Radiation Critical Path Roadmap (CPR)

Space Radiation Health Project

Radiation CPR

Initiating Event

- **Radiation exposure:**
  - *Galactic Cosmic Rays*
  - *Solar Particle Events*
  - *Trapped Radiation Belts*
  - *Nuclear Power Reactor*

Overarching Concern

Legal Exposure Limits

Risk Factors

- **Weightlessness**
- **Environmental toxic agents**
- **Microbial pathogens**
- **Malnutrition**
- **Genetic hypersensitivity**

Risks

- *Carcinogenesis Caused by Radiation*
- *Damage to CNS from Radiation Exposure*
- *Synergistic Effects from Exposure to Radiation, Microgravity, and Other Spacecraft Environmental Factors*
- *Early or Acute Effects from Radiation Exposure*
- *Radiation Effects on Fertility, Sterility, and Heredity*

Consequences

Legal Health Issues

- **Crewmember radiation sickenss; cataractogenesis; sterility; initiation &/or promotion carcinogenesis**
- **Death, cancer, sterility, cataract or brain injury to crew-member**
- **Loss of Mission Objectives**
- **Mission Abort**

- *Crew selection with genetic screening for radiosensitivity*
- *Preflight training*

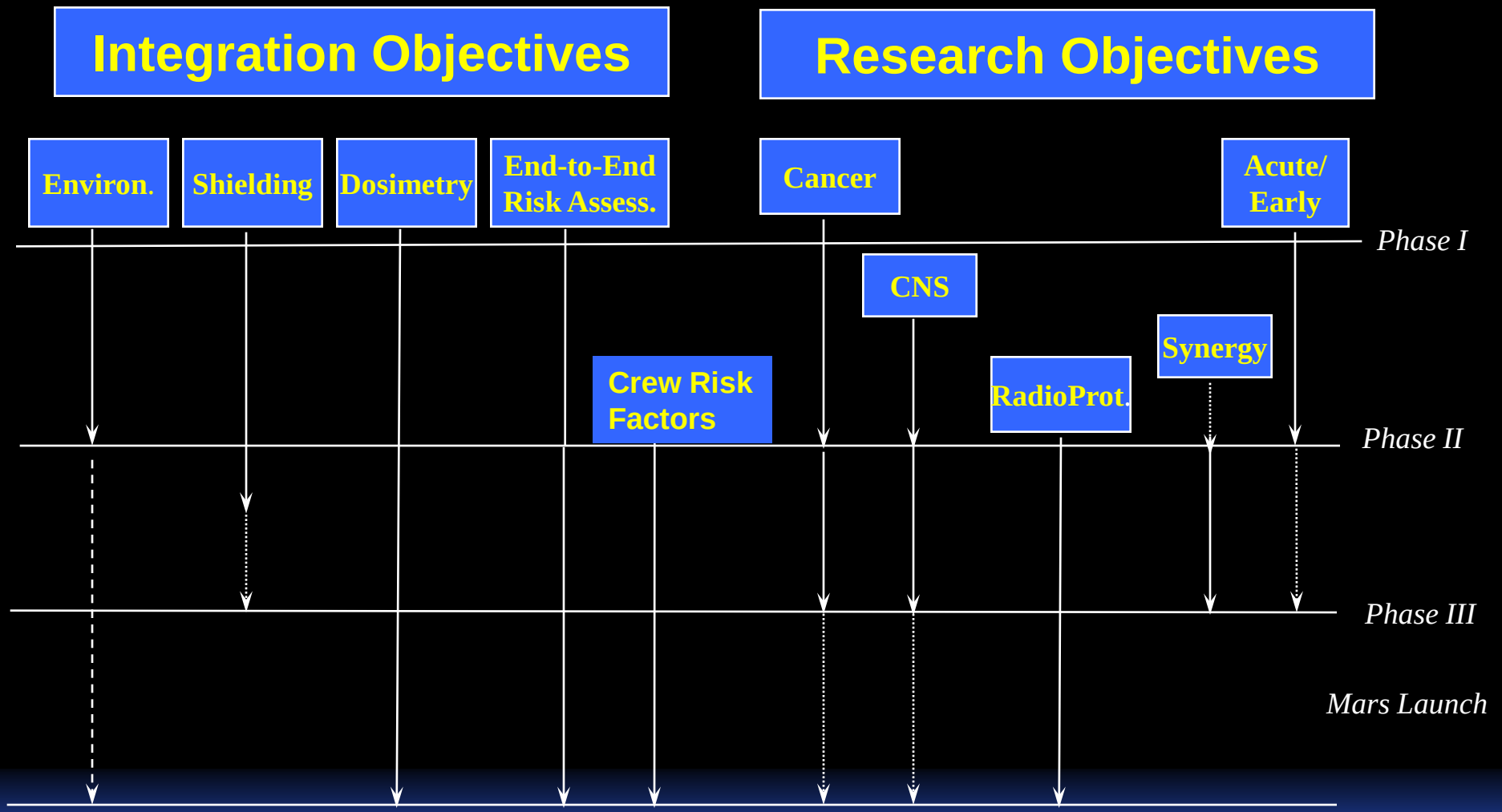
- *Optimal mission operations*
- *Shielding design & safe haven*

