The MarsREM Project
Emerging Requirements for Ion Physics

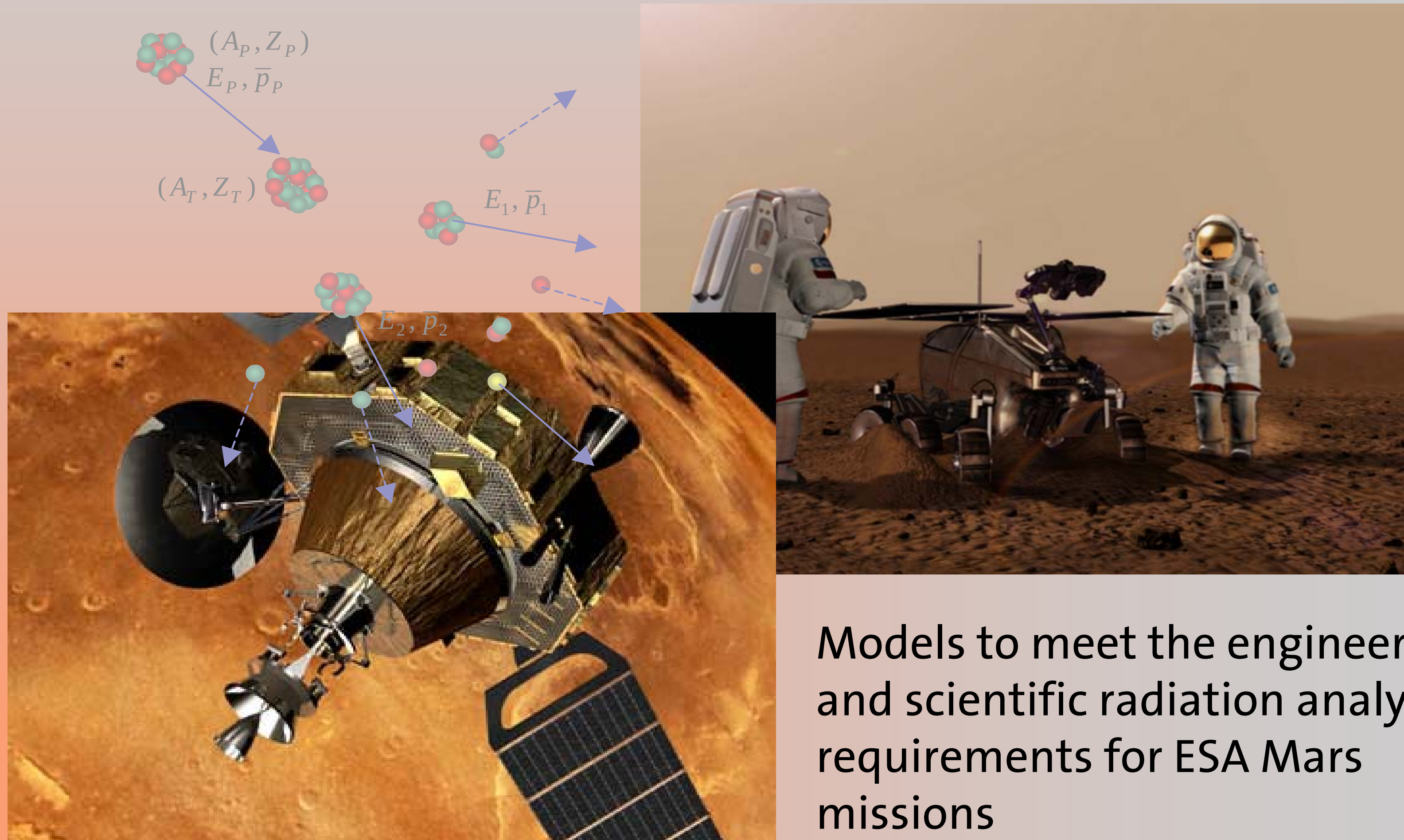
Pete Truscott, Fan Lei
QinetiQ, Farnborough, UK

