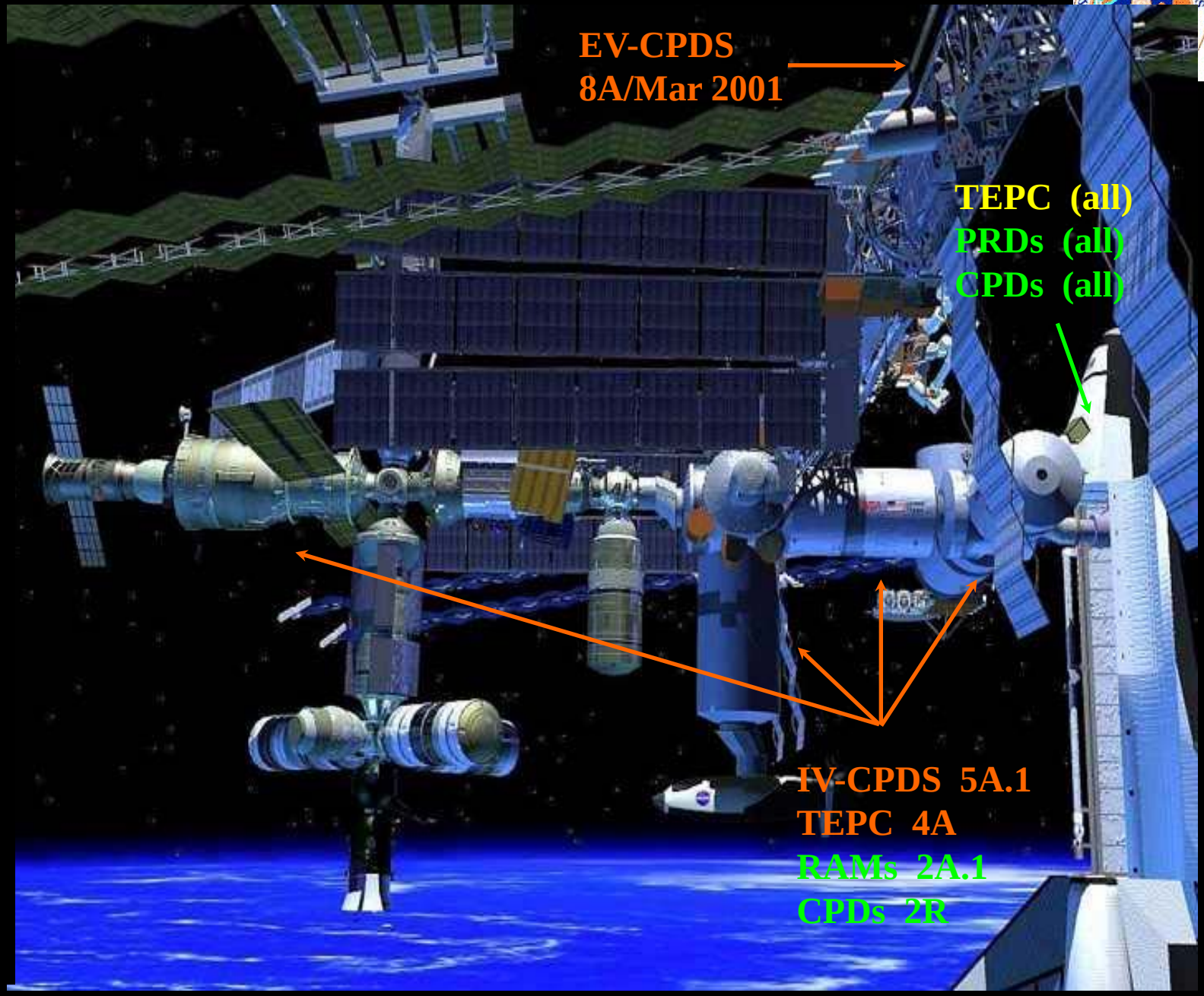
PRD: ***Passive Radiation Dosimeter*** **(TLDs)**

CPD: ***Crew Passive Dosimeter*** **(TLDs)**

Active instrument real-time telemetry

Active instrument no real-time telemetry

Passive instrument



Biodosimetry Evaluations

Advancements in Biodosimetry:

