The Future of Spacecraft Radiation Design

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The Future of Spacecraft Radiation Design: A Workshop at Aberystwyth University, UK, 28–30 November 2012

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In November 2012, a workshop on the topic of designing spacecraft for operations in harsh radiation environments was held at Aberystwyth University (http://juice2012.imaps.aber.ac.uk/index.shtml). The immediate motivation was the European Space Agency (ESA) Jupiter Icy Moons Explorer (JUICE) mission (http://sci.esa.int/juice/), for which the radiation to be encountered is a limiting factor in the design of instruments. The workshop was organized as part of the Europlanet (http://www.europlanet-ri.eu/) technology foresight program and included a day of hands-on tuition in radiation design tools by members of the ESA Radiation Design Team. After this and more conventional presentations, the meeting concluded with a discussion intended to establish a road map of the directions and technologies needed in the medium term. Discussions focused on the anticipated and desired developments in radiation modeling for spacecraft missions. These discussions considered the potential developments in two phases: changes in the immediate future, particularly in relation to JUICE, and the opportunities for long-term development over approximately the next 20 years.

The radiation analysis for JUICE represents a significant scientific challenge due to the ambitious nature of the mission and the harsh radiation environment of the Jovian system. The demand for high-quality measurements implies a trade-off between shielding mass and instrument capability, which places a critical importance on the accuracy of radiation modeling. Designs must employ effective mutual shielding (careful placement of all masses to maximize the combined shielding effect) and the usage of multiple coincidence detection schemes in all sensors where a penetrator can mimic a real signal. JUICE is unique in the dependence of measurement quality on radiation design, and an early appreciation of this requirement leads to a new approach to instrument optimization.

Increasing the accuracy of predictions of radiation levels and hence bringing down the shielding mass of the spacecraft must be achieved in two ways: more detailed simulation inputs and more accurate methodologies. Identical "benchmark" tests should be run using different models, so that the relative accuracy of each can be compared.

On the subject of the accuracy of simulation initialization, a number of additional factors should be folded into the model, including variability in construction materials (which would need to be measured), background inducing processes, and modeling of more intelligent background suppression, with graded shielding tailored to reduce background signals for specific instruments (as found by sector shielding analysis). The resulting analysis should be checked for a specific case by testing a predicted configuration in particle accelerators.

To improve the accuracy of simulation methodologies, the workshop participants recommended that information structures should be put in place to enable effective sharing of their collective experience of the radiation modeling. Among the many benefits, researchers would get a better understanding of complex or unfamiliar approaches, such as the reverse Monte Carlo method, or new modeling tools. They would also better be able to absorb new approaches to radiation design by learning them as a group. In order to achieve this for JUICE, the participants reiterated the usefulness of the forums and wikis which cover GRAS and other commonly used tools. In addition, they suggested the creation of a self-organized radiation modeling working team that would hold regular workshops during the development of JUICE.

Looking beyond JUICE to what radiation design analysis may look like in 20 years, the group considered both the evolution of instrumentation hardware components and the expected increase in computing power. Components are likely to be much smaller, commercial off-the-shelf products. Given their commercial nature, they are unlikely to be radiation hard, and thus, using current conventions would imply more shielding aboard spacecraft. However, the small size and the lower commercial price would allow for greater redundancy, and hence, there will be a push to make spacecraft radiation hard at the system level rather than the component level. The potential threat from single-event upsets, given smaller component sizes, could be

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addressed at the system level by more targeted mission analysis and component use. These systems would require testing, and thus, the participants suggested the use of a small satellite as a demonstrator. This would also prototype the new generation of small, smart, onboard radiation monitors. There was also speculation that solar cells would become more radiation tolerant, and this would also need mission testing.

Future space central processing units would be radiation-tolerant soft devices and would most probably be systems on a chip. The future of camera and detector elements is far more speculative, with three separate technologies discussed: charge-coupled devices, complementary metal-oxide-semiconductor chips, and dedicated amplifier/shaper/discriminator, as well as the design of detector planes which only allow specific size signals from specific pixels. In practice, choices will be market driven, although it is possible to identify desirable new approaches such as chips, including thinner gate structures, and the use of the p channel in place of the n channel to maximize signal.

Discussion of new simulation methodologies was considered highly speculative, and the group decided to consider the structure of the modeling process instead. Although novel solutions would still come from smaller enterprises, there will be a move to groupware as a working method for sharing large integrated radiation calculations, and that endeavour would benefit from greater system-level integration. This would create feedback within the groupware team and lead to greater design efficiency, better use of resources, and, hence, mass reduction. A drawback is that these ideas are dependent on sharing propriety information between potential commercial rivals. A further unknown will always be the details of the destination environment. In this context, "hidden margins" in the material parameters and predicted radiation analysis can be useful provided they are controlled and understood.

Thus, the outlook for the medium's future will very likely see large changes in the methodologies of spacecraft radiation design, and the JUICE experience, by its nature at the leading edge of current capabilities, can serve as a major driver to progress.

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