11th Geant4 Collaboration Workshop, LIP-Lisbon
13/10/2006

QinetiQ developments and research funded by ESA under contracts 17191/03/NL/LvH and 19770/06/NL/JD, and by the UK MOD under contract C/MAT/N03517

QinetiQ

Mars Radiation Environment Models

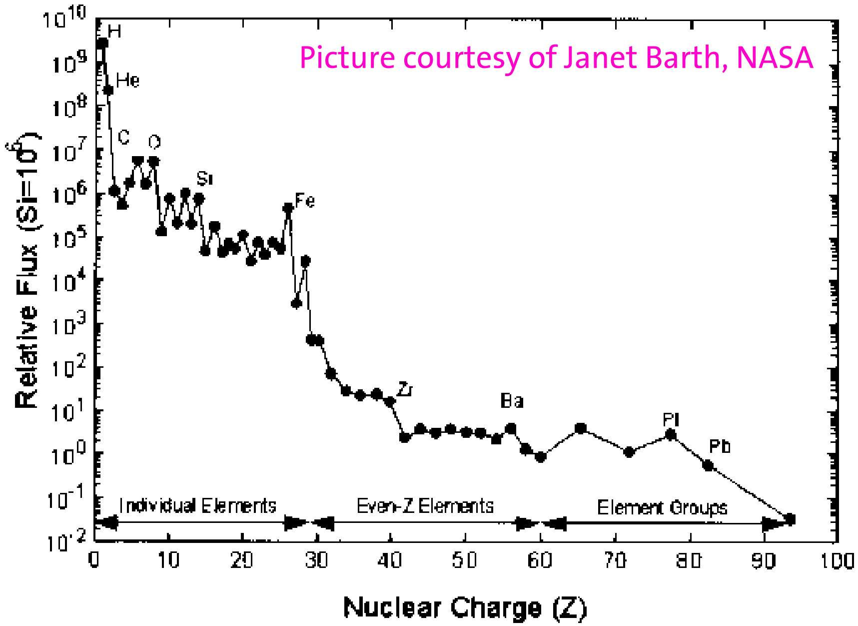


Mars images courtesy of ESA Portal Multimedia Gallery

Models to meet the engineering and scientific radiation analysis requirements for ESA Mars missions

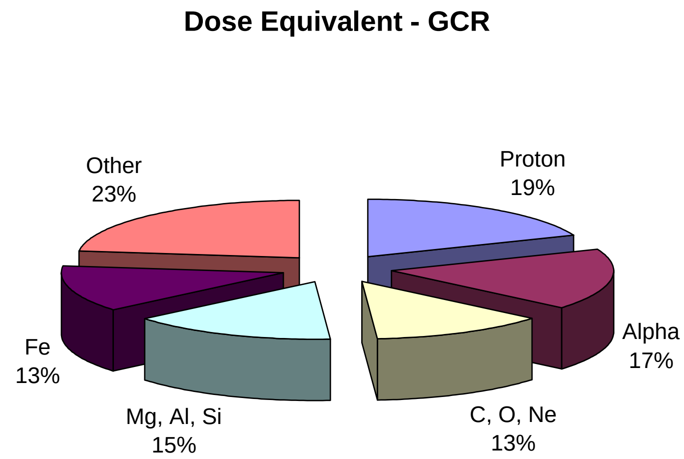
Radiation in Space

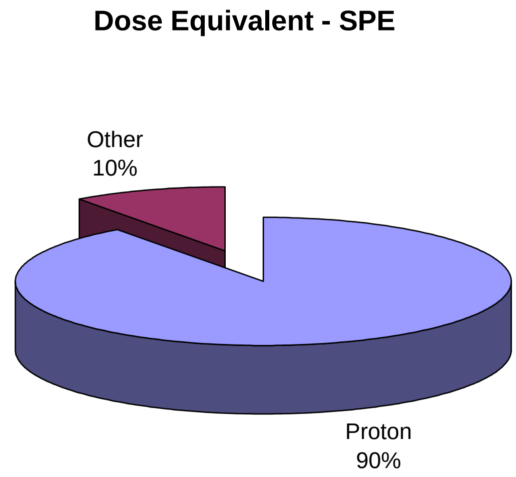
Species and energy range of source particles for interplanetary env.



