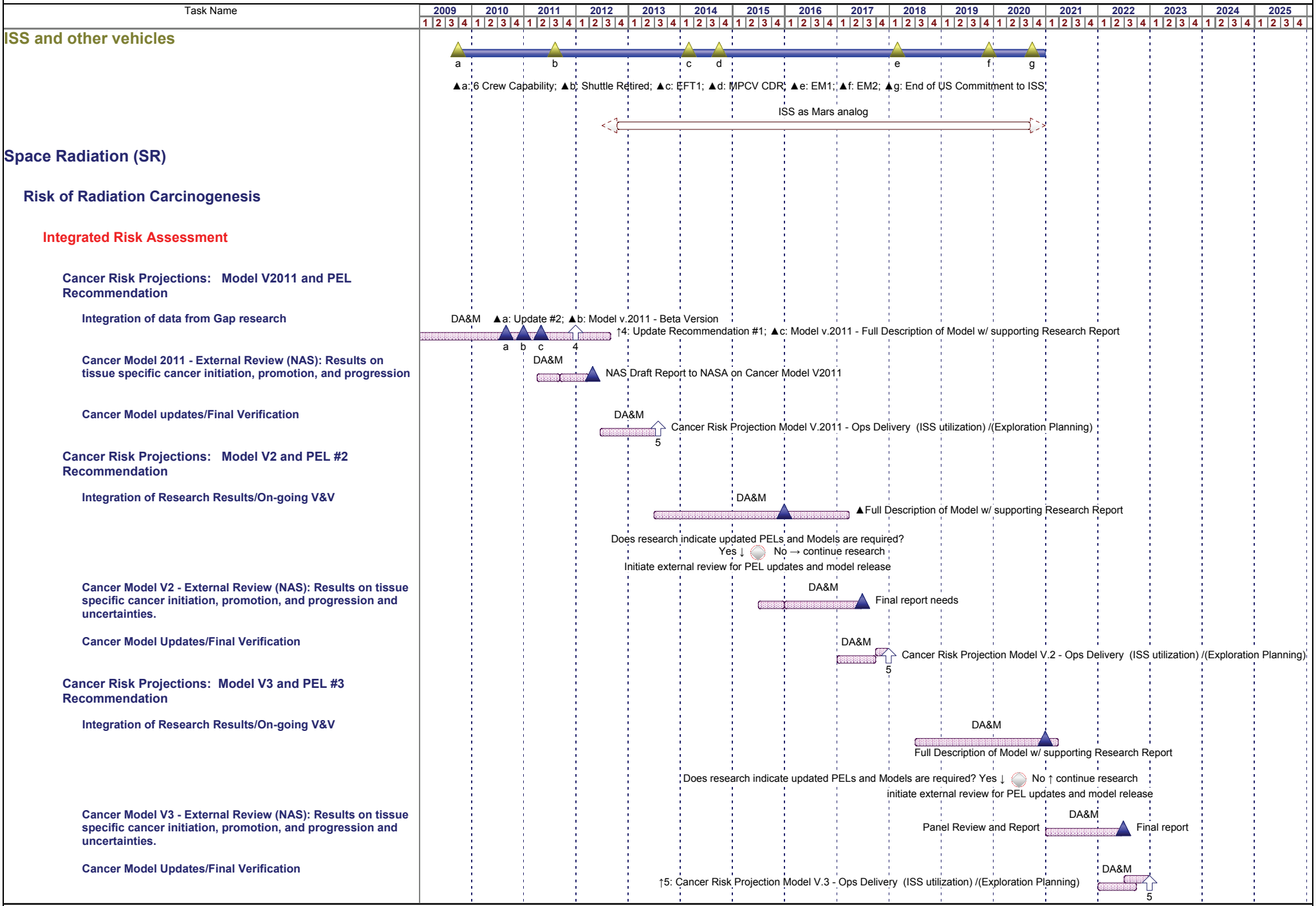
Summary
G: Ground Study
F: Flight Study
L: Lunar
NSBRI
DA&M: Data Analysis & Modeling
FP: Flight Prep
AO: Add on to another study
Planned/unfunded

Early Start
Task To Be Determined After Decision Point
Major Milestone/Event/Accomplishment
1) Risk Characterization
2) Task↓↑Task
3) Standards - New
4) Standards - Update
5) Tool
6) Technology

7) Countermeasure
8) Information To/From other Elements
9) Information to HSRB
10) Requirements
11) Study
Stop
Major Decision Point