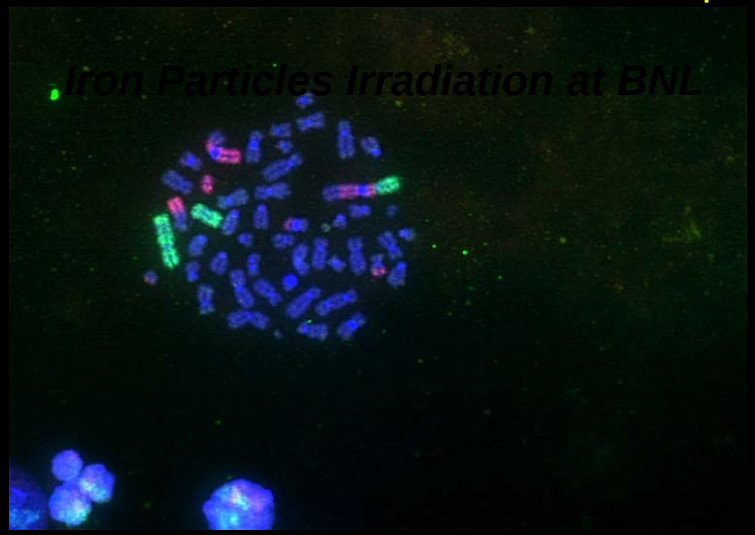
– Development of chromosome specific probes allows fluorescence in-situ hybridization (FISH) method to be extended to any chromosome

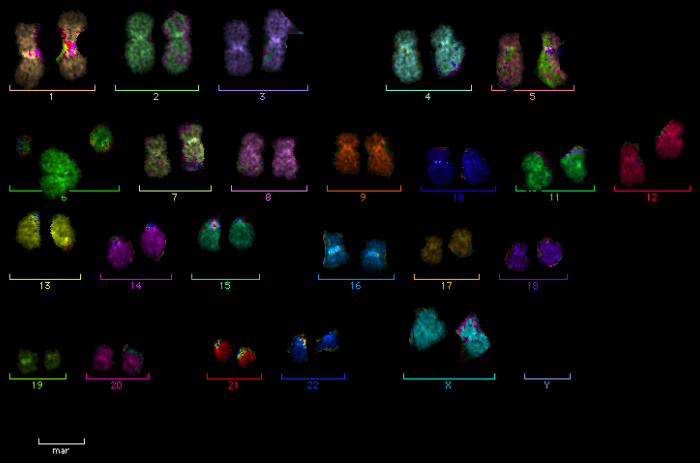
– FISH superior to Giesma staining for both sensitivity and detection of complex aberrations

– M-FISH feasible to evaluates aberrations on all chromosomes

– Premature chromosome condensation (PCC) increases sensitivity and study cell cycle effects

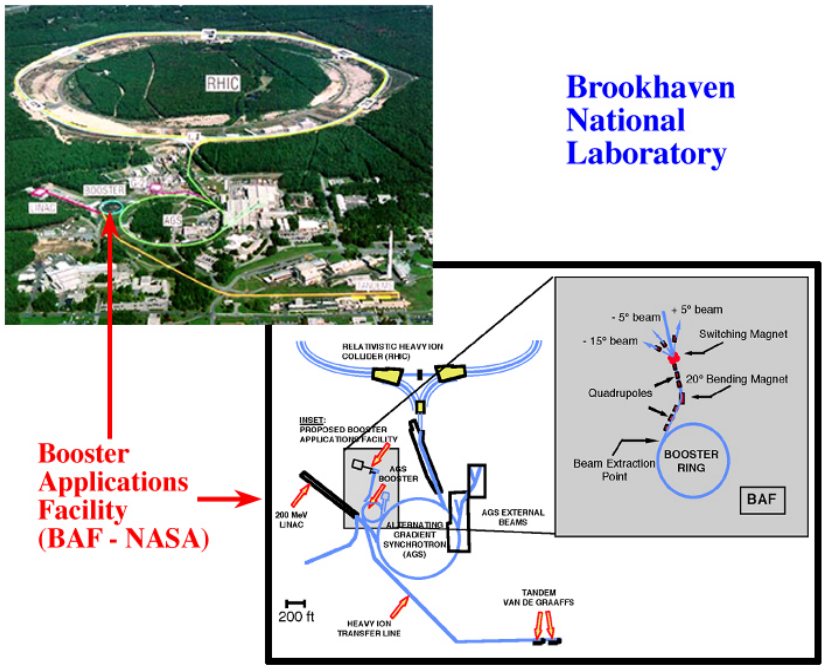
– BNL studies to understand radiation quality