- GCR:
  - Very wide range in species, with noticeable dips after He and Fe
  - Typical energy range of concern: 10's MeV/nuc - ~100 GeV/nuc , although mean energy is several hundred MeV/nuc.
- Solar particle events 10's MeV/nuc to ~1 GeV/nuc:
  - Impulsive, short-term events associated with solar flares have greater fraction of heavy particles
  - CMEs produce gradual events that are proton-rich and last longer

Radiobiological Dose





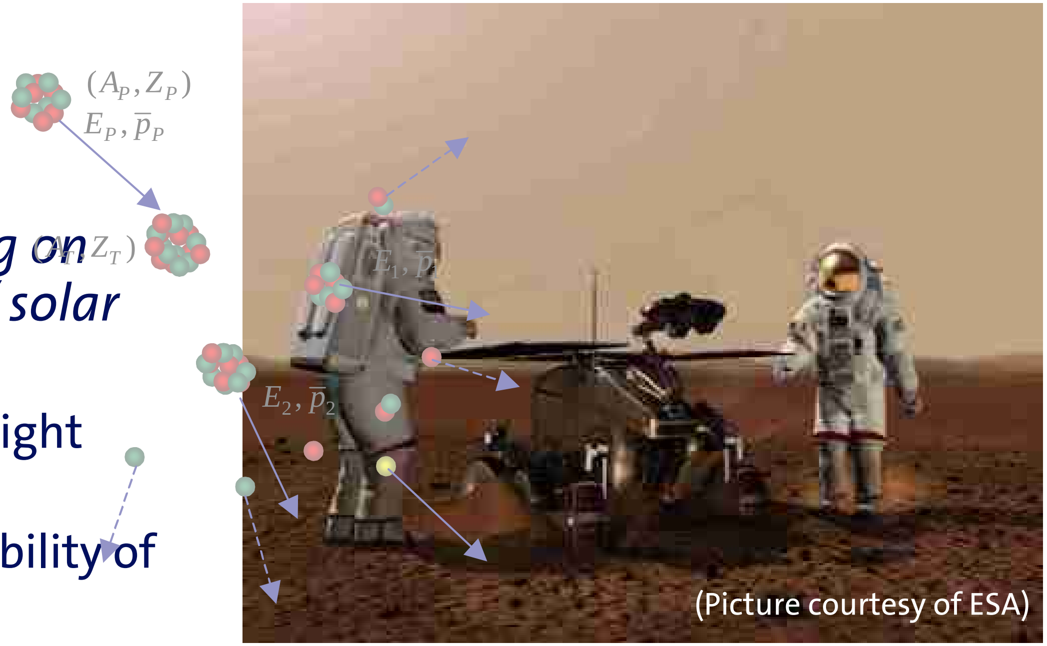
Contribution of GCR and SPE ions very important to radiobiological dose in the interplanetary environment

Data from W Schimmerling, J W Wilson, F Cucinota, and M-H Y Kim, 1998.

Background: Interplanetary

Assessment of influence of shielding on radiological effects of cosmic rays / solar particles

- Long-duration manned spaceflight (interplanetary)
- Investigating probability/possibility of extra-terrestrial life
- Degradation of Martian "pregnancy test" kits - assessment of radiation on biological agents used to indicate presence of extra-terrestrial life