Task Name
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025
ISS and other vehicles
a b c d e f g
▲a: 6 Crew Capability; ▲b: Shuttle Retired; ▲c: EFT1; ▲d: MPCV CDR; ▲e: EM1; ▲f: EM2; ▲g: End of US Commitment to ISS
ISS as Mars analog
Space Radiation (SR)
Risk of Radiation Carcinogenesis
Integrated Risk Assessment
Cancer Risk Projections: Model V2011 and PEL Recommendation
Integration of data from Gap research
DA&M ▲a: Update #2; ▲b: Model v.2011 - Beta Version
↑4: Update Recommendation #1; ▲c: Model v.2011 - Full Description of Model w/ supporting Research Report
a b c 4
Cancer Model 2011 - External Review (NAS): Results on tissue specific cancer initiation, promotion, and progression
DA&M
NAS Draft Report to NASA on Cancer Model V2011
Cancer Model updates/Final Verification
DA&M
Cancer Risk Projection Model V.2011 - Ops Delivery (ISS utilization) /(Exploration Planning)
5
Cancer Risk Projections: Model V2 and PEL #2 Recommendation
Integration of Research Results/On-going V&V
DA&M
▲Full Description of Model w/ supporting Research Report
Does research indicate updated PELs and Models are required?
Yes ↓ No → continue research
Initiate external review for PEL updates and model release
Cancer Model V2 - External Review (NAS): Results on tissue specific cancer initiation, promotion, and progression and uncertainties.
DA&M
Final report needs
Cancer Model Updates/Final Verification
DA&M
Cancer Risk Projection Model V.2 - Ops Delivery (ISS utilization) /(Exploration Planning)
5
Cancer Risk Projections: Model V3 and PEL #3 Recommendation
Integration of Research Results/On-going V&V
DA&M
Full Description of Model w/ supporting Research Report
Does research indicate updated PELs and Models are required? Yes ↓ No ↑ continue research
initiate external review for PEL updates and model release
Cancer Model V3 - External Review (NAS): Results on tissue specific cancer initiation, promotion, and progression and uncertainties.
DA&M
Panel Review and Report
Final report
Cancer Model Updates/Final Verification
DA&M
↑5: Cancer Risk Projection Model V.3 - Ops Delivery (ISS utilization) /(Exploration Planning)
5

Task Name

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

ISS and other vehicles

a b c d e f g

▲a: 6 Crew Capability; ▲b: Shuttle Retired; ▲c: EFT1; ▲d: MPCV CDR; ▲e: EM1; ▲f: EM2; ▲g: End of US Commitment to ISS

ISS as Mars analog

Space Radiation (SR)

Risk of Radiation Carcinogenesis

Cancer 01: How can experimental models of tumor development for the major tissues (lung, colon, stomach, breast, liver, and leukemias) be developed to represent the major processes in radiation carcinogenesis and extrapolated to human risk projections?

Ground Research at NSRL Major Tissuesr Phase I: Mechanisms of Radiation Carcinogenesis

Research Results

▲a: Leukemia Lifespan data for Iron; ▲b: 3D Human lung and Breast Data for Iron; ▲c: Initiation vs Promotion Findings for HZE's
▲d: Mouse lifespan data; ▲e: Lung Cancer Research Results

a b c d e

Grants

G

2004/05 NSCOR Research

↑2: to RAP - Model V.2011 development

a, b c, d 2

▲a: Barcellos-Hoff Final Report; ▲b: Ullrich Final Report; ▲c: Hlatky Final Report; ▲d: Minna Final Report

Do RBE's Apply to Heavy Ions?
No ↓ Yes → continue major tissues focused on RBE's and quality effects
ew focus on systems biology approach without RBEs

2009 NSCOR Research

G a, b, c

▲a: Barcellos Final Report; ▲b: Ullirch Final Report ; ▲c: Fornace Final Report

↑2: to RAP - Model V.2 development 2

2010 NSCOR - Lung Cancer Consortium

G

↑2: to RAP - Model V.2 development

2

Is the Uncertainty in Cancer Risk Projections <2-fold?
No ↓ Yes → Shift research focus to Gap 2 skin, bladder, brain, and esophagus cancer
Continue Gap1 - Gournd Based Research Phase II

Ground Based Research NSRL Major Tissues Phase II: Mechanisms of Radiation Carcinogenesis

G ▲: Update #4 on cancer risk uncertainty assessment: Goal of +/- 5

↑2: to RAP - Model V.3 development 2

Is the uncertainty in Cancer Risk Projections < +/- 50%?
No ↓ Yes → Stop
continue risk research gaps 2,9

Task Name

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ISS and other vehicles

a b c d e f g

▲a: 6 Crew Capability; ▲b: Shuttle Retired; ▲c: EFT1; ▲d: MPCV CDR; ▲e: EM1; ▲f: EM2; ▲g: End of US Commitment to ISS

ISS as Mars analog

Space Radiation (SR)

Risk of Radiation Carcinogenesis

Cancer 02: How can experimental models of tumor development for the other tissues (bladder, skin, esophagus, brain, etc) be developed to represent the major processes in radiation carcinogenesis and extrapolated to human risk projections?