Ground-based Research Facilities

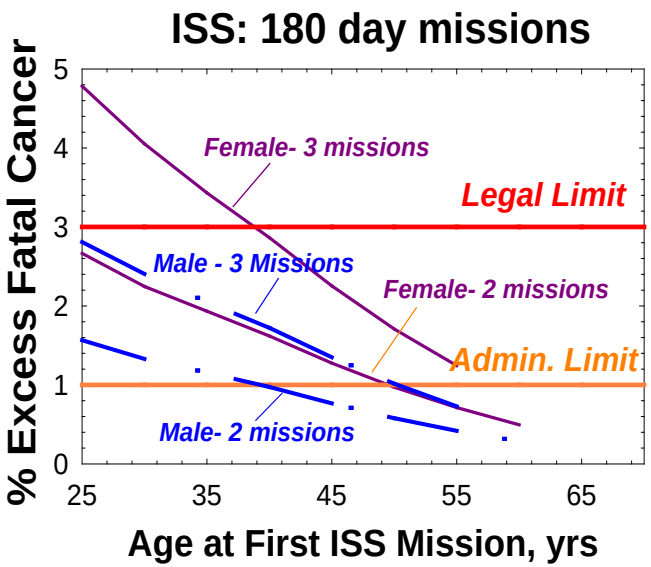
- **Brookhaven National Laboratory (BNL)**
- – **Booster Applications Facility (BAF):**
- » **Simulate GCR**
- » **NASA dedicated facility**
- » **NASA investigator laboratories**
- » **Under construction; use in 2003**
- – **Alternating Gradient Synchrotron (AGS):**
- » **High-energy heavy ions**
- » **Limited use available to NASA**

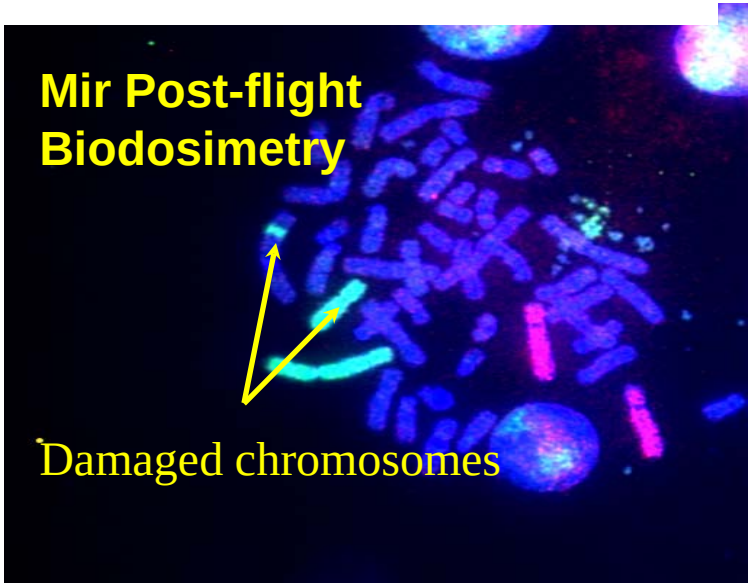


- **Loma Linda University Medical Center:**
- – **Medium energy protons**
- – **NASA investigator laboratories**
- – **Cancer patients responses**
- – **Simulate SPE**