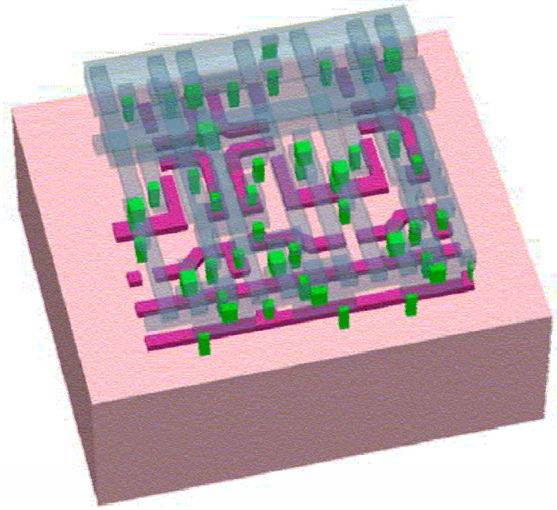
(Picture courtesy of ESA)

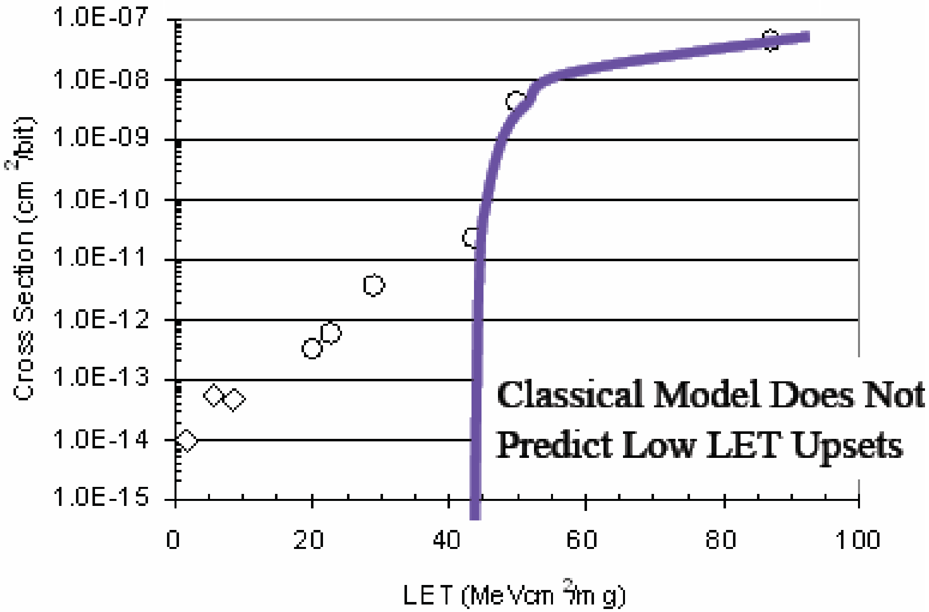
QinetiQ

Backgroun: Space & on Earth

Space and aviation environments

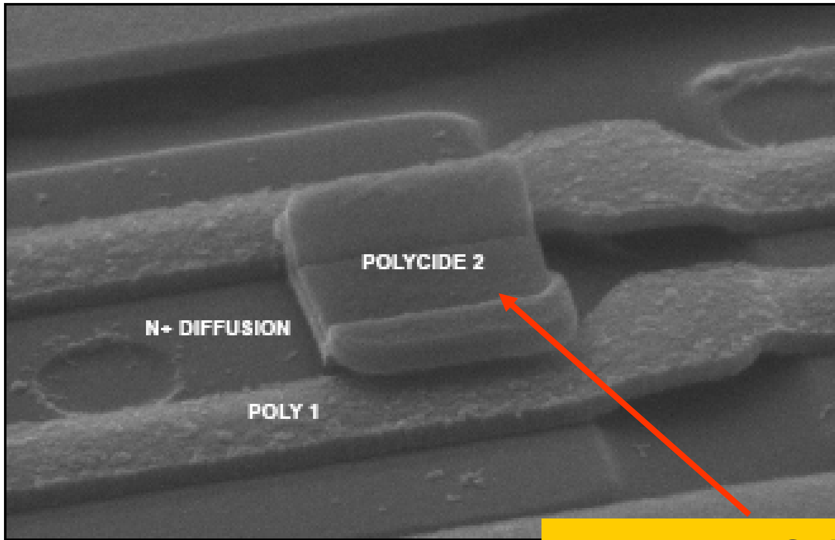
- Nuclear-nuclear models are also applicable to single event effects prediction
- Evidence that these interactions in tungsten vias and (potentially) tungsten silicide layers give rise to high-LET nuclear recoils from low-LET incident particles (work of Reed, Weller *et al* at Vanderbilt University)
- RTG: e.g. calculation of n flux for Po210 with Boron Carbide