Ground Based Research to investigate Mechanisms of Radiation Carcinogenesis in minor Tissues (Phase I)

↑2a: to RAP: Model V.1 development
G
▲a: 3D Human tissue results for minor solids
c
▲b: Mouse lifespan results for m
2a
↑2b,↑2c : to RAP: Model V.2 development
a
b
2b
2c
▲c: Update #4

Is the Uncertainty in Cancer Risk Projections <+/- 50%?
No ↓ Yes → Stop
Implement ground based research on minor tissues: Phase II

Ground Based Research to investigate Mechanisms of Radiation Carcinogenesis in minor Tissues (Phase II)

G
G: NRA R01 Research; 2014 NSCOR Selections

Cancer 03: How can models of cancer risk be applied to reduce the uncertainties in radiation quality effects from SPE's and GCR?

Research to establish new quality functions for space radiation

G
Cancer Model V.1
▲a:HZE results
Cancer Model V.2
▲b: EBIS results
Cancer Model V.3
2a
a
2b
b
2c

Receive information from Gaps 1,2 - Results on Cancer processes and IPP for HZE's received (on-going)

2

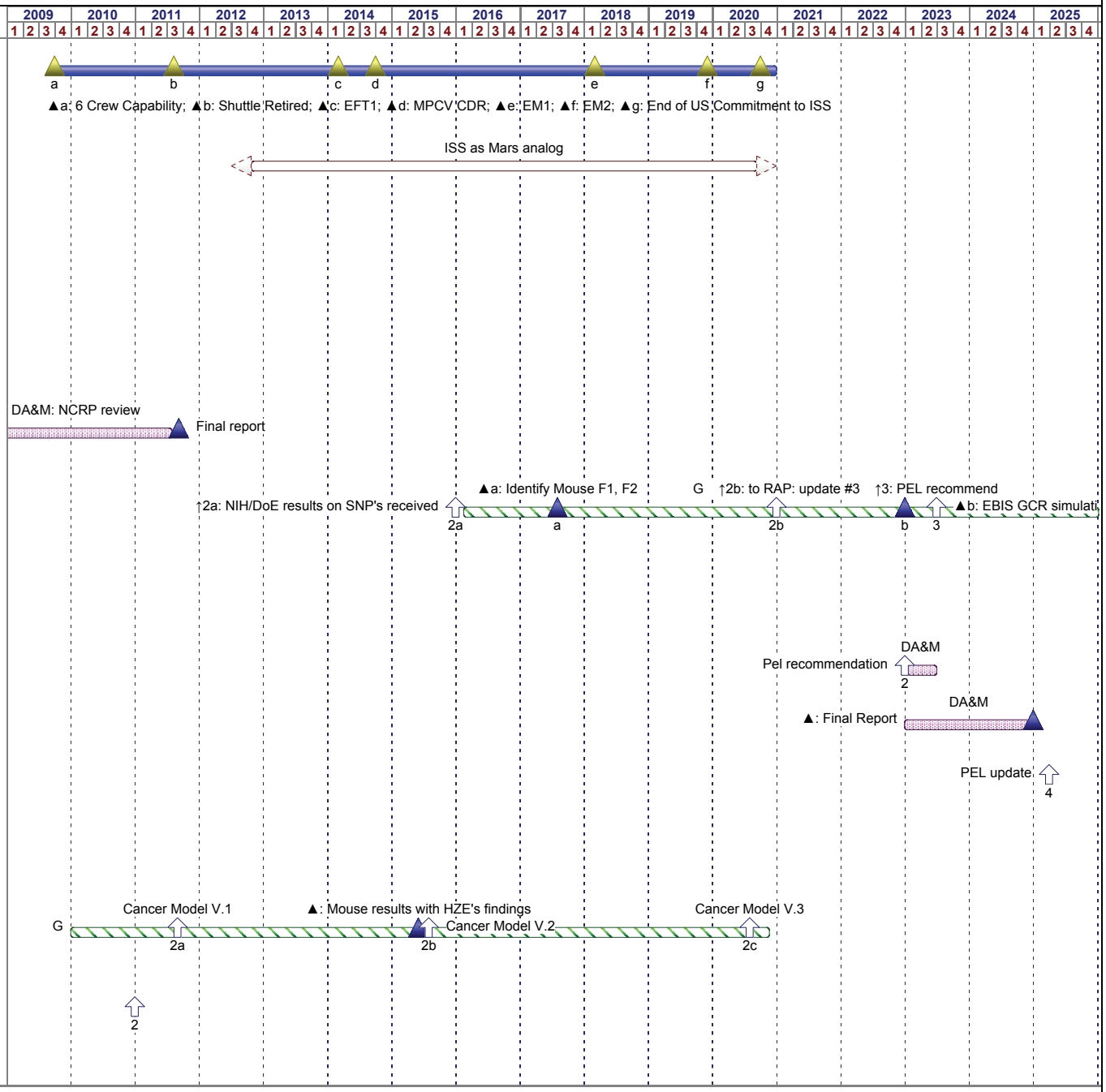
Cancer 04: How can models of cancer risk be applied to reduce the uncertainties in dose-rate dependence of risks from SPE's and GCR?