Improvements in Crew Health Management

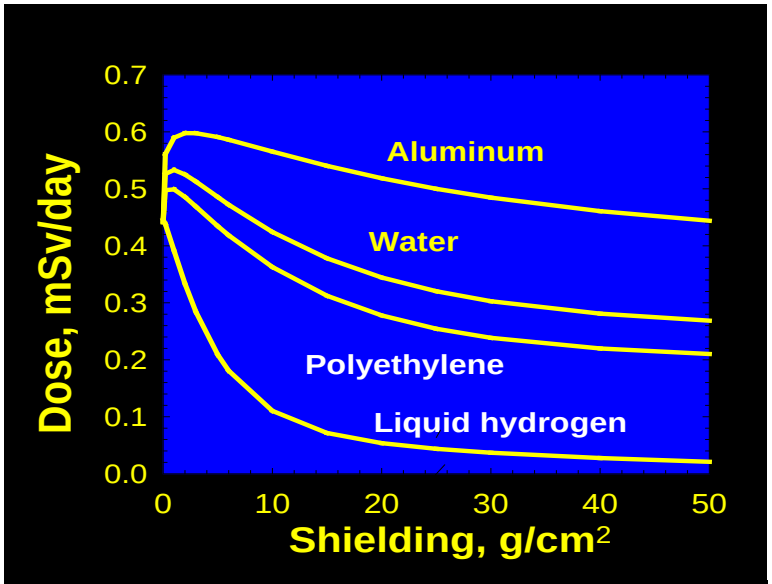
- **NCRP Guidelines for Legal limits with lower Administrative limits:**
  - Legal limit of 3% Excess Fatal Cancer
  - Administrative limit of 1% Excess
  - Continue 0.5 Sv/year legal limit for acute risk threshold
  - Set 0.2 Sv/yr Administrative limit based on ASAP recommendation
- **Improve projection methods and dosimetry used to evaluate crew life-time exposure histories**
  - Improve medical consultations on radiation risks and advise on age/sex/ genetic factors of risks
  - Utilize biodosimetry in post-mission analysis; develop biomarkers of disease
  - Develop genetic screening methods to identify individuals with higher susceptibility to radiation effects