Active radiation monitoring

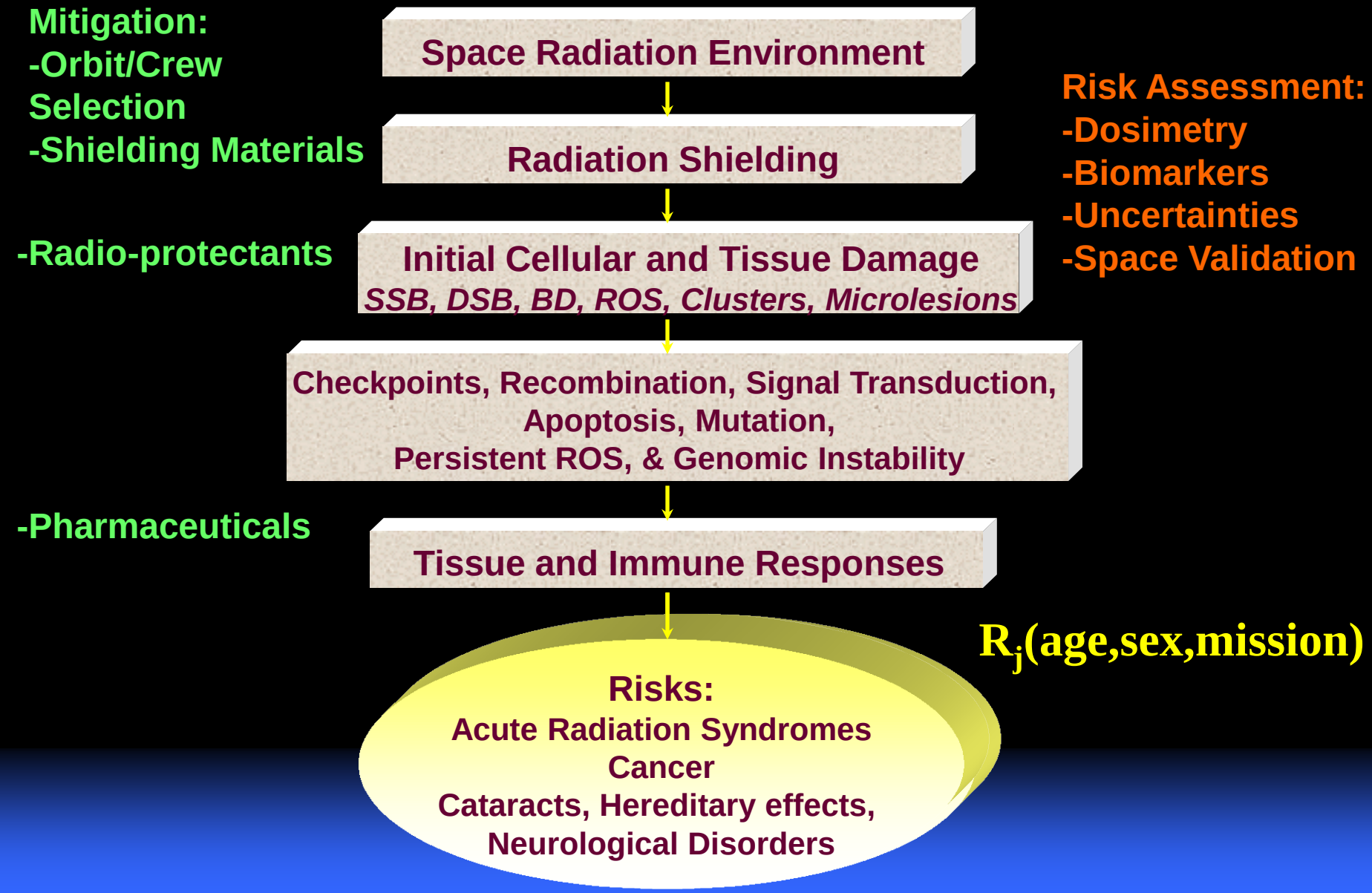
- *Risk assessment & dose projection*
- *Solar flare warning system)*
- *Radiation injury assessment*
- *Crew selection & training*
- *Apropriate nutritional requirements*
- *Atmosphere protection. parameters*

- *Chemical and biological agents*
- *Medical treatment*

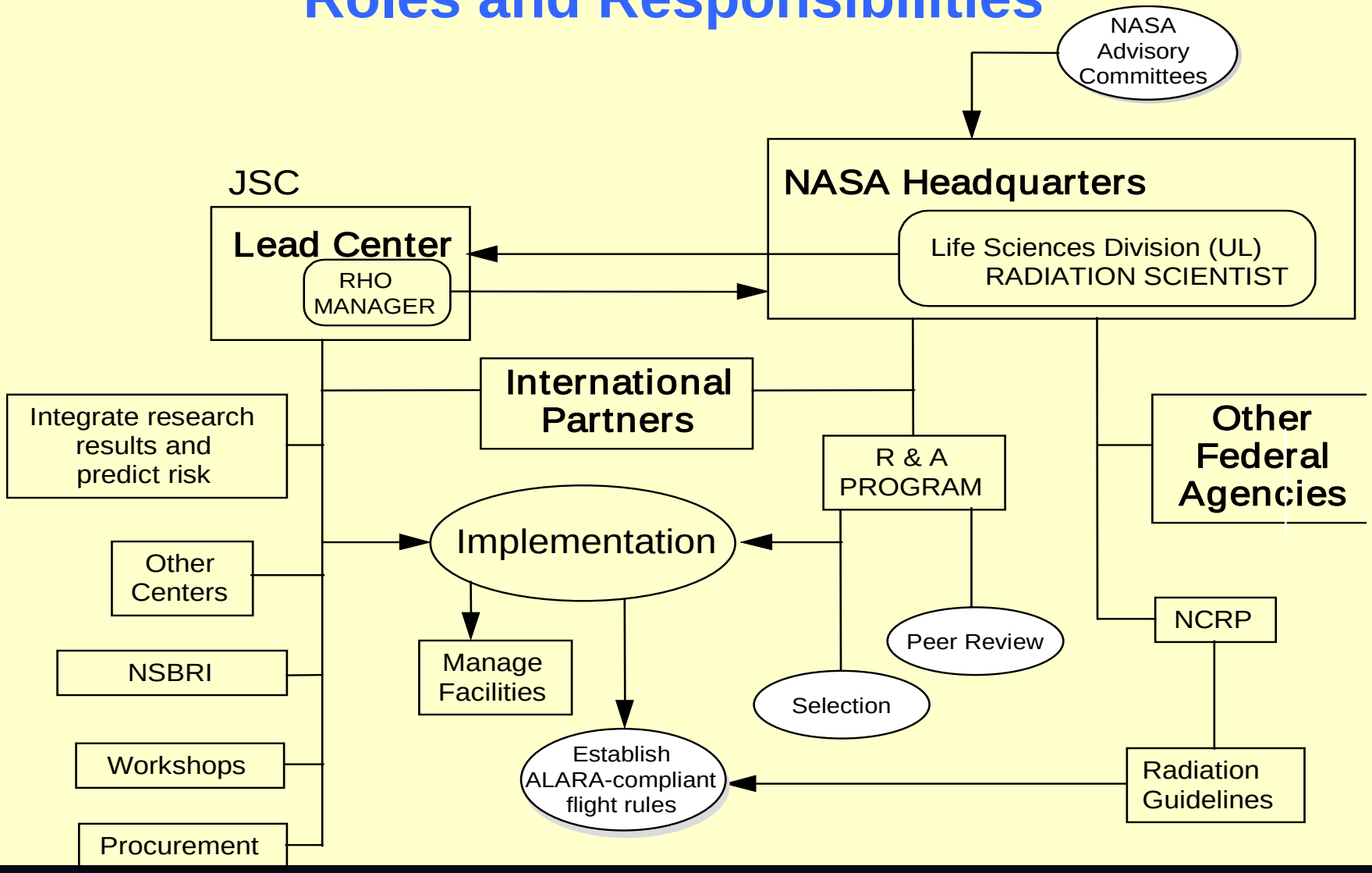
CPR Radiation Roadmap: Risk Assessment and Mitigation



