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Artemis I: Crystals of experimental detectors record radiation doses near the Moon

Do cosmic radiation doses near the Moon differ significantly from those received by astronauts in low Earth orbit? Experimental lithium fluoride detectors, installed aboard the Orion spacecraft during the Artemis I mission, have now made it possible to obtain preliminary estimates.

As the Orion capsule of the uncrewed Artemis I mission orbited the Moon in late November and early December 2022, more than ten thousand small crystals, embedded within two human phantoms, were collecting data on cosmic radiation doses. Among them were several dozen experimental fluorescent lithium fluoride detectors, developed at the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow. A method for reading the information stored in these detectors, providing interesting insights into radiation doses and the properties of the detectors themselves, has now been presented in the scientific journal *Radiation Measurements*.

"The fluorescent radiation dose detectors based on lithium fluoride, developed at our institute, are passive in nature. In other words, they work like photographic film: once the crystals have been exposed to radiation, the tracks left by individual particles must be analyzed optically under a microscope," explains Prof. Pawel Bilski (IFJ PAN), one of the co-authors of the paper.

The operating principle of passive radiation detectors based on lithium fluoride crystals is straightforward. As particles of ionizing radiation pass through a detector, they produce defects in the material's crystal lattice, which begin to act as color centers. During laboratory readout, these centers are excited by blue light and, as a result, emit red fluorescence, which can be observed under a microscope.

As part of the MARE (Matroshka AstroRad Radiation Experiment) experiment conducted during the Artemis I mission, several dozen experimental lithium fluoride detectors were installed in both human phantoms, some of them highly enriched in the lithium-7 isotope. However, IFJ PAN's overall contribution to the experiment was considerably greater, as Cracow physicists also supplied nearly 600 crystalline detectors of another type, namely thermoluminescent detectors.

Conventional passive track detectors made of plastic must undergo chemical etching before readout. Lithium fluoride crystals, by contrast, require no such cumbersome chemical treatment, and a standard fluorescence microscope is sufficient for observing the tracks. Reading the particle tracks recorded in the vicinity of the Moon was therefore quick and posed no difficulties for the researchers. Challenges arose when they attempted to extract quantitative information; this required the development of non-trivial methods for calibrating the results.

The fundamental difficulty stemmed from the nature of cosmic radiation. In typical physics experiments, detectors are irradiated with beams consisting of particles of the same type, all having well-defined energies and a precisely known direction of incidence. Cosmic radiation, however, arrives

from all directions and contains all naturally occurring types of particles and atomic nuclei, spanning a very broad energy range. When observed under a microscope, the tracks therefore run in various directions. Consequently, in addition to the track segment within the focal plane (approximately one micrometer in size), the camera also captures a blurred glow from the remaining portions of the tracks. This affects the fluorescence intensity, the primary parameter used to assess ionization density. The analysis was further complicated by the fact that tracks left by highly ionizing particles appeared as continuous, clearly defined lines, whereas weakly ionizing particles could leave behind only a series of discrete, separated dots. This, too, affected the fluorescence intensity of the tracks.

“After applying a series of corrections and developing software to appropriately remove the background interfering with the measurements, our results differed by no more than 15% from those obtained using conventional track detectors across the entire overlapping range of energy deposition values. Moreover, we also recorded numerous particle tracks corresponding to energy deposits below the detection threshold of the detectors used to date,” Prof. Bilski emphasizes.

During the MATROSHKA experiment, conducted aboard the International Space Station more than a decade earlier, low-energy protons from the Van Allen radiation belts surrounding Earth accounted for part of the radiation dose deposited in the phantoms. These protons lost their energy at different depths within the phantoms, resulting in a non-uniform distribution of radiation doses throughout the mannequins. Near the Moon, however, the Van Allen belts are absent; instead, galactic radiation is more prominent. Its energies are so high that the particles can pass through the entire human body, depositing only part of their energy along the way. The radiation dose distribution recorded inside the phantoms during the Artemis I mission was therefore essentially uniform.