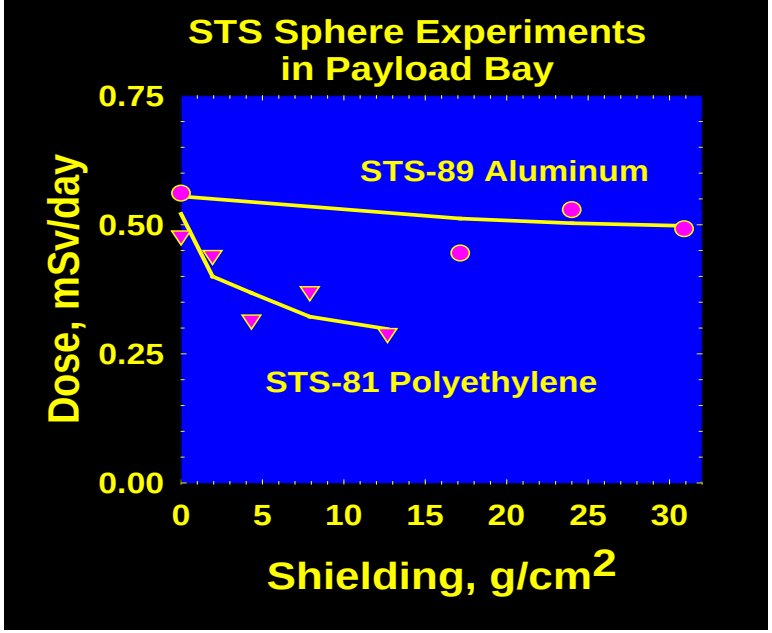




Improvements in ISS Shielding

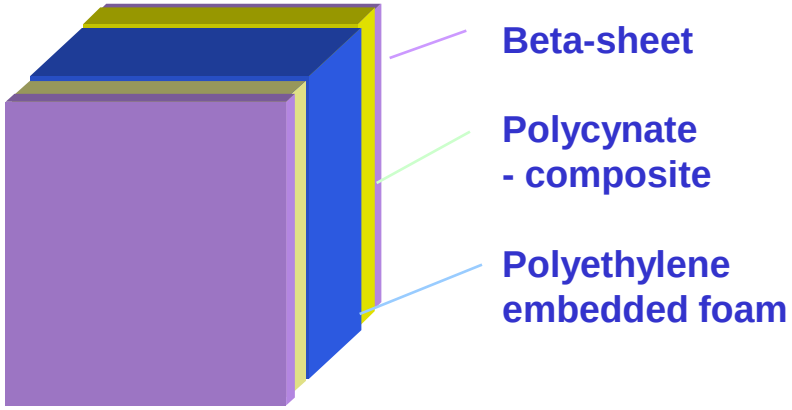
- **Strategy:** Integrate shielding knowledge to significantly lower ISS exposures
  - Research has established composite materials of low atomic mass as optimal for radiation protection
  - Aluminum poor shielding properties
  - Validation occurred at Heavy Ion Accelerators and STS Measurements
- **Goal: Achieve 45% dose reduction over current ISS Aluminum Structure:**
  - Crew Sleep-time (8 hr/d): Achieve 75% Reduction in Dose using Radiation Design of Crew Quarters and Improved Habitat
  - PSA-time (6 hr/d) Achieve 50% reduction through Habitat shielding augmentation or Transhab Module
  - Crew Work-time (10 hr/d) -achieve 15% dose reduction through Dose Management System (Operations) and Shielding Blankets

