Space Radiation Dosimetry: Lessons Learned and Recommendations

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OSU
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Primary Objectives of Operational Space Radiation Dosimetry

- Accurately *monitor* astronaut radiation exposures
  - Operate mission so as to not exceed radiation limits
  - Implement ALARA Principle
- Provide *warning* of dangerous changes in radiation environment
- Document and provide an *archival* record of each astronaut's radiation exposure history
  - Inform astronauts of their risks
  - Provide evidence that career radiation limits have not been exceeded
  - Provide data for ongoing and future epidemiological assessments of space flight radiation risks
- Provide important secondary information related to the interpretation of instrument readings and experimental results.

-Adapted from Radiation Dosimetry Working Group Final Report

What is Needed

- Specifications for dosimeters and instruments, building on Radiation Dosimetry Working Group's Final Report.
- Also must cover "Exploration" dosimetry requirements.
- Suggestion: Make specifications more concrete
  - SRAG could issue a set of specifications following a mil-spec model, i.e. spell out exactly what is needed and what form it should take.

Radiation Dosimetry Working Group requirements (partial)

Operational Requirements for Internal and External Area Dosimeters

1. Measure the point quantities D, the spectrum D(L), and H to adjacent tissue from radiation environment experienced at surface of astronauts inside a vehicle/module or EMU
    a. Expected radiation environment
        i. Protons: ~10 MeV – 10's of GeV
        ii. Electrons: ~ 0.5 MeV – 7 MeV
        iii. HZE (He to Fe): ~ 10 MeV/amu – 10's of GeV/amu
        iv. $^{1}n_{0}$: Thermal (<0.1 MeV) to 10's of GeV
    b. Equivalent depth in tissue
        i. TBD
    c. Sensitivity
        i. Minimum Detectable Dose: 0.1 mGy
        ii. Maximum dose to be measured: 0.4 Gy
        iii. Spectrum coverage of D(L): TBD
    d. Measurement accuracy in H_2O or tissue
        i. D: TBD
        ii. Spectrum coverage of fluence(L): TBD
        iii. H: TBD

Current Current Instrumentation

Passive Detectors

- TLD/OSLD (various laboratories including JSC)
- CR-39 PNTD (various laboratories including JSC)
  - *TLD/OSLD + CR-39 PNTD make up current CPDs and RAMs*
- Pille TLD System (KFKI, two systems on ISS)

Active Detectors

- Tissue Equivalent Proportional Counter (JSC)
- IV/EV Charged Particle Directional Spectrometer (JSC)
- DOSimetry TELescope (Kiel U./DLR)
- Bonner Ball Neutron Detector (JAXA)
- RMD-III (Waseda U./JAXA)
- Liulin-4/-5 (STIL-BAS)
- Altea/Alteino (IFN/Rome U.)
- R-16 (IMBP)
- DB-8 (IMBP)

Lessons Learned from Previous Experience, ICCHIBAN, MARIE, etc.

- No single instrument (detector) is capable of measuring all the radiation types, energies, and quantities of relevance to the dosimetry of space crews. e.g.
  - TLD/OSLD or CR-39 PNTD alone aren't enough… must be used together.
  - TLD + CR-39 PNTD are good solution for Crew Personal Dosimeter
- A single TEPC, Si telescope, or set of TLDs is not adequate for dosimetry inside spacecraft (especially if it is large and of complex geometry) due to differences in shielding throughout the habitable volume of the spacecraft.

Lessons Learned Concerning Shielding

- The shielding environment inside the habitable volume of a spacecraft is highly variable and extremely dependent on the localized 3-D mass distribution.
- Given the differences in localized shielding within a large spacecraft and the current levels of uncertainty in shielding models, radiation transport models, and radiation environment models, multiple measurements by different instruments at various locations should be part of the overall dosimetry strategy.
- At least one passive dosimeter should be co-located with each real-time active detector so that results from the different detector types can be reconciled with one another post-mission.
- Passive detectors add a layer of redundancy and remain operational in the event of a power failure or active detector malfunction.

The TEPC/CPDS Experience

- Both TEPC and CPDS were designed “covertly” by Gautam Badhwar.
- “Covert” design has its pluses and minuses.
- Minuses:
  - Design didn’t benefit from input from qualified individuals on the outside.
  - Documentation regarding the development of these instruments is murky at best.
  - Routine operation of the instruments has been a constant challenge.
  - There were a number of design “flaws.”
- Major Plus: Without this effort, SRAG currently might not have any active detector.
- MegaMinus: These stressful efforts likely hastened the early death of Dr. Badhwar.

