14th WRMISS WORKSHOP
on
Radiation Monitoring for the International Space Station

DUBLIN CASTLE
8TH - 10TH SEPTEMBER 2009

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Development of a Numerical Model for the MATROSHKA Phantom

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Outline

- MATSIM – the project
- Description of the MATROSHKA model
- Photon Measurements with the MATROSHKA head
- Simulations of MATSIM head
- Comparison between measurement and simulation
- Outlook
MATSIM – the project

MATROSHKA

- International collaboration of >19 research institutes, ESA experiment under the scientific and project lead of „Deutsches Zentrum für Luft- und Raumfahrt“ (DLR)
- Long-term dose measurements onboard International Space Station, started in 2004

MATSIM

- carried out at the Austrian Institute of Technologies, Seibersdorf in collaboration with DLR and Atomic Institute, Vienna
- Development of a novel numerical model
- Same geometry, material and density distribution as real phantom
- Simulation of energy deposition in photon and neutron reference fields
MATROSHKA - Computer Tomography Scan

- Two CT scans of MATROSHKA provided by DLR
  - Torso and
  - Head

<table>
<thead>
<tr>
<th>Axis</th>
<th>Torso</th>
<th>Head</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of pixels</td>
<td>Layer width (mm)</td>
</tr>
<tr>
<td>X</td>
<td>512</td>
<td>0.78</td>
</tr>
<tr>
<td>Y</td>
<td>512</td>
<td>0.78</td>
</tr>
<tr>
<td>Z</td>
<td>278</td>
<td>3.125</td>
</tr>
<tr>
<td></td>
<td>$7.3 \times 10^7$ voxels</td>
<td>$1.6 \times 10^8$ voxels</td>
</tr>
</tbody>
</table>
MATROSHKA CT scan – data processing

- Special software developed to read and manipulate CT data
- Definition of materials
- Append all slices to one file for Fluka

Matrix with Hounsfield numbers (HU)

Build regions (e.g. tissue from -80 to 80)

Implement in Monte Carlo code

Geometry model with assigned materials
Monte Carlo Code FLUKA

- Particle transport and interaction with matter
- 60 different particles
  - photons and electrons from 1 keV to thousands of TeV
  - muons of any energy, hadrons up to 20 TeV
  - neutrons down to thermal energies and heavy ions.
- Optimized computer algorithms
- high energy experimental physics and engineering, accelerator shielding, detector design, cosmic ray studies, dosimetry and micro-dosimetry, medical physics and radiobiology, neutrino physics
- **Voxel geometry**: translate a CT scan into a dosimetry model
FLUKA geometry – MATSIM Torso

vertical cut from the front (left) and from the side (right)

- Cortical bones (ICRU), \( \rho = 1.92 \, \text{g/cm}^3 \)
- Compact bone (ICRU), \( \rho = 1.85 \, \text{g/cm}^3 \)
- Detectors: LiF, \( \rho = 2.65 \, \text{g/cm}^3 \)
- Active box: Mixture, \( \rho = 0.68 \, \text{g/cm}^3 \)
- Lung (ICRU), \( \rho = 0.3 \, \text{g/cm}^3 \)
- Passive box: Mixture, \( \rho = 1.3 \, \text{g/cm}^3 \)
- Tissue soft (ICRU), \( \rho = 1 \, \text{g/cm}^3 \)
- Rod, cables: polyethylene, \( \rho = 1.2 \, \text{g/cm}^3 \)
- Vacuum
FLUKA geometry – MATSIM Head

vertical center cut from the side

horizontal cut in slice #4 from the top

detector location in slice #4
Reference measurements - Co-60 photons

- Reference Point: rod center, slice #5
- Distance Source – Head: 450 cm, field size: 27 x 27 cm
- $K_{\text{Air}} = 200 \text{mGy}$, $\dot{K}_{\text{Air}} = 159.5 \text{ µGy/s}$
- Beam incidence: front, omni directional (30° steps)

MATROSHKA head in front of the irradiation facility, reference point is marked

TLD set in slice#4

Ionization chamber
Reference measurements - Co-60 photons

Active box eye

Chamber in PMMA rod, slice #2

Experimental set-up:
TLD numbering and beam incidence (30 degree steps)
MATSIM Head Simulation of the Energy Density due to $^{60}$Co

Front beam incidence

60 degree beam incidence

 Deposited spatial energy density (GeV/cm$^3$) in the head, side view.