End-to-End Risk Assessment



Roles and Responsibilities



Summary

- The construction of BAF will allow NASA for the first-time to collect critical data and perform research to reduce the uncertainties in risk projection and develop mitigation approaches
- BAF Utilization plan is needed to support exploration mission design:
  - Long-time lines for data collection using animal models places priority on optimizing use of BAF upon completion in FY02
- RHO Focus:
  - Ensure data collection to determine dose response and RBE's or other relative risk factors for solid tumors and leukemia's from heavy ions
  - Integrate radiobiology research:
    - **Advocate partnerships with NSBRI, DOE and NCI on cancer research**
    - **Advocate partnerships with NIH's National Institute of Aging (NIA) on CNS effects**
  - Achieve program objectives:
    - **Expand support for shielding and material technologies**
    - **Perform Mars environment measurements**
    - **Improve technology for early SPE warning**

Summary- continued

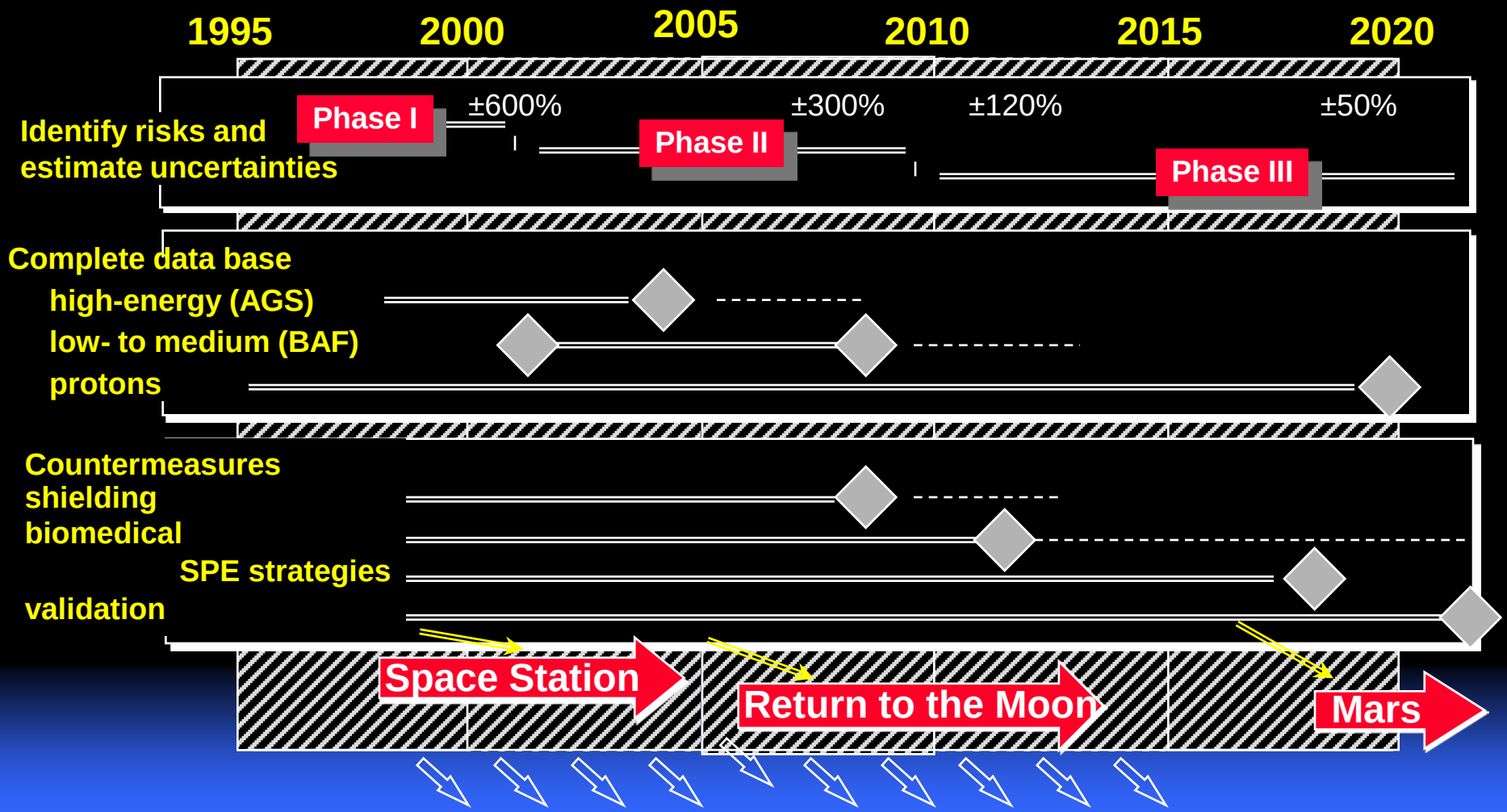
- Bioastronautics Radiation Health Office (RHO) to lead achievement of radiation safety goals:
  - **Mission support and Astronaut Health (Code M and U)**
  - **Ground-based research facilities development and usage (Code U)**
  - **CPR for reduction in risk uncertainties and development of countermeasures**

- Continued Guidance from NCRP/NAS on exposure limits and research priorities

- Integrate knowledge across Enterprises:
  - **Space environments and forecasting (Code S / M and NOAA)**
  - **Radiation Shielding and Materials Technologies Tasks (Code U / M/ R)**
  - **Integration of radiobiology results for risk assessment (Code U)**
  - **Integration and validation of biological countermeasures (Code U / M)**