Research to Improve mechanistic understanding for the variability of dose-rate dependencies for cancer

G
Cancer Model V.1
▲a: SPE dose-rate data sets
Cancer Model V.2
▲b: EBIS on SPE+ GCR results
Cancer Model V.3
a
2a
2b
b
2c

Receive information from Gaps 1,2 - Results on Cancer processes for HZE's received (on-going)

2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ISS as Mars analog
Space Radiation (SR)
Risk of Radiation Carcinogenesis
Cancer 05: How can models of cancer risk be applied to reduce the uncertainties in individual radiation sensitivity including genetic and epigenetic factors from SPE and GCR?
NCRP: Initial Report (1-13) on Individual Sensitivity Research, Ethics & Legal Assessment
DA&M: NCRP review
Final report
Research to Determine how genetic and epigenetic factors influence radiation sensitivity
↑2a: NIH/DoE results on SNP's received
▲a: Identify Mouse F1, F2
G
↑2b: to RAP: update #3
↑3: PEL recommend
▲b: EBIS GCR simulati
2a a 2b b 3
PEL Recommendations on individual sensitivity
Integration of Research Results
DA&M
Pel recommendation
2
External Review: Primary Individual Sensitivity Research, Ethics & Legal Assessment
DA&M
▲: Final Report
Update to Cancer PELs - Individual Sensitivity
PEL update
4
Cancer 06: How can models of cancer risk be applied to reduce the uncertainties in the age and gender dependence of cancer risks from SPE's and GCR?
Research to improve mechanistic understanding of Age and Gender Effects Analysis
G
Cancer Model V.1
▲: Mouse results with HZE's findings
Cancer Model V.2
Cancer Model V.3
2a 2b 2c
Receive information from Gaps 1,2 - Results on Cancer processes for HZE's received (on-going)
2

Task Name

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

ISS and other vehicles

a b c d e f g

▲a: 6 Crew Capability; ▲b: Shuttle Retired; ▲c: EFT1; ▲d: MPCV CDR; ▲e: EM1; ▲f: EM2; ▲g: End of US Commitment to ISS

ISS as Mars analog

Space Radiation (SR)

Risk of Radiation Carcinogenesis

Cancer 07: How can systems biology approaches be used to integrate research on the molecular, cellular, and tissue mechanisms of radiation damage to improve the prediction of the risk of cancer and to evaluate the effectiveness of CM's?

Construct Mathematical Network Models using Systems Biology Approach

Cancer Model V.1 — 2a
Cancer Model V.2 — 2b
Cancer Model V.3 — 2c
G: NRA R01 Research
CM efficacy
GCR & SPE simulations

Receive Results on Cancer processes for HZE, validity of RBEs from Gaps 1,2 (on-going)