More Lessons Learned

1. There has to be a better way to design detectors than Badhwar's "covert" method.

The TEPC/CPDS Experience (cont.)

- TEPC isn't (and never was) the do-all perfect instrument to solve all space dosimetry problems.
- Parts of TEPC are really great and shouldn't be abandoned
  - the TE ion chamber and FET preamplifier is a robust, sound design. The chamber has never leaked.
  - The TEPC spectrometer is, at best, obsolete.
- IV/EV CPDS was probably an overly ambitious and complicated design that tried to do too much with too little resources...and has required heroic efforts to make use of the data.
- Budget Constraints meant that no Non-Flight Engineering Units for ground-based testing were ever built.
- Neither instrument was really tested at a heavy ion accelerator until the advent of ICCHIBAN (2002),

Liulin and DOSTEL compared to CPDS

- On paper, CPDS is by far the superior instrument:
  - Position Sensitive Detectors;
  - Larger Dynamic Range;
  - Cerenkov Detector.
- DOSTEL and Liulin are much more modest detectors...and they work as advertised:
  - COTS parts;
  - Simple data format;
  - fairly inexpensive;
  - no “heroic” efforts are needed for data analysis.

Still More Lessons Learned

1. There has to be a better way to design detectors than Badhwar's "covert" method.
2. Just because an instrument has problems, don't throw out the whole thing (i.e. design a new spectrometer for TEPC).

Still Even More Lessons Learned

1. There has to be a better way to design detectors than Badhwar's "covert" method.
2. Just because an instrument has problems, don't throw out the whole thing (i.e. design a new spectrometer for TEPC).
3. Make sure the instrument design is realistic, practical, doable, cost effective, etc. rather than trying to do everything (e.g. DOSTEL works, CPDS...well).

Etc.

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4. Include at least one engineering unit for use in ground-testing, troubleshooting, etc. in the program.

The Need for Engineering Units

High-fidelity flight quality (but not flight-qualified) “engineering unit” versions of each detector should be built. The use of non-flight-qualified engineering units would enable:

- Calibration and characterization of the detectors at ground-based accelerator facilities such as NSRL, HIMAC, and Loma Linda;
- Platforms on which to reproduce failures in the flight units;
- Platforms on which to test modifications (implemented in software) prior to their implementation in flight units;
- Environmental testing including radiation hardness.

Etc., Etc.