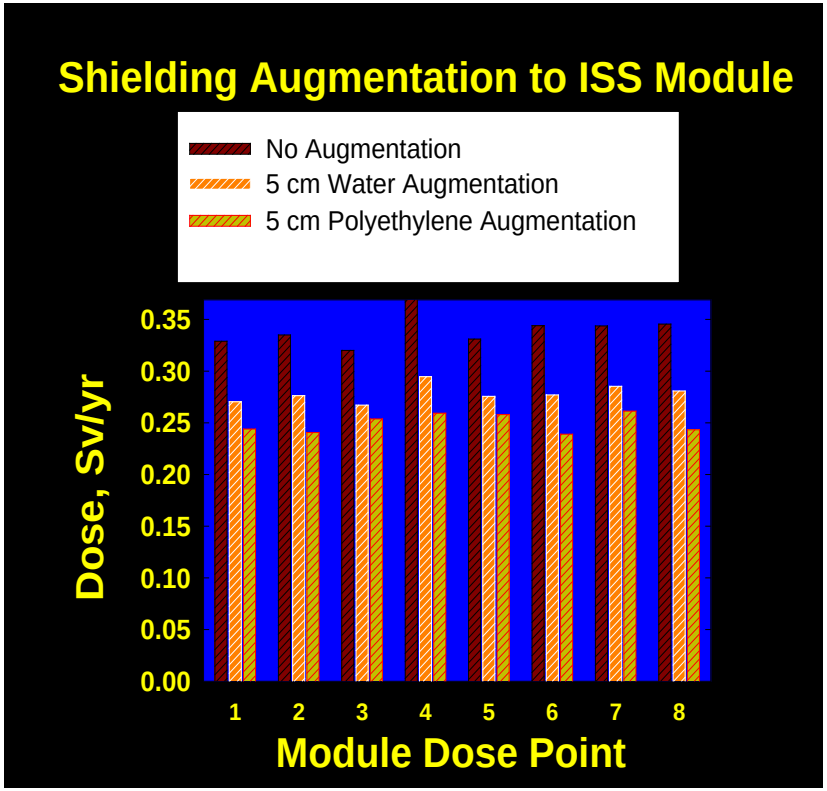




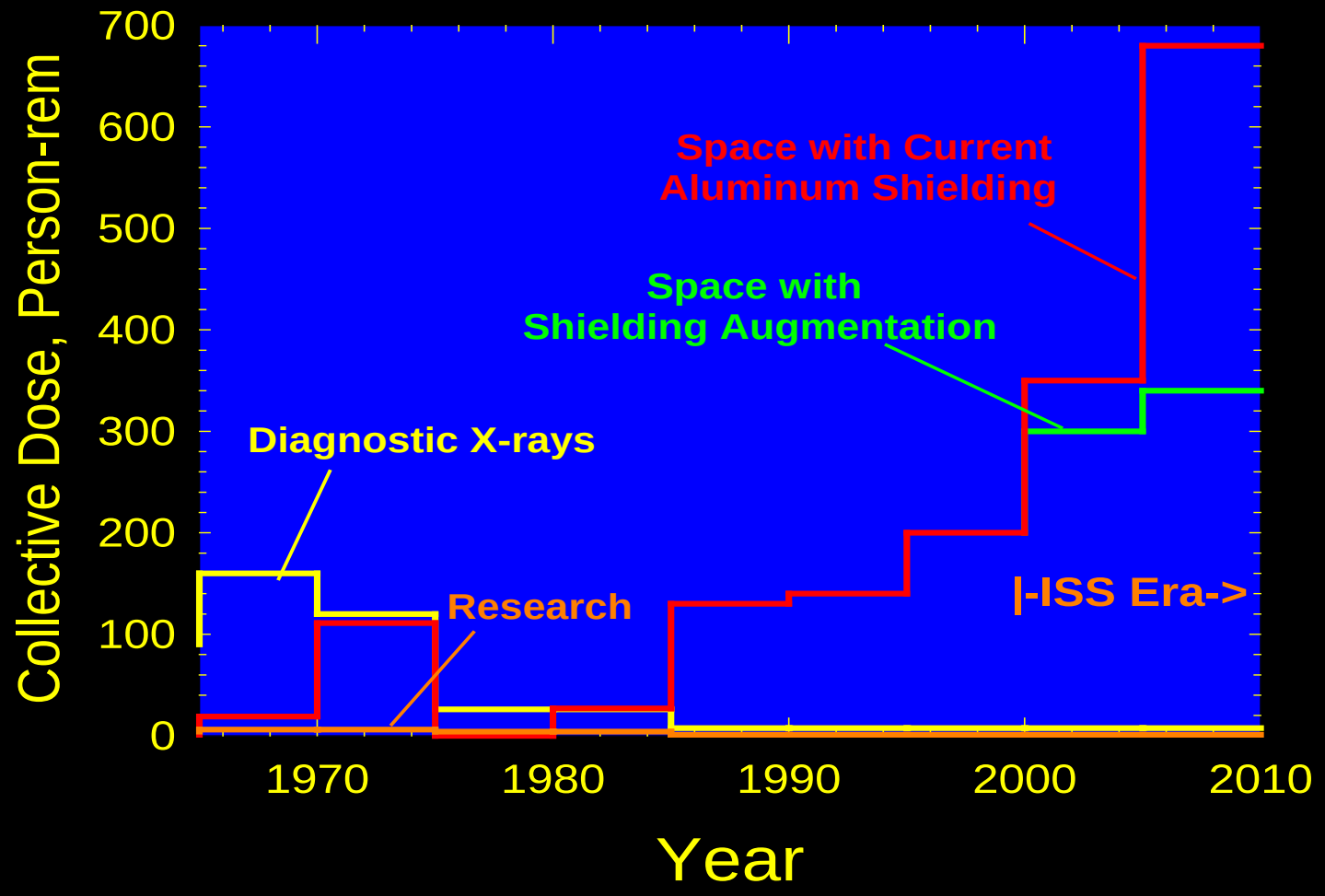
Improvements in ISS Shielding- continued

- **Multi-layer Shielding Approach:**
  - Polyethylene (5-8 g/cm^2) embedded in open cell polyimide foam or plastic honeycomb board
  - Encapsulation by beta-cloth and polycynate composite for AO/UV protection and rigidity
- **ISS Implementation:**
  - LaRC/JSC Crew Quarter Design Complete (Q1/2001)
  - Testing of DCQ at Brookhaven National Lab and Loma Linda University (Q4/2000)
  - ISS CR to set exposure standard for Habitat of < 0.15 mSv/day (Q3/2000)
  - Habitat Design with improved materials and use of directionality of internal radiation to minimize shielding mass (Q1/2001)
    - » Earth-shadow for isotropic GCR
    - » Trapped protons angular distribution
    - » Shadow shielding of adjacent nodes