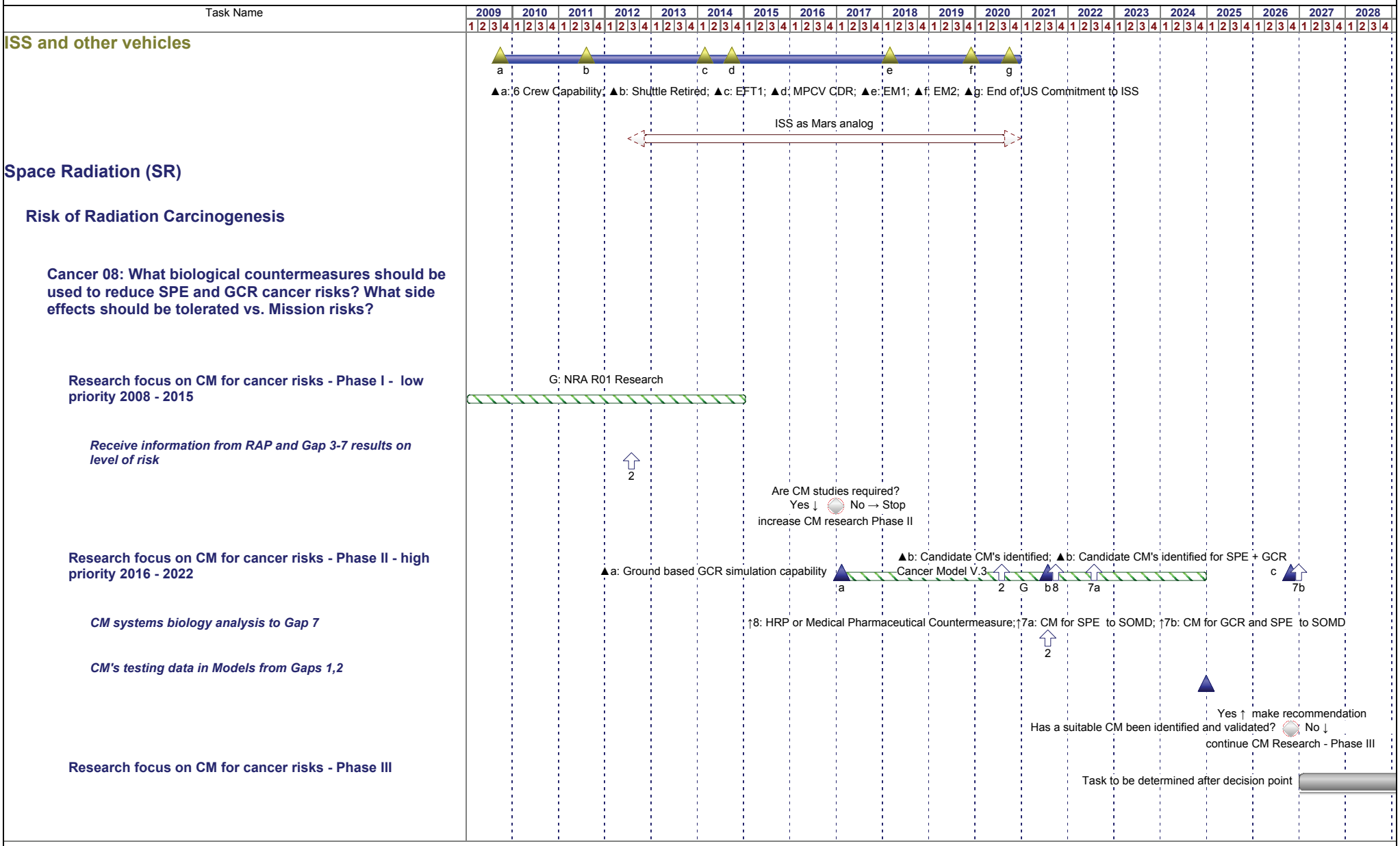
2

High throughput genomics and proteomics data sets for processes found in Gaps 1,2

Is Systems Model Complete?
Yes → Stop
No → continue

Risk assessment "omics" inititative (unfunded)

↑2a: to RAP: Model V.2 develop.; ↑2b: "omics" data from Gaps 1,2,3; ↑2c: to RAP: Model V.3 develop.;
P/U: G
2a 2b 2c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ISS as Mars analog
Space Radiation (SR)
Risk of Radiation Carcinogenesis
Cancer 08: What biological countermeasures should be used to reduce SPE and GCR cancer risks? What side effects should be tolerated vs. Mission risks?
Research focus on CM for cancer risks - Phase I - low priority 2008 - 2015
G: NRA R01 Research
Receive information from RAP and Gap 3-7 results on level of risk
2
Are CM studies required?
Yes ↓ No → Stop
increase CM research Phase II
Research focus on CM for cancer risks - Phase II - high priority 2016 - 2022
▲a: Ground based GCR simulation capability
▲b: Candidate CM's identified; ▲b: Candidate CM's identified for SPE + GCR
Cancer Model V.3
a 2 G b 8 7a c 7b
CM systems biology analysis to Gap 7
↑8: HRP or Medical Pharmaceutical Countermeasure; ↑7a: CM for SPE to SOMD; ↑7b: CM for GCR and SPE to SOMD
2
CM's testing data in Models from Gaps 1,2
Yes ↑ make recommendation
Has a suitable CM been identified and validated?
No ↓
continue CM Research - Phase III
Research focus on CM for cancer risks - Phase III
Task to be determined after decision point

Task Name

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

ISS and other vehicles

a b c d e f g

▲a: 6 Crew Capability; ▲b: Shuttle Retired; ▲c: EFT1; ▲d: MPCV CDR; ▲e: EM1; ▲f: EM2; ▲g: End of US Commitment to ISS

ISS as Mars analog

Space Radiation (SR)

Risk of Radiation Carcinogenesis

Cancer 09: Are there significant synergistic effecs from other spaceflight factors (microgravity, stress, altered circadian rhythms, changes in immune responses, depressed nutrition, bone loss, etc) that modify the carcinogenic risk from space radiation?

NAS/NCRP Commentary on Cancer Synergistic Risks

P/U

Final Report

3

Research on Spaceflight Snyergies with HHC and BHP - PHASE I

G: NRA R01 research

↑2: to RAP: Model V.3 develop.