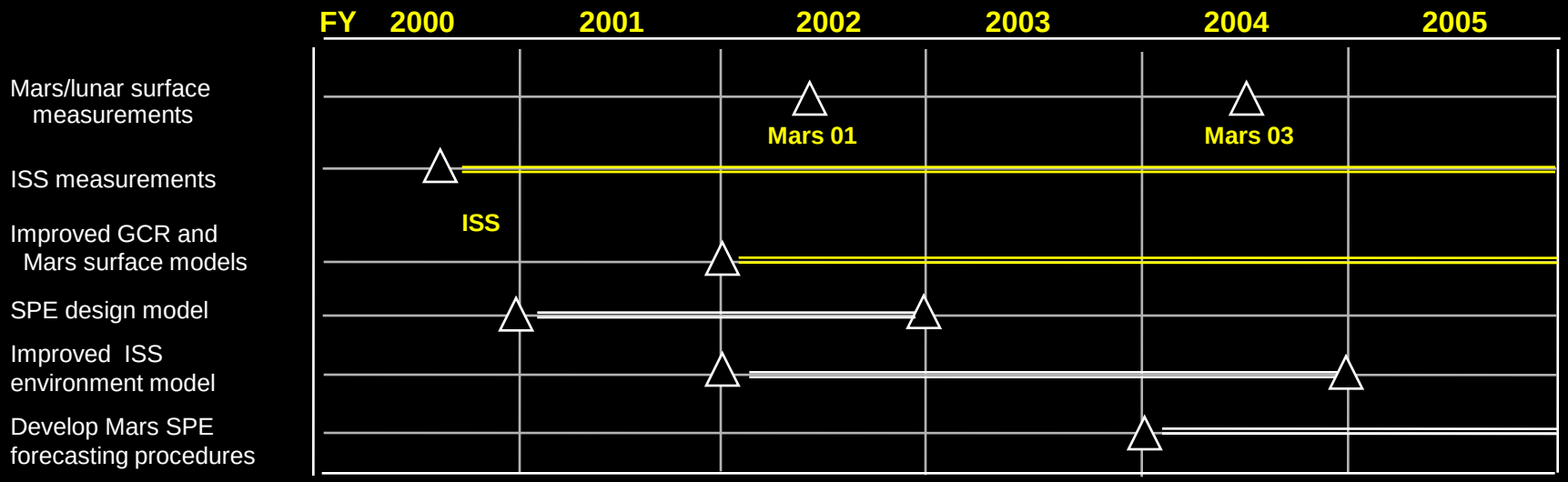
- Bioastronautics Initiative will provide resources for vital radiobiology research and assure implementation of identified shielding technologies

Space Radiation Research- Phased For Exploration



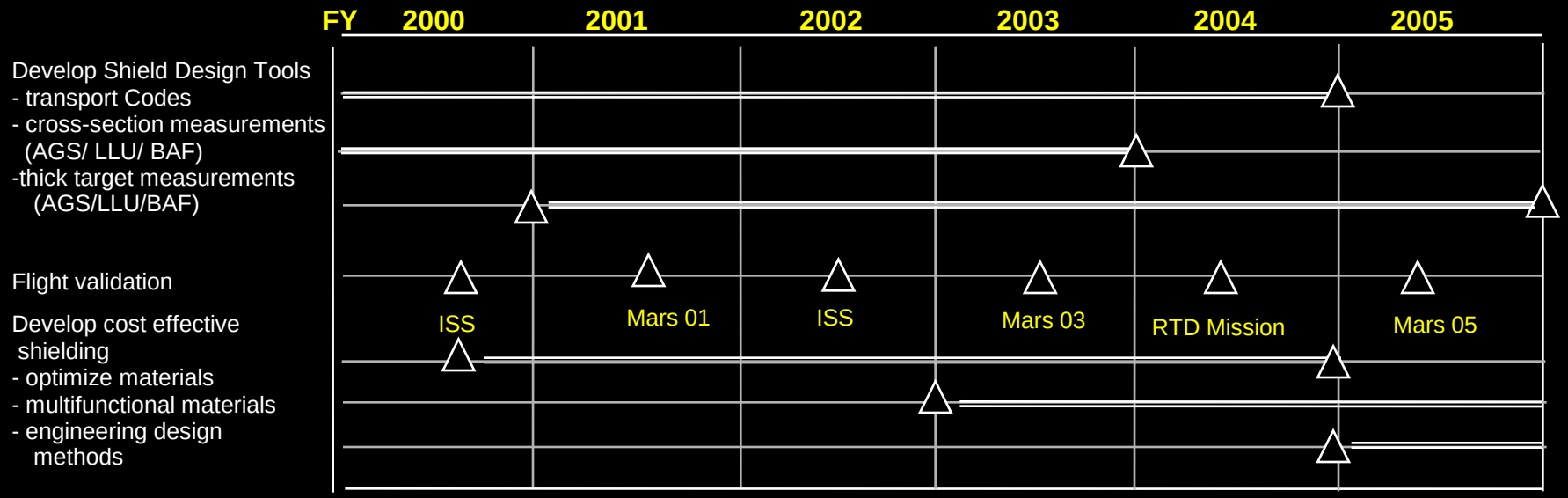
Applications: cancer, aging, crops, electronics, communications

Environmental Definition



- **Goal:** Improved understanding of space radiation environment including temporal variations is needed to support risk assessment to crews and define Mars countermeasures requirements.
- **Problem definition:** Solar Particle Event workshop at JSC in 1997 made recommendation on improvements in SPE forecasting and approaches to understanding largest events. NCRP reviews of environmental models.
- **Program needs and deliverables:**
  1) Mars 01, 03, and 05 measurements for Mars transit and Mars surface environments
  2) ISS measurements of radiation belts and GCR in LEO
  3) establish SPE reference design environment
  4) understand GCR composition and temporal variations with accuracy of factor of +/15%
  5) establish SPE forecasting approach for Mars transit and Mars surface
  6) study other factors such as possible nuclear propulsion and planetary neutron albedo components

Radiation Shielding & Spacecraft Design



- **Goal:** Improved understanding and design of radiation shielding is needed to define risk levels on exploratory class missions and for risk mitigation
- Problem Definition: 1995 Workshop on Shielding Strategies defined issues for reducing uncertainties in shielding assessment and strategies for material and engineering design improvements.
- **Program needs and deliverables:**

  1) accelerator measurements at AGS, LLU, and BAF of nuclear reaction cross sections and thick-target particle fluxes