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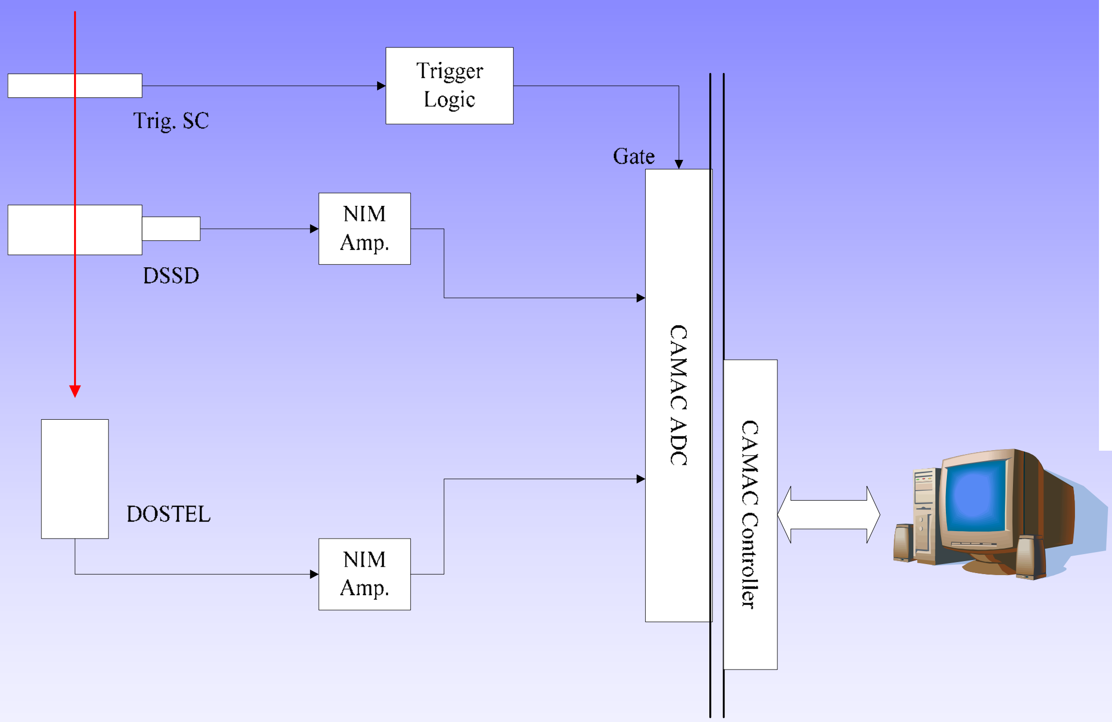
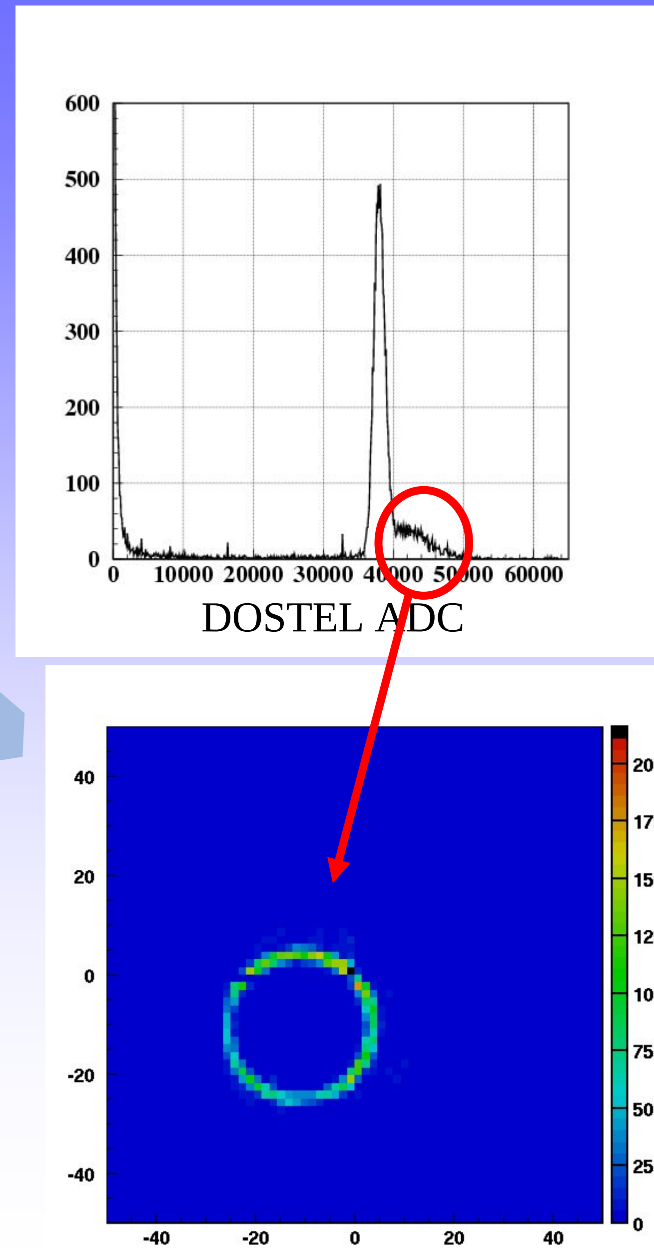
4. Include at least one engineering unit for use in ground-testing, troubleshooting, etc. in the program.
5. Perform extensive ground-based calibration and testing (participate in ICCHIBAN, get your own beam time).

DOSTEL during ICCHIBAN-3





Quick ICCHIBAN Update

- ICCHIBAN-3/-4 Report nearly finished.
- Currently writing two part paper for *Radiation Measurements*: Part 1-active IC-1/-3, Part 2-passive IC-2/-4.
- Next ICCHIBAN will be *Space ICCHIBAN* for passive detectors:
  - Up to 12 participating laboratories;
  - Inside Russian BRADOS container;
  - Scheduled for launch in December 2006.
- Next ground-based ICCHIBAN will probably be in late 2007 at HIMAC or Loma Linda

What We Have Done Right

- WRMISS
- ICCHIBAN
- Lots of cooperation in space experiments: STS-114, Matroshka, Expedition-2, BRADOS, etc.
- This Meeting!!!

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  - No single laboratory (research group or NASA center) possesses the expertise in all the problems inherent in space dosimetry.
  - Design and implementation of the next generation of space radiation dosimetry system needs to be a collaborative effort making use of the diverse skills of different groups.