2

Stop ← No

Is more research required to identify and understand synergies with other spaceflight factors?

Yes ↓

Implement Phase II research on synergies

Independent review of approaches on synergies

DA&M

Final Report

3

Research on Spaceflight Snyergies with HHC and BHP- Phase II

G: NRA R01 research

Task Name

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

ISS and other vehicles

a b c d e f g

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ISS as Mars analog

Space Radiation (SR)

Risk of Radiation Carcinogenesis

Cancer 10: Are space validation experiments needed for verifying knowledge of carcinogenic or other risks prior to long-term deep space missions, and if so what experiments should be undertaken?

Yes → Conduct review
No ↓ Do current research results indicate flight validation experiements are required?
Continue to look at uniques ways/methods to compare NSRL results vs. crew. Re evaluate as new research results available

NAS/NCRP Commentary: Determine if space validation experiments are necessary to address space radiation risks

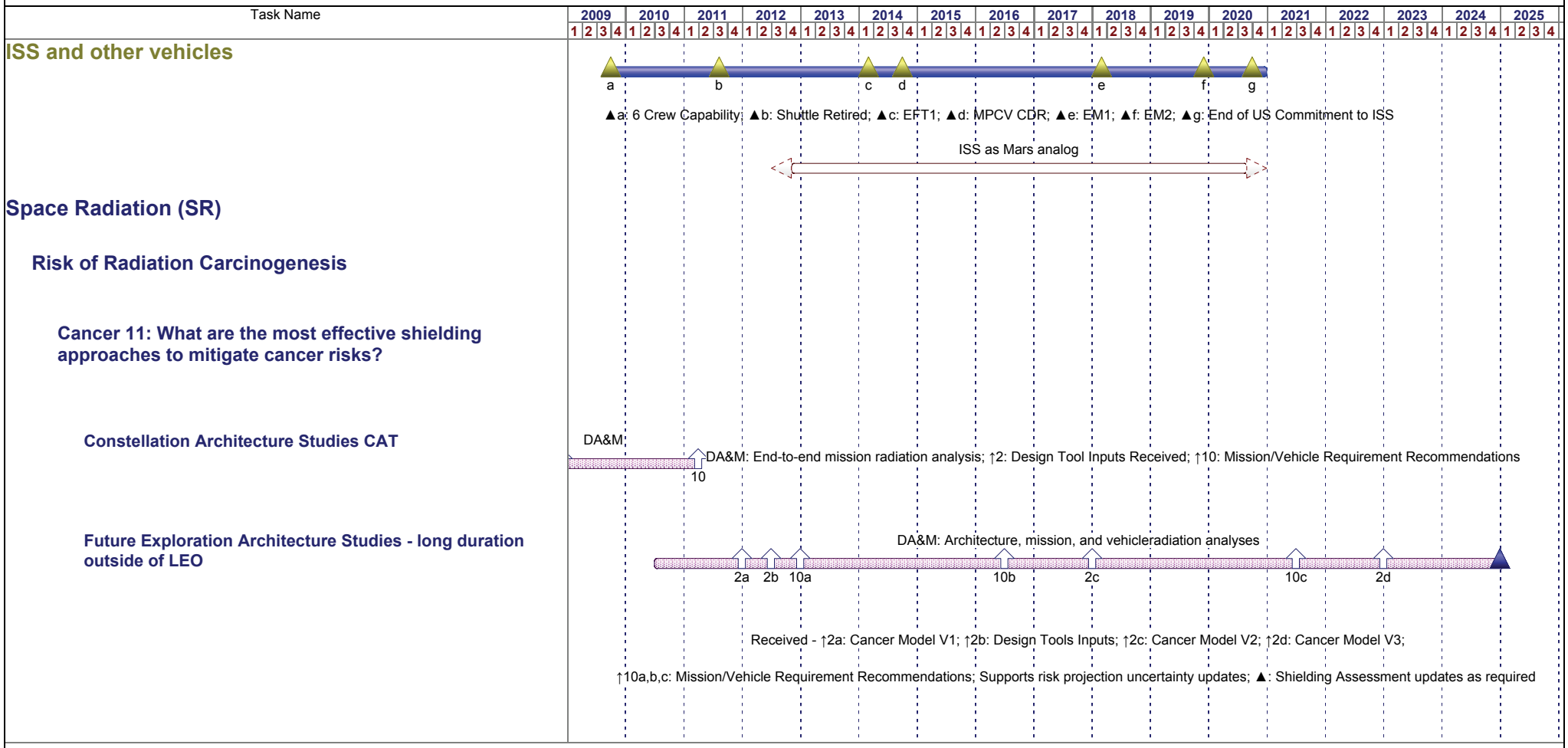
DA&M
2

Are flight experiments required?
Stop ← No Yes → determine mass, power, sample size; negotiate launch vehicles and platforms