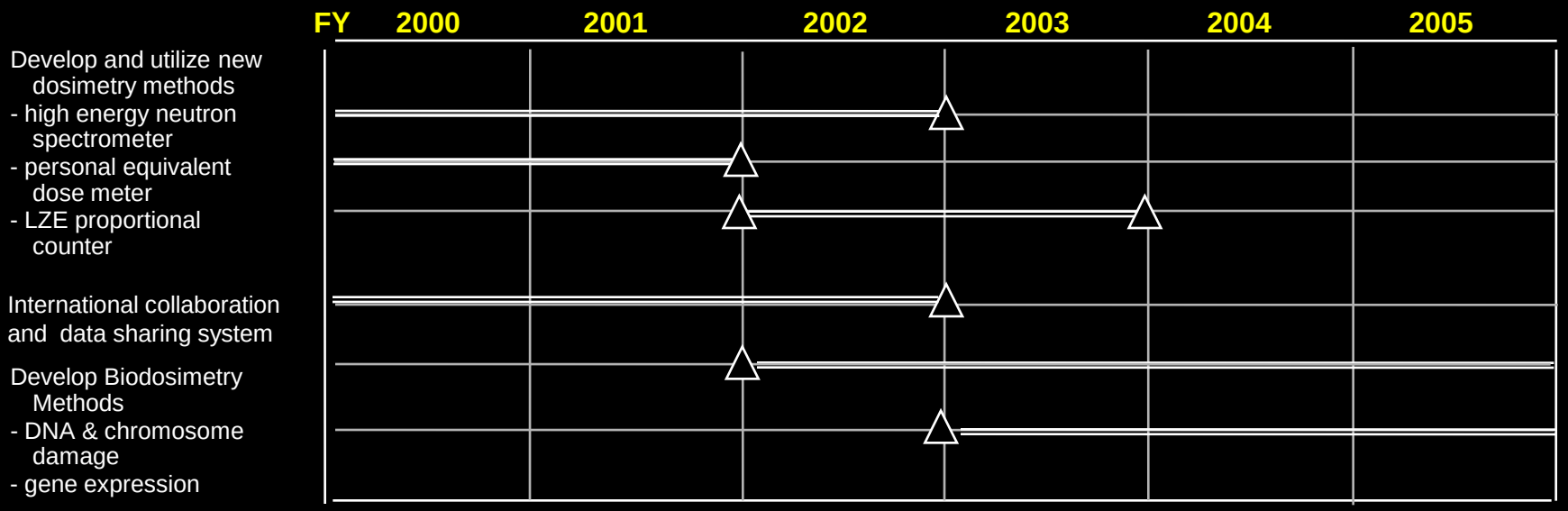
  2) develop improved transport methods and predictive codes validated to 25% accuracy by 2004 using laboratory and spaceflight tests

  3) test new candidate shielding materials for possible use for improved risk mitigation

  4) develop standard design tools for spacecraft engineers

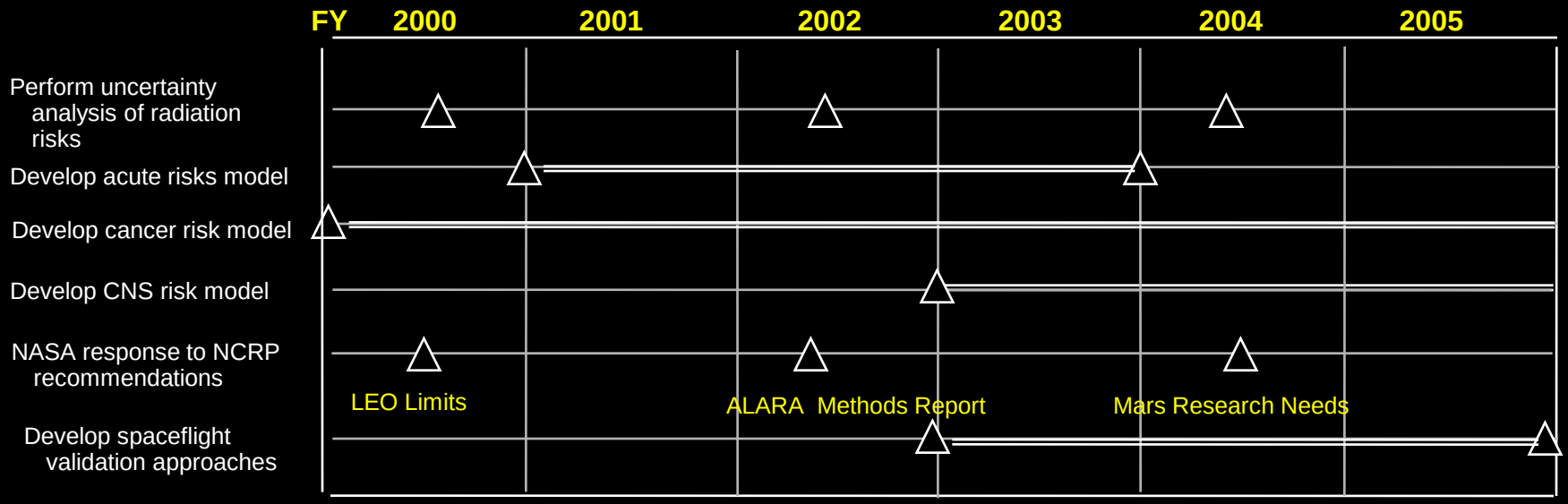
  5) Flight validation on Mars 01, 03, and 05 and Radiation Technology Demonstration (RTD) Mission

Dosimetry



- **Goals:** New dosimetric approaches required for understanding spectral components of LZE, HZE, and neutrons for individual tissues. Biodosimetry needs to be fully developed in support of exploratory class mission. Develop adequate ground-based calibration facility
- **Problem definition:** ISLSWG Meetings in 1996 and 1997, JSC meeting on neutrons in 1998 made dosimetry recommendations. JSC Workshop on Biodosimetry in 1996. 1998 NIH Workshop on Biodosimetry summarized current approaches and future directions.
- **Program needs and deliverables:**
  1) improved physical dosimetry of LZE, HZE , and neutron energy spectra
  2) crew personal equivalent-dose meter
  3) develop international collaboration system for dosimetry calibrations and ISS data sharing
  4) develop biological dosimetry including use of chromosome aberration and protein expression as biomarkers
  5) Use of BNL AGS and BAF (heavy ion accelerators) for ISS and Mars dosimetry calibration

End-to-End Risk Assessment



- **Goal:** Ongoing evaluations and new risk assessment methods are required to understand risk and uncertainties, and to make optimal use of radiobiology research results for mission evaluation.
- **Problem Definition:** NCRP, NRC and LBNL panels assessed current status and recommended need for new risk approaches. Biannual meetings on risk assessment methods will be held.
- **Program needs and deliverables:**

  1) perform uncertainty analysis for environmental, radiation transmission, and biological factors