Space Dosimetry: The Next Generation

While this presentation is primarily focused on solving the dosimetry needs within the habitable volume of spacecraft such as:

- ISS,
- Space Shuttle, and
- Crew Exploration Vehicle (CEV),

The individual detectors and instrument bus could be designed in such a way that it could be used on

- exterior of spacecraft,
- satellites,
- space probes, and
- landers.

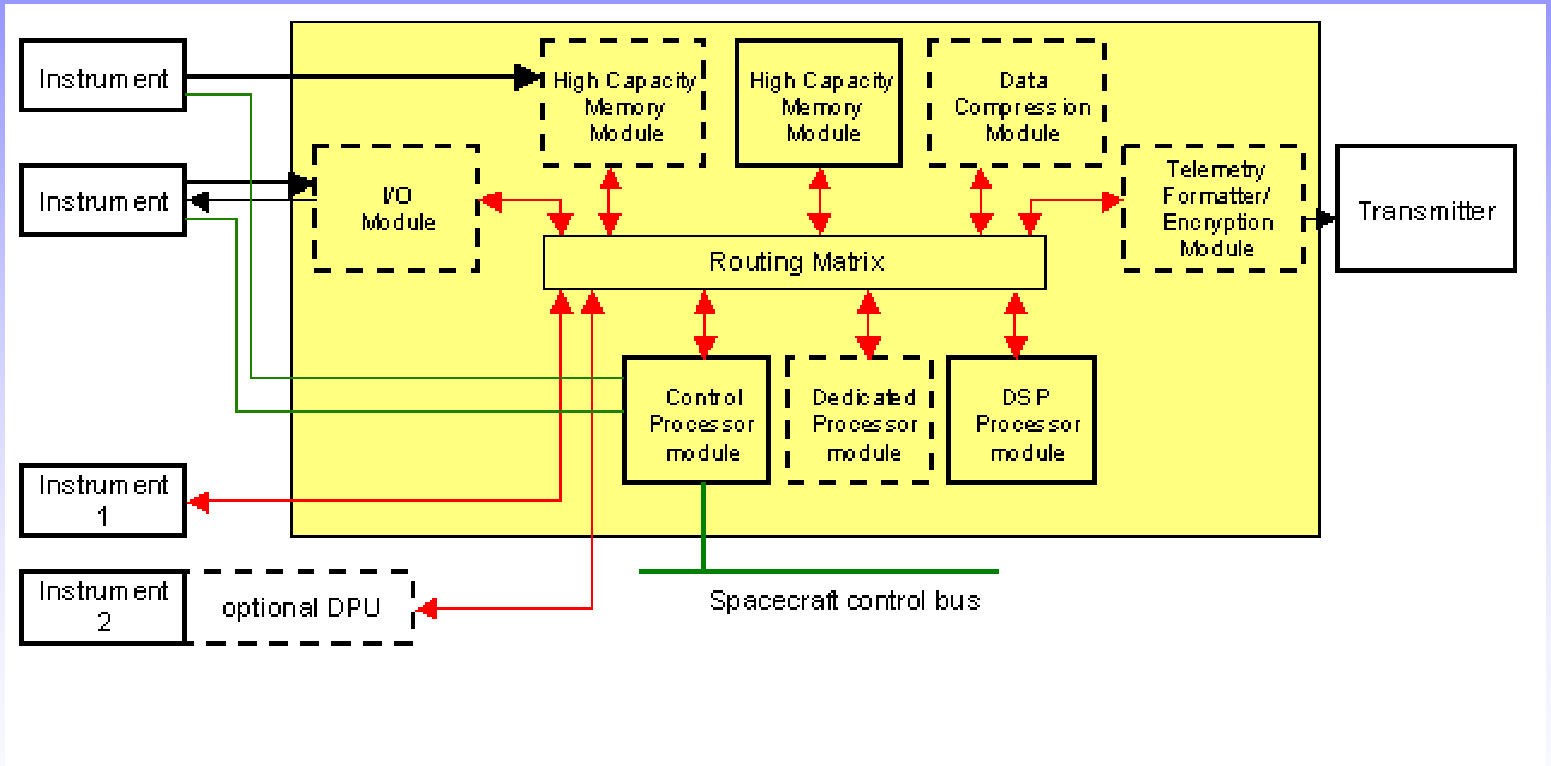
Space Dosimetry: The Next Generation

1. Tissue Equivalent Proportional Counter: redesign the spectrometer.
2. Silicon Telescope: make use of existing designs (DOSTEL, Alteino/Altea, RRMD-III, etc.).
3. Active Neutron Detector (sensitive to 1 MeV $\leq E_n \leq$ 500 MeV): BBND only good up to ~15 MeV, possibilities include phoswich detectors, scintillation fiber detectors, larger Bonner spheres.
4. CR-39 PNTD (in both crew and area dosimeters) For long duration exploration missions (permanent Lunar base, trip to Mars), CR-39 PNTD will no longer be adequate for use in Crew Passive Dosimeter.
5. Portable TLD or OSLD system for both crew and area dosimetry (necessary for Exploration Class missions).
6. Portable Si dosimeters (e.g. Liulin-4) for area dosimetry, SPE alarm, and EVA dosimetry.