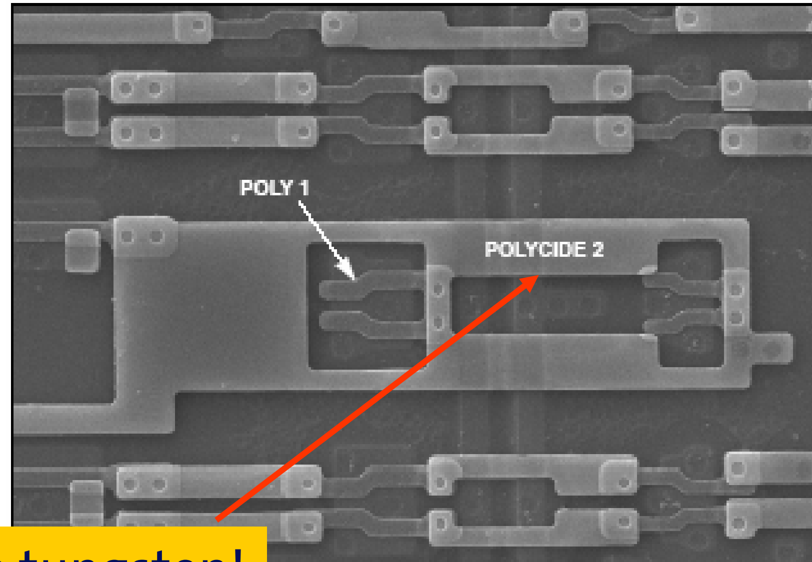




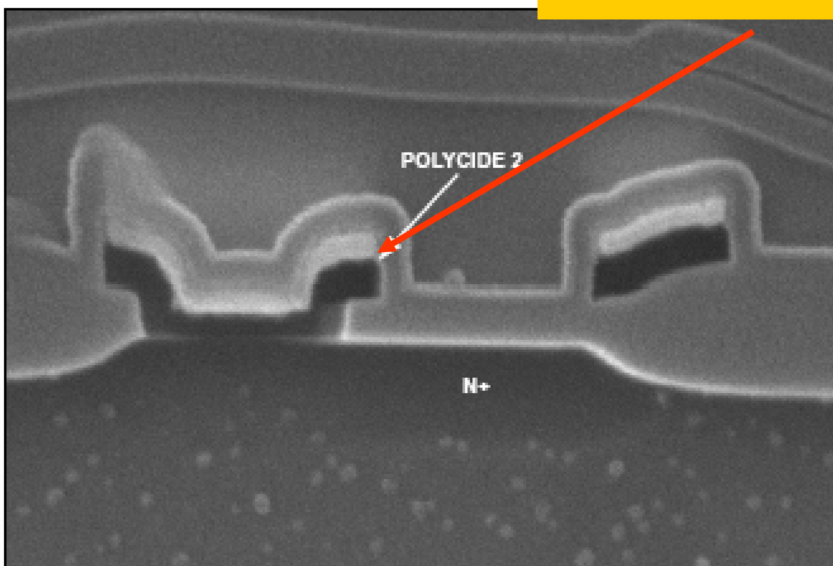
(Pictures courtesy of Vanderbilt University)

QinetiQ





Beware of the tungsten!



(Pictures from Chipworks Inc.)