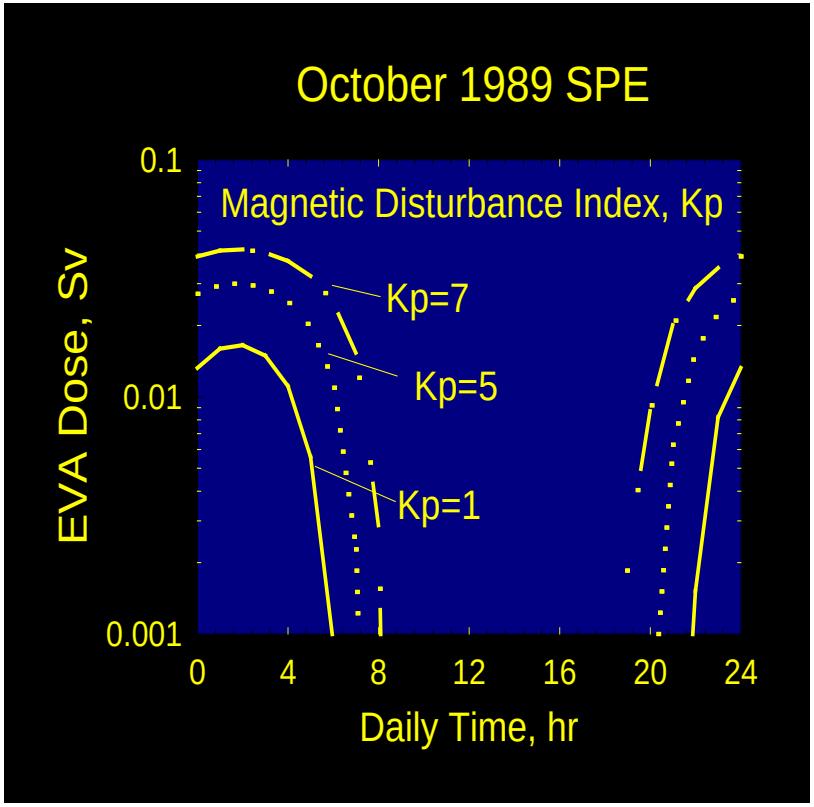


Impact of Improvements in Radiation Safety
- Collective Doses for 5 Year Periods



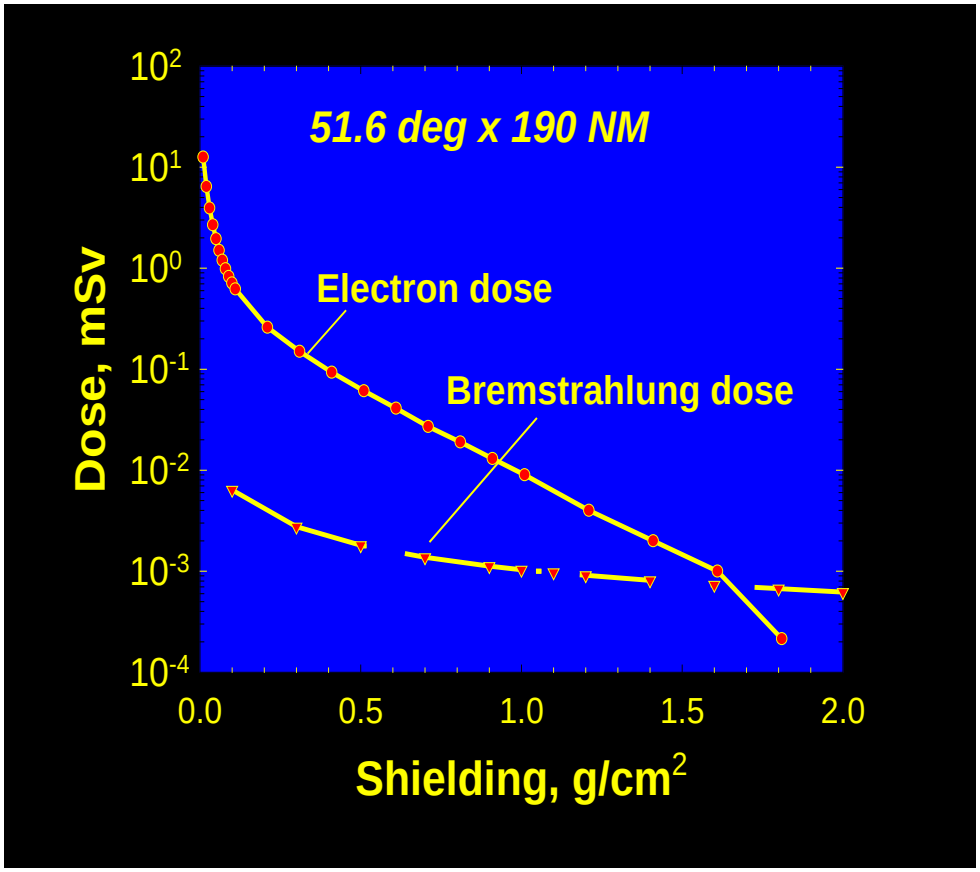
Improvements in EVA Protection

- Recent ASAP and NAS reports note ISS construction phase is during period of maximum solar activity where probability of SPE and Earth trapped radiation belt enhancements are large
- **Initiatives to Improve ISS Safety**:
  - Ground-rule imposing EVA-Safe Window with Earth Magnetic field protection(Q3/2000)
  - Flight-rule to improve SPE actions (Q2/2000)
  - Utilize active dosimetry as alarm system for electron belt enhancements/SPE's (Q3/2000)
  - Redundancy in data from space weather satellites and improved forecasting methods (ongoing)
  - Utilize radiation transport codes/dosimetry for Dose Management System utilize of local shielding variations (Q4/2000)



Improvements in EVA Protection- continued

- Active crew dosimetry to replace crew passive dosimetry (Q3/2000)
- Accelerator testing of EMU and LCVG at Loma Linda University (Q3/2000)
- Redesign study of LCVG and Space Helmut to enhance EVA shielding (Q4/2000)
  - » Use light mass materials to reduce weight and secondary bremstrahlung dose
  - » Light-mass materials in helmet to reduce nuclear secondaries



Issues: Improving ALARA

- Could current ground/flight rules be improved or are there other possible ground/ flight rules that could be proposed to improve ALARA?
- How should unique factors to space flight be integrated into implementation of ALARA for radiation protection?
- How could a “cost” analysis best be performed for considering effectiveness of shielding augmentation’s to ISS, changing length of crew stays, solar cycle effects, etc.?
  - **Should Astronauts receive any meaningful radiation exposure during sleep times or other non-working times if shielding technologies are available to eliminate? At what level of cost?**
  - **To what extent should crew sleep-times be disrupted to minimize radiation exposures including ground operational support?**
    - » **For protection from possible SPE’s and electron belt enhancements?**
    - » **For protection from Trapped Proton exposures?**