 Deposited spatial energy density (GeV/cm$^3$) in the head', side view.
## Results – Ionization chamber

<table>
<thead>
<tr>
<th>Location</th>
<th>Beam incidence (°)</th>
<th>Measurement</th>
<th>Simulation</th>
<th>Ratio SIM / MEAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye, slice#3</td>
<td>0</td>
<td>219.9</td>
<td>213.1</td>
<td>0.96</td>
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<tr>
<td></td>
<td>± 0.2</td>
<td>± 0.9</td>
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<tr>
<td>Rod center, slice#2</td>
<td>0</td>
<td>159.0 ± 0.6</td>
<td>163.0 ± 0.6</td>
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<td>± 1.6</td>
<td>± 0.7</td>
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<td>30</td>
<td>159.7 ± 1.6</td>
<td>163.7 ± 0.7</td>
<td>1.05</td>
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<tr>
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<td>± 1.8</td>
<td>± 0.8</td>
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<td>60</td>
<td>177.7 ± 1.8</td>
<td>180.7 ± 0.8</td>
<td>1.00</td>
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<tr>
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<td>± 1.8</td>
<td>± 0.8</td>
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<td>90</td>
<td>178.4 ± 1.8</td>
<td>185.5 ± 0.8</td>
<td>1.06</td>
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<tr>
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<td>± 1.8</td>
<td>± 0.8</td>
<td></td>
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<tr>
<td></td>
<td>120</td>
<td>169.1 ± 1.7</td>
<td>176.7 ± 1.0</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>± 1.7</td>
<td>± 1.0</td>
<td></td>
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</tr>
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<td>150</td>
<td>160.2 ± 1.6</td>
<td>160.1 ± 0.7</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>± 1.6</td>
<td>± 0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>158.6 ± 1.6</td>
<td>164.1 ± 0.9</td>
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<td></td>
<td>± 1.6</td>
<td>± 0.9</td>
<td></td>
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</tr>
</tbody>
</table>
Results – Measurements TLD & IC, Front Irradiation

![Graph showing absorbed dose in water (mGy) vs. distance (cm) for various TLD types and IC labels. The graph includes markers for TLD_A, TLD_B, TLD_C, TLD_D, TLD_E, TLD_F, TLD_G, IC_eye, and IC_rod_slice#2. The beam angle is indicated with BEAM 600 and BEAM 700. There is a significant decrease of 50% at a certain distance.]

- TLD_A
- TLD_B
- TLD_C
- TLD_D
- TLD_E
- TLD_F
- TLD_G
- IC_eye
- IC_rod_slice#2

Absorbed dose in water (mGy) vs. Distance (cm)
Results – Simulations TLD & IC, Front Irradiation

Deposited spatial energy density (GeV/cm³) in slice #4 in the head.

50 % decrease
Results – Measurements TLD & IC, Omni directional

Absorbed dose in water (mGy) vs Distance (cm)
Results - Simulations TLD & IC, Omni directional Irradiation
Comparison Measurements and Simulations, Front Irradiation

The graph shows the ratio of measurements (MEAS) to simulations (SIM) for various detectors and distances. The detectors are labeled as TLD_A, TLD_B, TLD_C, TLD_D, TLD_E, TLD_F, TLD_G, IC_rod_eye, and IC_rod_slice#2. The x-axis represents the distance in centimeters, while the y-axis represents the ratio of MEAS to SIM. The data points are marked with different symbols and error bars indicating variability.
Comparison Measurements and Simulation, Omni directional Irradiation

![Graph showing comparison measurements and simulation results for various TLDs and IC_rod_slice#2]
Conclusion: Co-60 Measurement and Simulation

Ionization chamber
- Good agreement between measurements and simulation (within 5%)
- Agreement compared to TLD measurements within 20-30%

Thermoluminescence dose meters
- Agreement for omni directional irradiation within 10%
- For front within 35%

Next steps
- Detectors of the scan geometry will be adapted to the actual measurements
- Detectors will be simulated for LiF as well as for tissue and/or water
- Investigations of the electron spectrum within TLD detectors
- Investigation of the TLD calibration
- Reference measurements and simulations with neutrons, protons, and heavy ions
Outlook: MATSIM Investigations in Space Radiation Environment

Fluence proton spectrum, outside ISS during solar maximum at 400 km (Armstrong, 1998)
Outlook: MATSIM Investigations in Space Radiation Environment

Isotropic proton irradiation
Cross section through the lung, MATSIM torso slice 15

Isotropic proton irradiation
Cross section center MATSIM to
Acknowledgments

The funding and the support by the Austrian Space Applications Programme (ASAP) and the MATROSHKA consortium is acknowledged.

Many thanks to DLR for providing the MATROSHKA phantom and the CT scans.

Many thanks also to ATI for the quick analysis of the TLD data during vacation time!

Thank you for your attention!