DA&M: Look at unique ways/methods to compare NSRL results vs. crew ground study

Flight experiment on synergistic effects (yes, from decision point: Priority dictated by annual review of research progress, NASA major MS, and assessment of future low cost platform availability (ISS or other)

P/U: FP P/U: F P/U: DA&M
↑2: Results to Gap 9
▲: Flight results assessment of risk model
2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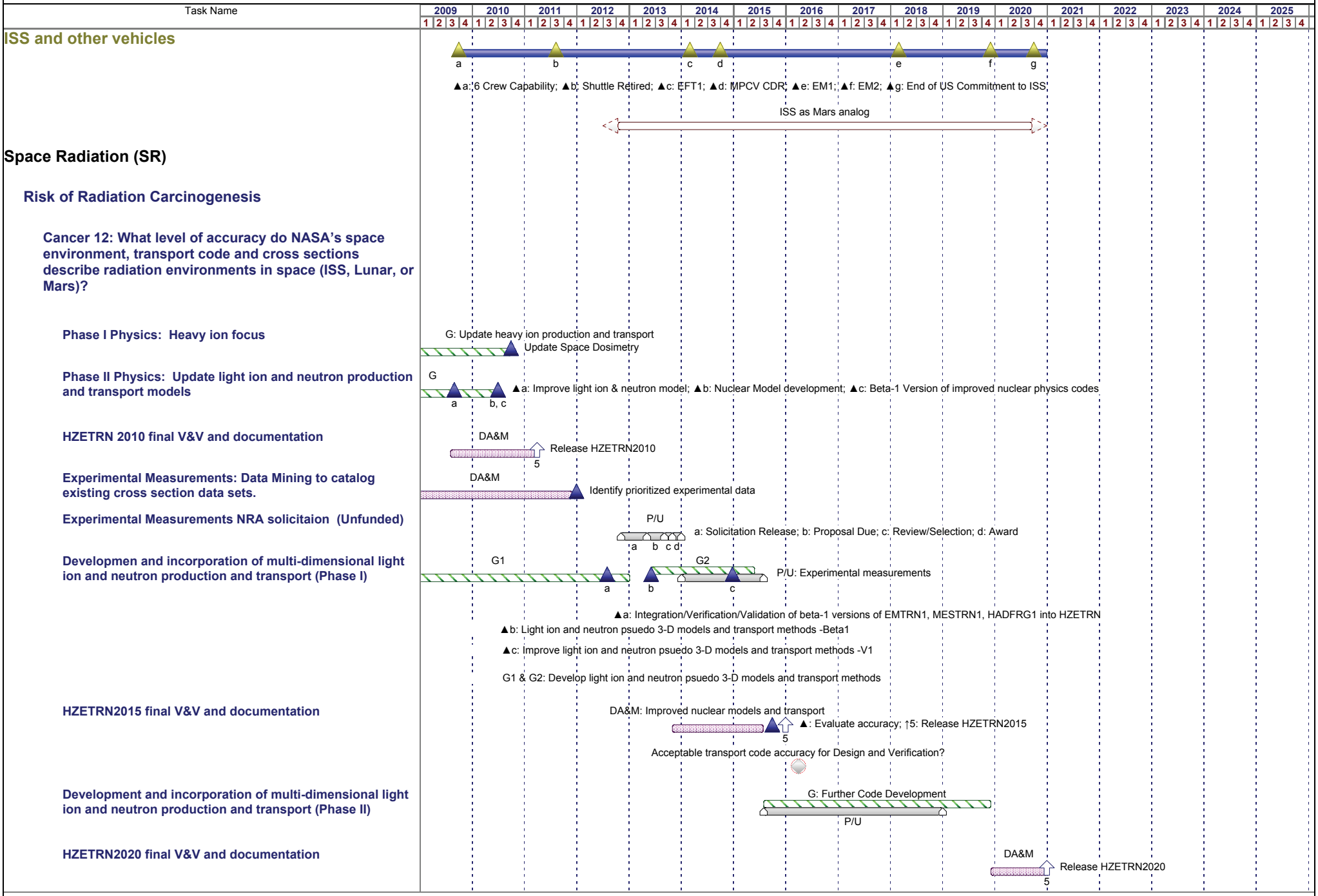
ISS as Mars analog
Space Radiation (SR)
Risk of Radiation Carcinogenesis
Cancer 11: What are the most effective shielding approaches to mitigate cancer risks?
Constellation Architecture Studies CAT
DA&M
DA&M: End-to-end mission radiation analysis; ↑2: Design Tool Inputs Received; ↑10: Mission/Vehicle Requirement Recommendations
10
Future Exploration Architecture Studies - long duration outside of LEO
DA&M: Architecture, mission, and vehicleradiation analyses
2a 2b 10a 10b 2c 10c 2d
Received - ↑2a: Cancer Model V1; ↑2b: Design Tools Inputs; ↑2c: Cancer Model V2; ↑2d: Cancer Model V3;
↑10a,b,c: Mission/Vehicle Requirement Recommendations; Supports risk projection uncertainty updates; ▲: Shielding Assessment updates as required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ISS as Mars analog
Space Radiation (SR)
Risk of Radiation Carcinogenesis
Cancer 12: What level of accuracy do NASA's space environment, transport code and cross sections describe radiation environments in space (ISS, Lunar, or Mars)?
Phase I Physics: Heavy ion focus
G: Update heavy ion production and transport
Update Space Dosimetry
Phase II Physics: Update light ion and neutron production and transport models
G
a b, c
▲a: Improve light ion & neutron model; ▲b: Nuclear Model development; ▲c: Beta-1 Version of improved nuclear physics codes
HZETRN 2010 final V&V and documentation
DA&M
Release HZETRN2010
5
Experimental Measurements: Data Mining to catalog existing cross section data sets.
DA&M
Identify prioritized experimental data
Experimental Measurements NRA solicitaion (Unfunded)
P/U
a b c d
a: Solicitation Release; b: Proposal Due; c: Review/Selection; d: Award
Developmen and incorporation of multi-dimensional light ion and neutron production and transport (Phase I)
G1
G2
a b c
P/U: Experimental measurements
▲a: Integration/Verification/Validation of beta-1 versions of EMTRN1, MESTRN1, HADFRG1 into HZETRN
▲b: Light ion and neutron psuedo 3-D models and transport methods -Beta1
▲c: Improve light ion and neutron psuedo 3-D models and transport methods -V1
G1 & G2: Develop light ion and neutron psuedo 3-D models and transport methods
HZETRN2015 final V&V and documentation
DA&M: Improved nuclear models and transport
▲: Evaluate accuracy; ↑5: Release HZETRN2015
5
Acceptable transport code accuracy for Design and Verification?
Development and incorporation of multi-dimensional light ion and neutron production and transport (Phase II)
G: Further Code Development
P/U
HZETRN2020 final V&V and documentation
DA&M
Release HZETRN2020
5