- In this examples, polycide = tungsten silicide
- The problems will likely get worse, as manufacturers replace Al metallization (tracks connecting transistors) with Cu ⇒higher-Z recoils into the silicon

Requirements - Nuclear-Nuclear

- Energies:
  - ~100 MeV/nuc → 10s GeV/nuc
  - 10s MeV/nuc → ~100 MeV/nuc
  - 100s GeV/nuc
- Projectile species: He → Fe essential, > Fe desirable
- Target species
  - Interplanetary missions A≤60: metal alloys, plastics & composites, oxidants & fuels, consumables, Martial soil / regolith ... but possibly U-238 desirable
  - Semiconductor radiation effects: standard semiconductor materials + tungsten, indium, silver, copper...
- Double-differential cross-sections, with treatment of kinematics of recoiling nuclear fragment & secondaries (though effects of prompt secondary nucleons not as important for semiconductor effects)
- Treatment of fragment de-excitation processes

QinetiQ

A-A Geant4 Models: Functional & interface requirements

UR ID	Description of Requirement	Importance	Application
UR 1	Nuclear-nuclear processes should be able to treat ion species (heavier than protons) relevant to galactic cosmic rays and solar energetic ions:		
	He → Fe	Essential	
	>Fe	Desirable	
UR 2	Nuclear-nuclear processes should be able to treat ion energies relevant to galactic cosmic rays and solar energetic ions:		
UR2.1	10s MeV/nuc → 100MeV/nuc	Desirable?	GCR + SEP
UR2.2	100 MeV/nuc → several GeV/nuc	Essential	GCR + SEP
UR2.3	several GeV/nuc → 10s GeV/nuc	Essential	GCR
UR2.4	10s GeV/nuc → 100s GeV/nuc	Desirable?	GCR
	[NOTE: there is a need to quantify contributions to dose]		
UR 3	It should be possible to treat interactions in common spacecraft / surface habitat materials: Metal alloys of Al, Ti, Fe, Mg, Be plastics and composites (incl glass, B and C-fibre) oxidants and fuels (e.g. UDMH + NOx) radiation shielding materials polythene, water crew consumables	Essential	

QinetiQ

A-A Geant4 Models: Functional & interface requirements

UR ID	Description of Requirement	Importance	Application
UR 4	It should be possible to treat interactions in materials common to the surface of Mars or which may be used for external radiation shielding of a surface habitat, e.g. Mars regolith O=40.4%; Si=14.1%; Fe=4.4%; Mg=39.2%, Ca=1.9%) Mars basalt O=61.3%; Si=19.2%, Al=3.3%; Fe=6.1%; Mg=6.2%, Ca=4.1%)	Essential	
UR 5	The nuclear-nuclear processes should generate an accurate energy and angular distribution of the secondary nuclear fragments. This shall include the projectile and target post-interaction	Essential	Dose calcs as well as SEE
UR 6	The nuclear-nuclear processes should generate an accurate energy and angular distribution of the secondary particles from the projectile and target		
6.1	nucleons	Essential	
6.2	$\pi^{\pm}$	Desirable?	

