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Accelerator Facilities for Radiation Research

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Glossary of Terms

- AGS- alternating gradient synchrotron
- BAF- Booster Application Facility
- BNL- Brookhaven National Laboratory
- CNS- central nervous system
- GCR- galactic cosmic ray
- H(<E)- Dose equivalent from ions with energy less than E
- HIMAC- heavy ion accelerator in Chiba, Japan
- HZE- high charge and energy
- ISS- International Space
- LLU- Loma Linda University
- MeV/amu- million electron volts per atomic mass unit
- MOA- memorandum of agreement
- NAS- National Academy of Sciences
- NRC- National Research Council
- SPE- solar particle event
- SRHP- Space Radiation Health Project
- TEPC- tissue equivalent proportion counter

HSRP Goals in Accelerator Use and Development

- Need for ground-based heavy ion and proton facility to understand space radiation effects discussed most recently by NAS/NRC Report (1996)
- Strategic Program Goals in facility usage and development:
  - Operation of AGS for approximately 600 beam hours/year
  - Operation of Loma Linda University (LLU) proton facility for approximately 400 beam hours/year
  - Construction of BAF facility
  - Collaborative research at HIMAC in Japan and with other existing or potential international facilities
- MOA with LLU has been established to provide proton beams with energies of 40-250 important for trapped protons and solar proton events
- Limited number of beam hours available at Brookhaven National Laboratory's (BNL) Alternating Gradient Synchrotron (AGS)

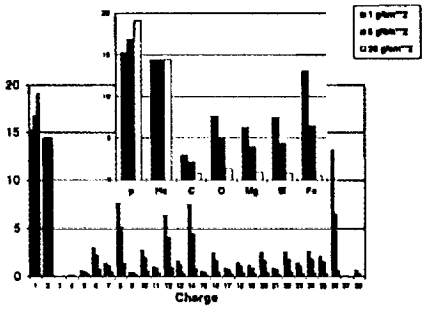
NASA-Loma Linda University (LLU) Memorandum of Agreement (MOA)

Proton and heavy ion contributions to dose equivalent behind shielding

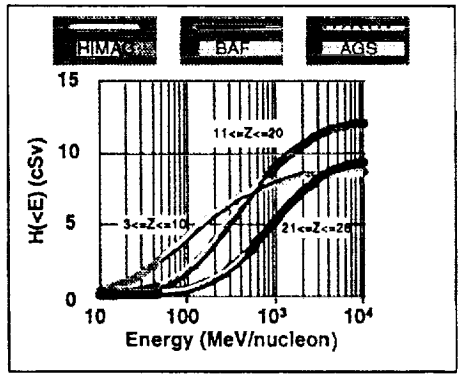
- Accelerator Facilities at LLU provide proton beams that allow for simulation of solar particle effects, trapped protons and portion of GCR spectrum
- NASA-LLU MOA Highlights:
  - to enhance basic knowledge of living systems and their response to radiation
  - apply of this knowledge to radiation protection, risk assessment, diagnosis, and treatment of cancer
  - exploit the synergy between NASA research requirements and charged particle therapy to establish a collaborative peer-reviewed research base which benefits the Loma Linda academic community

Space Radiation Charge and Energy Components

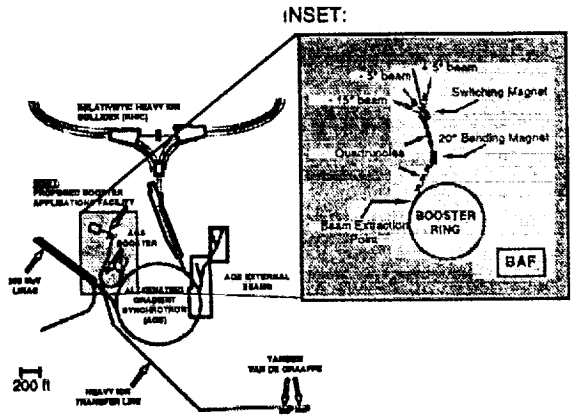
Relative contribution of various charge groups to Eye dose equivalent behind shielding



Accelerator Energy Ranges and GCR Doses Equivalent (H) contributions from energy, E



Accelerators at Brookhaven National Laboratory (BNL)



BNL Accelerator Facilities

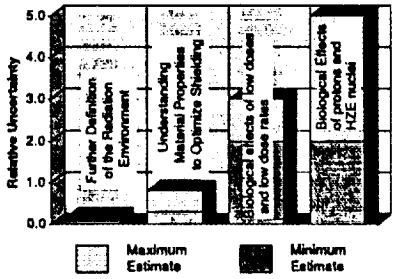
- Alternating Gradient Synchrotron (AGS) provides relativistic heavy ion beams for study of high energy GCR components. NASA use in competition with high energy physics community
- Booster application facility (BAF) a dedicated facility under construction for NASA to perform radiobiology and shielding research, and for space dosimetry calibrations
- Major deliverables from BAF
  - Example beam energy and charges