  2) predict acute risks to a factor of +/ 200% by end of Phase I

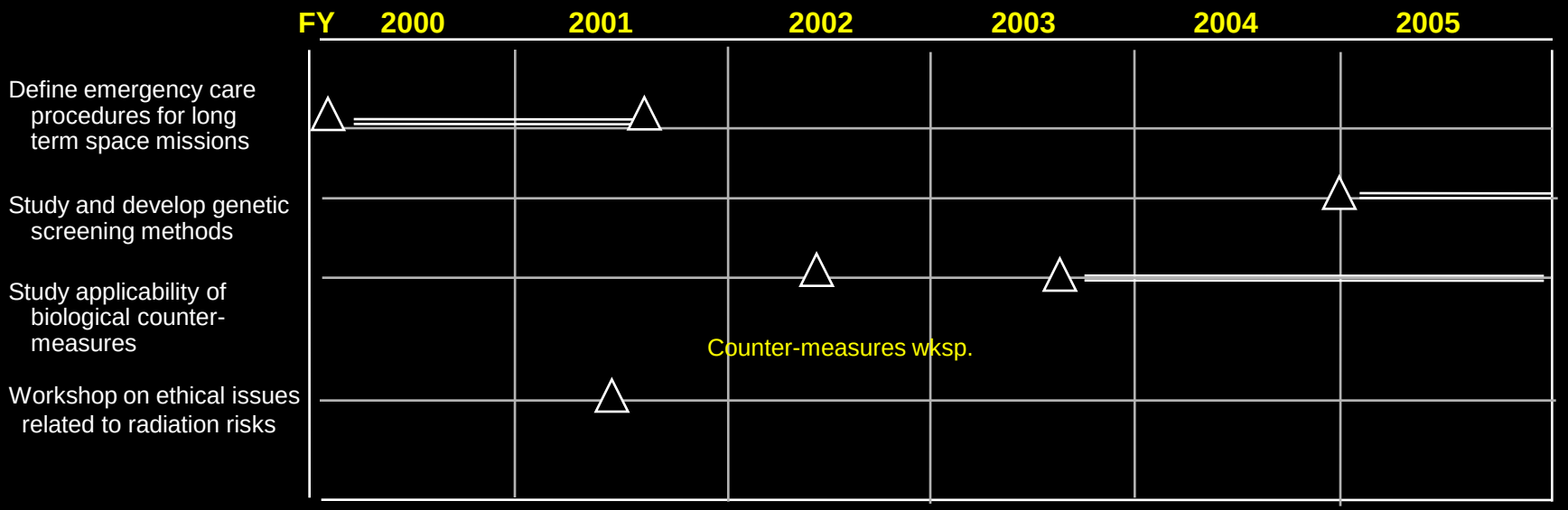
  3) develop cancer and CNS risk models using alternative risk methodologies including molecular and genetic approaches

  4) assess RBE data for late effects to understand to a factor of +/200% by 2002 and +/50% by 2009

  5) integrate results from radiobiology research with spacecraft and mission parameters to assess mission risks

  6) study implications of new NCRP guidelines and recommend new flight rules as necessary

Crew Risk Factors



- **Goal:** Biomedical countermeasures for risk mitigation include possible use of pharmaceuticals and genetic screening for radiation sensitivity of crew members. Emergency care may be required for radiation injury on ISS and exploratory class mission. Develop innovative approaches to Biomarkers for crew follow medical examination
- **Problem definition:** Biomedical countermeasures are a Phase II element of radiation strategic plan. At this time a workshop of experts will define a roadmap for establishing need based on risk projections and recommend possible countermeasures.
- **Program needs and deliverables:**

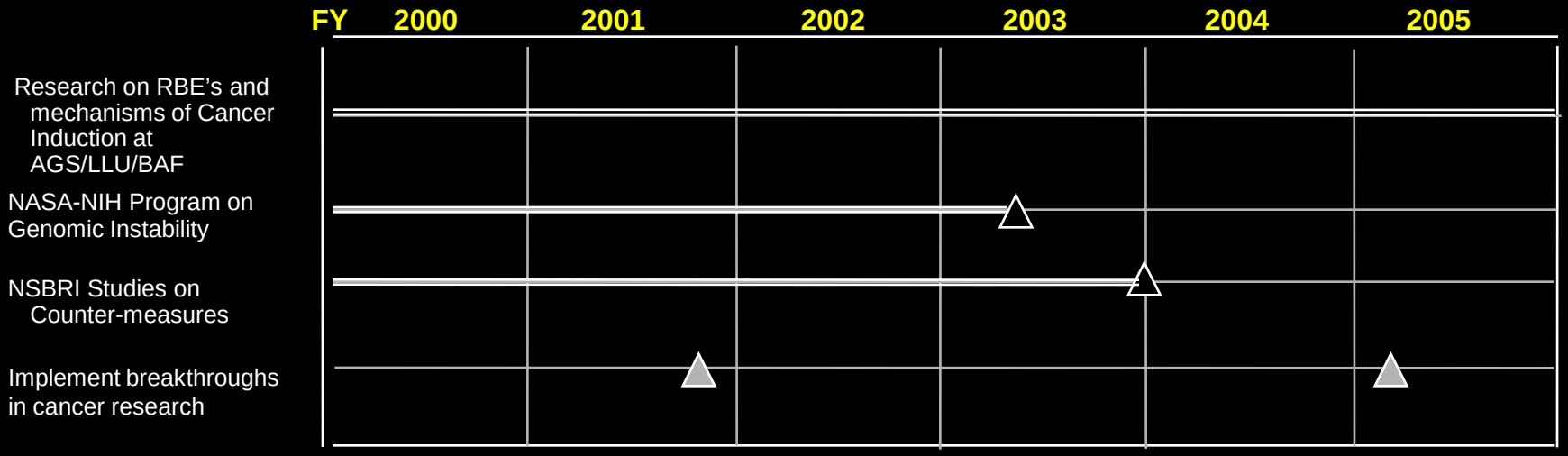
  1) emergency care procedures for ISS and exploratory missions

  2) study ethical issues related to permissible radiation exposures in human exploration and development of space

  3) study applicability of genetic screening approaches for identifying crew candidates at higher risk of radiation damage