Issues: Radiation Dosimetry

- What accuracy is needed/achievable for Crew dosimetry (25%)?
- What accuracy is needed/achievable for Area dosimetry (25%)?
- How can accuracy best be validated?
- What is accuracy of current dosimetry used operational by NASA?
  - **Do TLD's over-respond to high-energy proton and helium ions?**
  - **Can a meaningful estimate of Q_{ave} be made by using LET dependent response of multiple TLD's materials and multiple glow-curve peaks?**
  - **Should JSC add a CR-39 capability to its passive dosimetry program or rely on active dosimetry to determine LET spectra?**
  - **Are neutron contributions currently under-estimated?**
  - **What are best methods to understand neutrons in space? Are their useful methods to indirectly measure neutron effects?**
  - **Is $Q_{ave}(y)$ measured by a TEPC significantly different than $Q_{ave}(LET)$?**
  - **What other approaches NASA should be using?**
- Is their any value in use of Dosimetry that has not been evaluated at ground-facilities for HZE, LZE, high-energy protons, or neutron response?
  - **What should be extent of a "NASA Ground-based Dosimetry Testing Facility"?**

Issues: Crew Exposure Records

- What is expected/required accuracy of life-time exposure records? (25%)
- Evaluation of Effective Dose: Application of the NCRP recommended weighting factors is significantly higher than use of Q(LET)
  - **JSC plan to use Q(LET) at specific organs evaluated using transport codes and shielding models that are normalized to crew dosimetry**
  - **What methods should be developed to improve this approach?**
- Should crew dosimetry utilize both passive and active dosimetry (TLD's, CR-39, and Silicon technology)? or rely on a single method?
- What should be role of biodosimetry be in crew exposure records?

Issues in Biodosimetry

- What confounding factors could arise when applying cytogenetic biodosimetry methods for space radiation exposures?
- Are their bio-markers that could be used in an operational radiation protection program at this time?
- Is their any preferred method for “biological” dose determination in space-flight?
- How could ground based facilities best support understanding of biodosimetry in space?