Proton	730-3100 MeV	Oxygen	120-1500 MeV/amu
Silicon	90-1200 MeV/amu	Iron	100-1100 MeV/amu

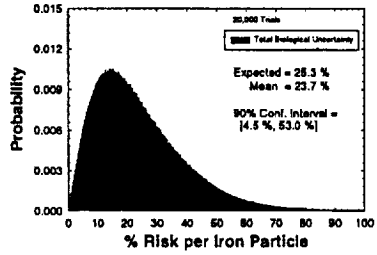
  - Ability for rapid beam switching allowing for mixed ion fractionation studies
  - Construction includes major modifications to tandem, beam transport, and booster systems
  - Adequate experimental buildings for animal, cellular biology and shielding studies
- First experiments at BAF to occur in 2002 or 2003
- Plans to include compatible dosimetry and support labs at LLU and BAF

Space Radiation Risk Uncertainties

NAS/NRC Uncertainty Estimates



Quantification of Uncertainties: U(total) = U(DS86) x U(Dose-rate) x U(bias) x U(pop.transfer) x U(Quality factor) x .....



Lifetime Fatal Cancer Risk Uncertainties from 600 MeV/u Iron (LET = 180 keV/μm) at average of 1 track per cell nucleus

Validation: Physical and Biological Dosimetry

Comparisons to measurements for dose- and dose equivalent rate on Mir-18.

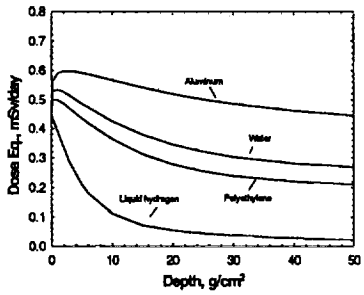
	GCR		Trapped Protons		TOTAL	
	Dose mGy/day	Dose Eq. mSv/day	Dose mGy/day	Dose Eq. mSv/day	Dose mGy/day	Dose Eq. mSv/day
TEPC	0.142	0.461	0.153	0.298	0.299	0.781
HZETRN						
Naussica	0.138	0.535	0.191	0.295	0.329	0.830
TEPC	0.141	0.526	0.140	0.219	0.281	0.745
Location						
Lyulin	0.134	0.547	0.254	0.391	0.388	0.938

Comparisons of Calculations to Measurements for Fraction of lymphocytes with chromosome aberration (dicentrics) from Mir-18 Crew Member

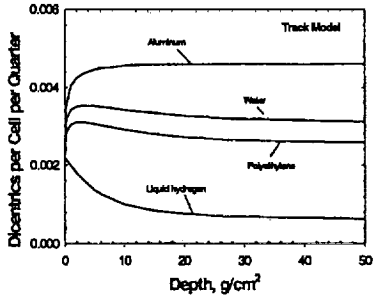
Shielding	Model	GCR	Trapped p+	*Total*
Naussica	LET	2.20×10^{-3}	2.19×10^{-3}	4.39×10^{-3}
Naussica	Track	2.78×10^{-3}	2.66×10^{-3}	5.44×10^{-3}
Lyulin	LET	2.23×10^{-3}	2.46×10^{-3}	4.69×10^{-3}
Lyulin	Track	2.76×10^{-3}	3.02×10^{-3}	5.78×10^{-3}
Mir-18-Crew Member	Biodos.			$6.4(\pm 2) \times 10^{-3}$

Risk Mitigation through Shielding?

GCR Dose Equivalent on ISS

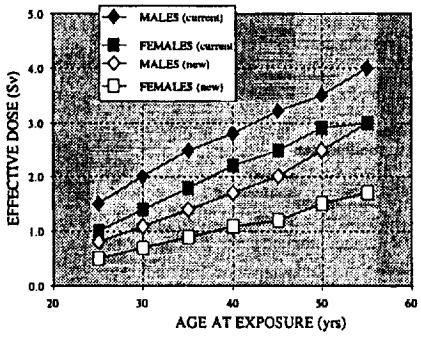


Chromosome aberrations on ISS



Issues in Risk Limits, Bioethics, and Flight Rules

Draft NCRP Limits for ISS



- Issues:
  - Differences in dose limits by NASA and International partners
  - Ethics of limiting cancer mortality versus cancer incidence

Tissue	Lethality factor
Leukemia	0.95
Breast	0.55
Colon	0.5
Thyroid	0.10

  - Inability to assess CNS risk and cancer risk for exploration limits
  - Long-term planing for including role of individuals genetic pre-disposition
  - Ground-based facilities for proper dosimetry calibrations