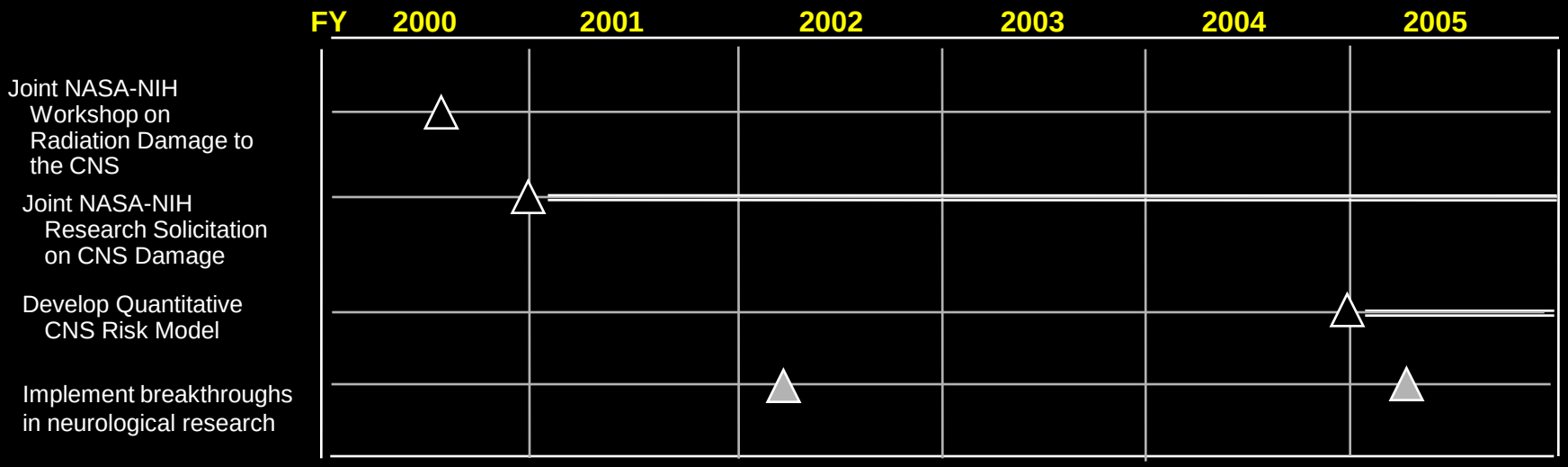
  4) study applicability of pharmaceutical agents suggested by research programs, DOD studies or NIH clinical trials

Risk of Carcinogenesis



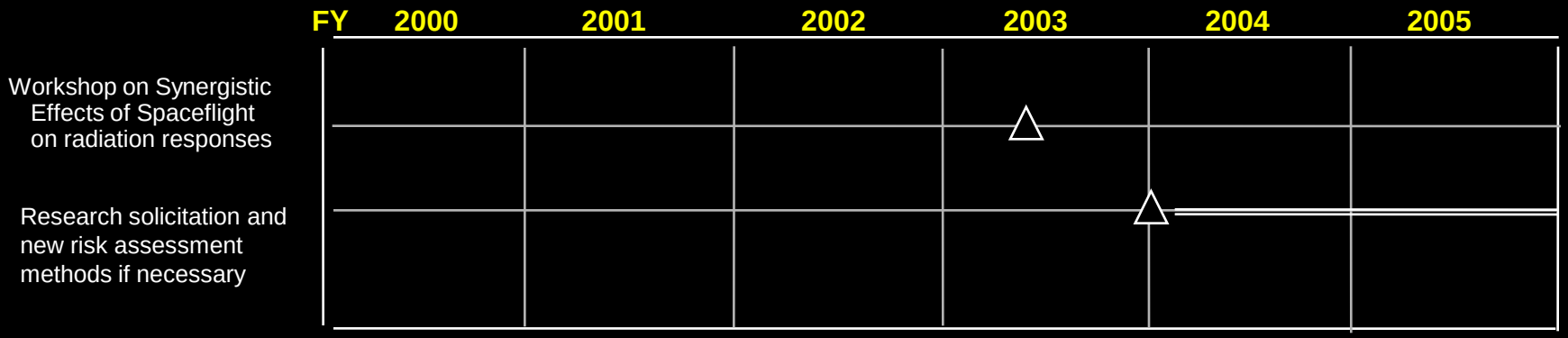
- **Goal:** Understand and mitigate the risk of cancer from space radiation which may pose the most serious health challenge for exploratory missions. Understand role of genomic instability in radiation induced cancer.
- **Problem definition:** Review of existing data and research roadmap have been provided by NCRP and NRC reports and LBNL select panel.
- **Research goals and deliverables:**
  1) provide data to determine RBE's for cancer induction to factor of +/200% by 2002 and +/50% by 2009
  2) tumor induction studies using lower species models for protons and high charge and energy (HZE) ion exposures
  3) mechanistic studies comparing carcinogenic events in human and murine cell culture models
  4) new approaches for extrapolation of risk in animals to man
  5) implement breakthroughs in cancer research into research program
  6) understand the role of genomic instability in radiation induced carcinogenesis

Risk of CNS Damage



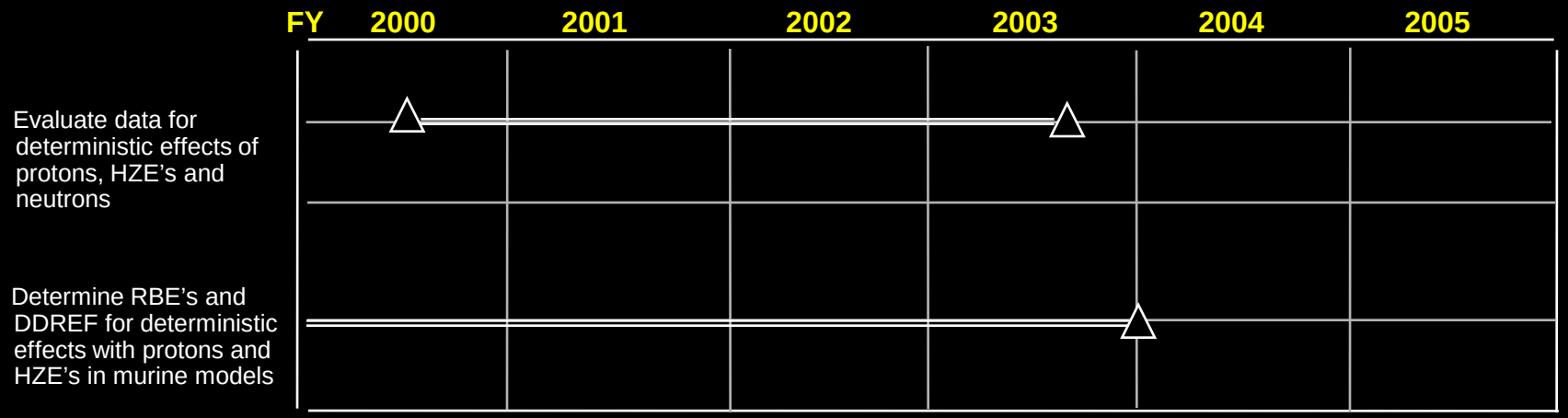
- **Goal:** Understand and mitigate harmful effects of protons and HZE's on the central nervous system (CNS).
- **Problem definition:** a joint NASA-NIH study will be made to define a roadmap for understanding possible risks.
- **Research goals and deliverables:**
  1) identify any unique effects of HZE's on damage to CNS
  2) understand cumulative effects of protons and HZE's on CNS for a 2-3 year exploration class mission
  3) implement breakthroughs in neurological science into research program
  4) develop data to quantify risks in order for risk methodology to be developed