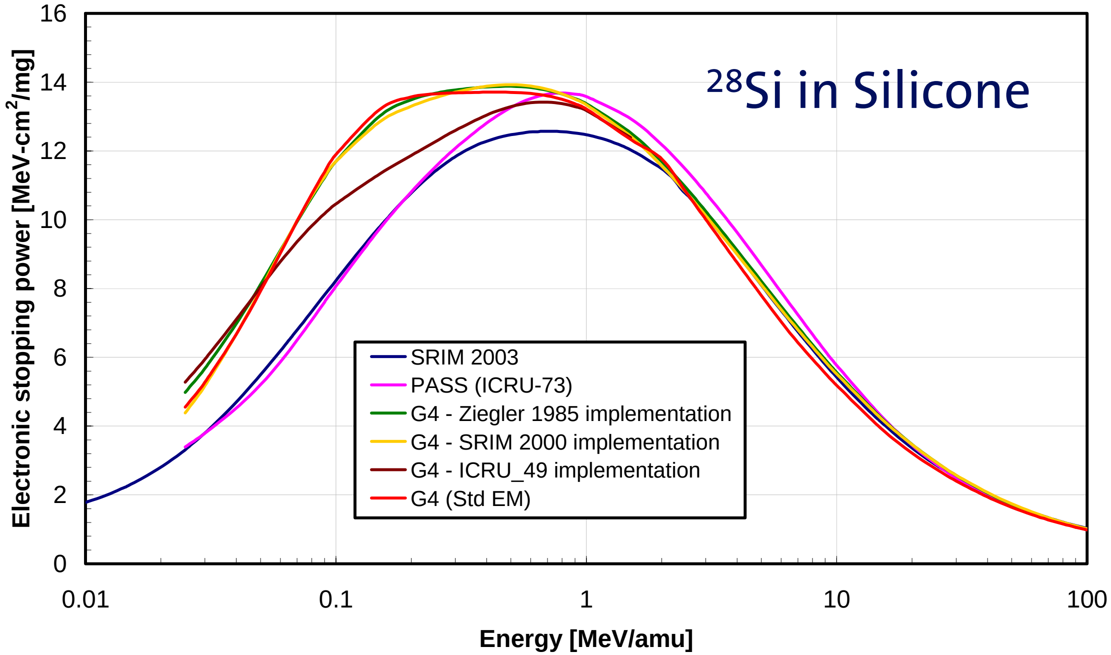
QinetiQ

A-A Geant4 Models: Interface & performance requirements

UR ID	Description of Requirement	Importance	Application
UR 7	The model will interface with the existing low-energy models to allow simulation of nuclear de-excitation by evaporation/fission/fermi-breakup/photo-evaporation.	Essential	
UR 8	The nuclear-nuclear process shall be able to simulate these interactions in reasonable time (TBD) even for Fe-Fe nuclear collisions.	Essential	

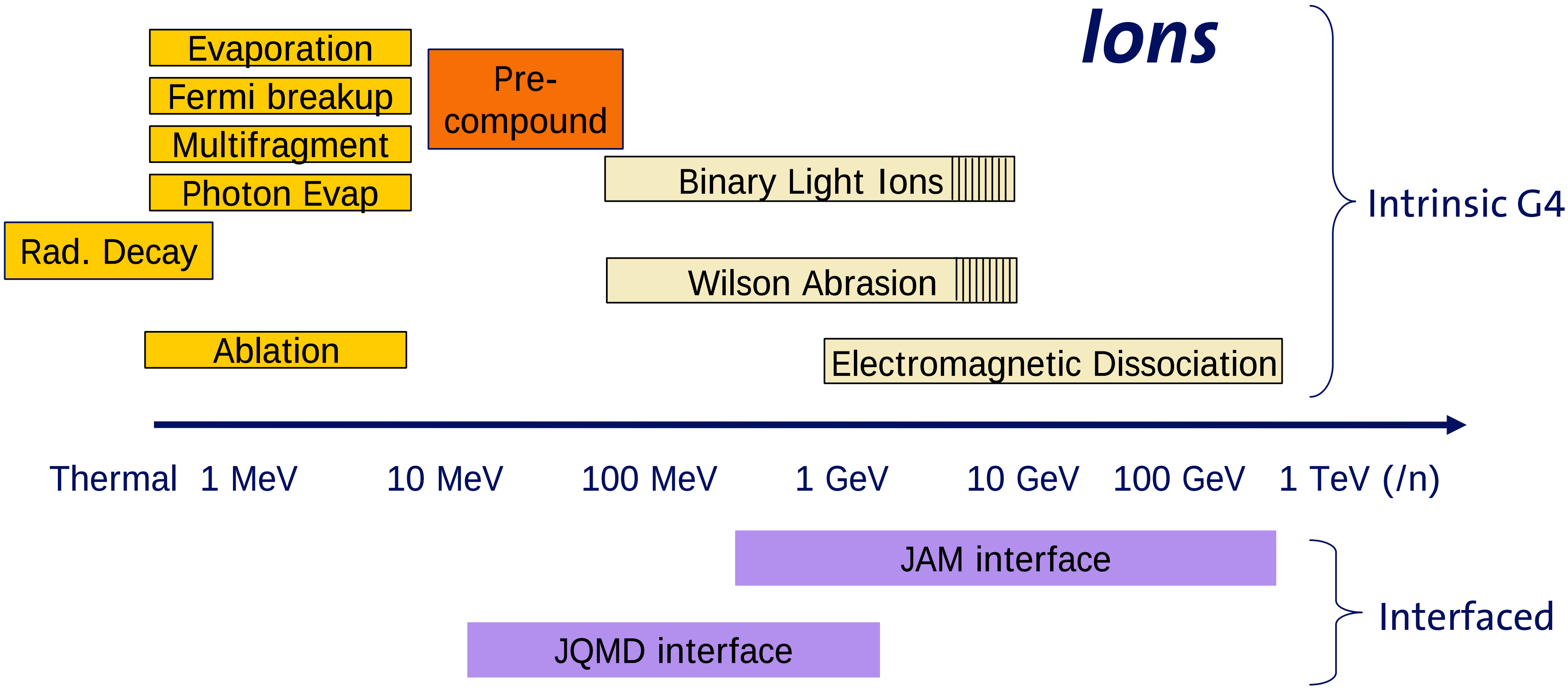
Requirements/Options - Ion-electromagnetic