Common Data Format/Bus for Active Detectors

- Active detectors would share a common “radiation dosimetry server:”
  - store data from all the instruments;
  - host telemetry with the ground;
  - carry out limited analysis of the measured data.
- Active detectors would all use a common ADC and bus, common data structures, format and compression.
- Spectrometer front-ends to each detector would share as much as possible in common so that parts could be interchangeable.
- Instruments would implement most parameters (e.g. gains, offsets, sampling times, trigger thresholds, etc.) in software so that they could easily (and systematically) be changed.
- A common instrument bus will permit addition of new detectors or easy replacement of detectors with improved versions.

SpaceWire
http://www.spacewire.esa.int/tech/spacewire/overview/



Space Cube (SEMC5701B)

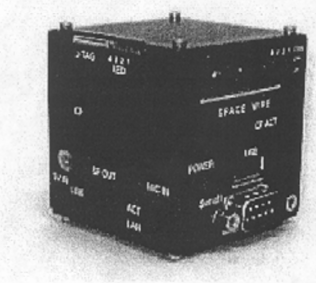
SHIMAFUJI

Very Small Network Computer (52mm × 52mm × 55mm)

Space Wire (Extension of IEEE1355) × 3 port

High Performance 64bit RISC Processor VR5701 (NEC)

Designed for Space Application with Japan Aerospace Exploration Agency



Space Wire *1, *2

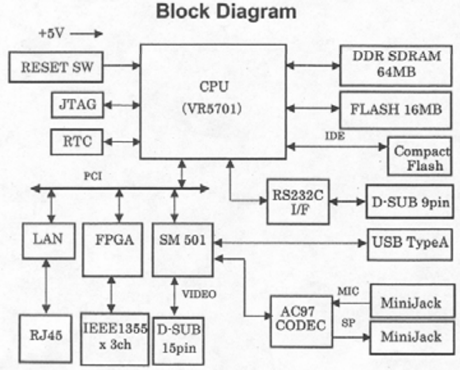
- Networking Protocol Working Group (ESA/NASA/JAXA)
- High speed *3 and real-time response capability exceeding IEEE 1394 in addition to high reliability.
- Unlimited topology including switch matrix configuration. (bus bridge and router are also possible)
- Versatile functions like ATM (Asynchronous transmission mode) for digital consumer products as well as satellites data bus.

*1 SpaceWire is a customized specification originated from IEEE 1355. Its simple architecture and high reliability are widely accepted in space industry for inter-component and inter-module connection.

*2 SpaceWire Draft, ECSS-E-50-12A, http://www.estec.esa.nl/tech/spacewire/

*3 The transmission speed on each port is compatible to with IEEE 1394 whereas the whole link speed surpasses IEEE 1394 by selecting suitable topology for each system.

Block Diagram



Specification

CPU	VR5701 200MHz/250MHz/300MHz
FlashROM	16M Byte
DRAM	DDR SDRAM 64M Byte
INPUT/ OUTPUT	IEEE1355 (SpaceWire), RTC, CF (True IDE), XGA (1024 × 768), USB1.1, LAN (100BASE), Audio (Stereo) RS232C, JTAG I/F (Debug)
POWER	+5V
SIZE	52mmx52mmx55mm

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 SP1521001

Recommendations

- Make the most of the Lessons Learned;
- Make the most of the Existing Instrumentation...from all laboratories (e.g. Pille, Liulin);
- Carefully consider what is needed, what is practical, what is affordable, what is doable...then issue specifications or requirements;
- Consider common data format, common hardware, client/server model, etc. for active detectors;

Motherhood & Apple Pie

- A redefined relationship between SRAG & the rest of the radiation community.
- Create an open, transparent process for defining & procuring SRAG's tools.
  - Competition is good.
    - Need clarity in AO/NRA.
  - An open call can bring in new groups with helpful expertise.
- Also o.k. if not competed, provided the team has the needed expertise.
- We want to help, in whatever form that takes.

"All I'm saying is <u>now</u> is the time to develop the technology to deflect an asteroid."

Eril Research, Inc.

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