Synergistic Effects of Spaceflight and Radiation



- **Goal:** Understand and mitigate possible synergistic effects from microgravity and other spaceflight factors that may alter biological responses to radiation.
- **Problem definition:** A workshop on synergistic effects with leading experts will be held to define a roadmap for understanding this risk.
- **Research goals and deliverables:**
  1) establish whether altered cytokine levels effect carcinogenic, CNS or acute damage risks from space radiation
  2) study whether bone degradation or altered immune response effect carcinogenic risk , CNS damage, or acute/early risks of space radiation
  3) establish effects of microgravity on cellular and molecular processes related to radiation r r response

Acute and Early Effects

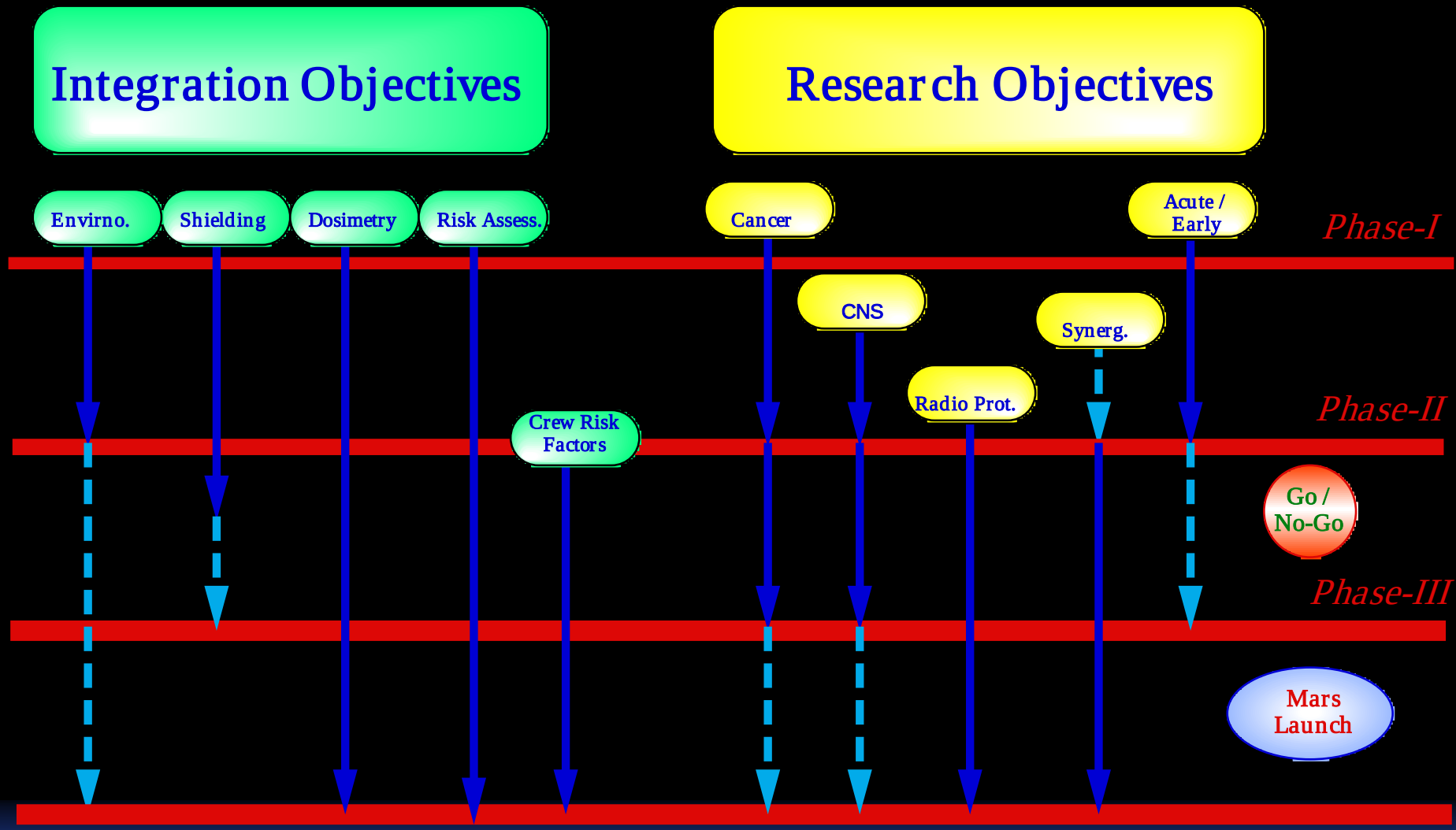


- **Goal:** Understand and mitigate possibilities of acute radiation sickness and death that may occur from large solar particle events. Understand early organ effects from heavy particle.
- **Problem definition:** NCRP and NRC reports have outlined basic issues and questions.
- **Research goals and deliverables:**

  1) provide data to determine acute risk from space radiation to factor of +/200% by end of 2002

  2) determine exposure-rate and radiation quality dependence on early effects to bone marrow, skin, central nervous system, and lymphopietic tissue using animal and molecular studies

  3) determine cumulative effects of protons and HZE's for a 2-3 year exploratory class mission on acute/early responses


Integration Objectives
Research Objectives
Envirno.
Shielding
Dosimetry
Risk Assess.
Cancer
Acute / Early
Phase-I
CNS
Synerg.
Radio Prot.
Crew Risk Factors
Phase-II
Go / No-Go
Phase-III
Mars Launch