Task Name

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025

ISS and other vehicles

a b c d e f g

▲a: 6 Crew Capability; ▲b: Shuttle Retired; ▲c: EFT1; ▲d: MPCV CDR; ▲e: EM1; ▲f: EM2; ▲g: End of US Commitment to ISS

ISS as Mars analog

Space Radiation (SR)

Risk of Radiation Carcinogenesis

Cancer 13: What are the most effective approaches to integrate radiation shielding analysis codes with collaborative engineering design environments used by spacecraft and planetary habitat design efforts?

Initial DesignTool Capability accessible through web-based interface

6a: Phase A/B Design Tool capability complete; 6b: Phase B/C simulation Tool capability complete

Develop Enhanced Design and Analysis Tool Capabilities

G DA&M ↑5a: Phase C/D Simulation Tool Capability; ↑5b: Baseline enhanced computational design tools

5a 5b

Develop Simulation Tools Capability

DA&M a, b, c ↑6: Enhanced Phase C/D Simulation Design Tool for vehicle radiation shielding assessments

6

▲a: Incorporate as-designed and what if cases; ▲b: Incorporate advanced spacecraft material handling techniques
▲c: Independent verification and validation

Lunar Surface Environmental Modelling

G DA&M ↑10: Lunar Neutron Environment and design interface complete

a, b c, d ϵ10

▲a: Lunar Surface modeling; ▲b: Lunar neutron model (beta version)
▲c: Validation with benchmark and LRO CRaTER, LEND
▲d: Baseline Lunar Surface Environmental model; ▲e: Validation with other benchmark/ experimental data sets

Mars Surface Environmental Modelling

G DA&M ↑10: Mars Surface Environmental Model and design interface complete

a b, c d10

▲a: Mars surface environment model (beta version); ▲b: Validation w/ MSL RAD measurements, Earth upper atmosphere data (BESS, CAPRICE)

▲c: Baseline Mars Surface radiation Environmental Model; ▲d: Validation of EM with earth upper atmospheric data

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ISS and other vehicles

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ISS as Mars analog

Space Radiation (SR)

Risk of Radiation Carcinogenesis

Cancer 14: What are the biodosimetry methods for Lunar and Mars missions, and are biomarker approaches needed?

G: NRA R01 research

DA&M

↑3: Biomarker/Biodosimetry Requirements

3

Cancer 15: Are there research approaches using simulated space radiation that can elucidate the potential confounding effects of tobacco use on space radiation cancer risk estimates?

↑2a: Research updates to RAP: Cancer Model V2

G

↑2b: Research updates to RAP: Cancer Model V3

2a

2b