- Detailed ion-track physics models for spatial distribution of charge
  - From Katz and co-workers, e.g. Kobetich & Katz (1968, 1969), Zhang, Dunn & Katz (1985) ...
- Updated stopping power models
  - Work of Sigmund et al, including ICRU-73
  - Ziegler 2003



QinetiQ

Existing Geant4 Nuclear-Nuclear Final State Models



(from T Koi, 28/07/06)

Backup slides

Options - Nuclear-Nuclear

HIGH ENERGY

- Treatment of relativistic regime essential (>5GeV/nuc):
  - Completion and testing of G4 QGSM (QGSC/QGSP) - how difficult is this?
  - Super CHIPS model for N-N – when?
  - Interfaces with other high-energy nuclear-nuclear models
    - DPMJET-III (also used by FLUKA)
    - CORSIKA atmospheric shower code underpinned by VENUS (10^7GeV max), QGSJET, DPMJET-II (10^{11}GeV) - note implied lower-energy limit (lab-frame) of 80GeV/nuc for these models
    - LAQGSM from LANL - results for Ne on Cu shown, and intended to treat 100's GeV/nuc. LAQGSM to be included in next MCNPX release

QinetiQ

Options - Nuclear-Nuclear

HIGH ENERGY (CONT.)

  - Abrasion-ablation model in ABRABLA, based on Gaimard & Schmitt - results given up to 2GeV/nuc by G&S, but expected to treat higher-energies?

- Other abrasion-ablation physics ... but limited information about upper-energy limits:
  - Townsend (optical fragment) abrasion model - not clear about energy regime (published tests over 0.77 - 1.65 GeV/nuc)
  - Cucinotta microscopic abrasion model - avoids reliance on parametric fits and reports more accurate secondary neutron production (published tests cover 0.74 - 1.6 GeV/nuc)

Options - Nuclear-Nuclear

- Require a better description of the kinematics of nuclear recoil - especially for microdosimetry - abrasion models will have difficulties here
- Extension of electromagnetic dissociation so that fragments heavier than protons & neutrons treated - Not high priority for low-Z

LOW ENERGY

- Boltzmann Transport Equation
  - Describes thermalisation of nucleus from N-N collisions
  - Appears to be tested over 11-30 MeV/nuc, *i.e.* very much solution for low-energies - **Not a high priority**
  - Available in latest version of FLUKA
- Extensions of pre-equilibrium physics