“Low-energy protons, trapped by our planet's magnetic field within the Van Allen belts, can account for the majority of the radiation dose received by astronauts in low Earth orbit. In the vicinity of the Moon, this substantial contribution disappears. Our measurements from the MARE experiment indicate that, although total radiation doses near the Moon are higher than those in Earth orbit due to the considerable levels of galactic radiation, the difference is not as large as one might intuitively expect,” Prof. Bilski notes.

The fluorescent lithium fluoride-based track detectors used during the Artemis I mission were grown using the Czochralski method. They were developed at IFJ PAN a decade ago and have been continuously improved ever since. Their main advantages include small size (on the order of millimeters rather than centimeters), which makes them convenient for people to wear; better track resolution than conventional chemically etched plastic detectors, allowing higher radiation doses to be recorded with clearly distinguishable tracks; and a broad range of detectable particle types and energies, enabling a better assessment of total radiation exposure. Furthermore, lithium fluoride detectors – particularly those enriched in the lithium-6 isotope – can be used to record neutron doses, since neutrons then undergo reactions with lithium nuclei, locally producing secondary charged particles that interact with the material in much the same way as external ionizing radiation.

The research conducted as part of the MARE project was supported by a grant from the National Science Centre, Poland (NCN), under its OPUS programme.

The Henryk Niewodniczański Institute of Nuclear Physics (IFJ PAN) is currently one of the largest research institutes of the Polish Academy of Sciences. A wide range of research carried out at IFJ PAN covers basic and applied studies, from particle physics and astrophysics, through hadron physics, high-, medium-, and low-energy nuclear physics, condensed matter physics (including materials engineering), to various applications of nuclear physics in interdisciplinary research, covering medical physics, dosimetry, radiation and environmental biology, environmental protection, and other related disciplines. The average yearly publication output of IFJ PAN includes over 600 scientific papers in high-impact international journals. Each year the Institute hosts about 20 international and national scientific conferences. One of the most important establishments of the Institute is the Bronowice Cyclotron Centre (CCB), which is an infrastructure unique in Central Europe, serving as a clinical and research centre in the field of medical and nuclear physics. In addition, IFJ PAN runs four accredited research and measurement laboratories. IFJ PAN is a member of the Marian Smoluchowski Kraków Research Consortium: “Matter-Energy-Future”, which in 2012-2017 enjoyed the status of the Leading National Research Centre (KNOW) in physics. In 2017, the European Commission granted the Institute the HR Excellence in Research award. As a result of the categorization of the Ministry of Education and Science, the Institute has been classified into the A+ category (the highest scientific category in Poland) in the field of physical sciences.

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SCIENTIFIC PUBLICATIONS:

"Application of LiF fluorescent nuclear track detectors for measurements of cosmic radiation at the lunar orbit within the MARE experiment"

P. Bilski, A. Kilian, M. Sankowska, T. Horwacik, T. Berger
Radiation Measurements 2026, 198, 107806
DOI: [10.1016/j.radmeas.2026.107806](https://doi.org/10.1016/j.radmeas.2026.107806)

LINKS:

<http://www.ifj.edu.pl/>

The website of the Institute of Nuclear Physics, Polish Academy of Sciences.

<http://press.ifj.edu.pl/>

Press releases of the Institute of Nuclear Physics, Polish Academy of Sciences.

IMAGES:

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HR: http://press.ifj.edu.pl/news/2026/10/22/IFJ261022b_fot01.jpg

A lithium fluoride crystal exposed to blue light, showing recorded tracks of ionizing particles under a fluorescence microscope.
(Source: IFJ PAN)

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Tracks of cosmic radiation particles recorded in lithium fluoride crystal detectors during the Artemis I lunar flyby mission.
(Source: IFJ PAN)

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Cross-sections of the phantoms used in the Artemis I mission, showing the locations where radiation detectors were mounted.
(Source: DLR)

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Phantoms equipped with radiation detectors, installed inside the Orion capsule during the Artemis I lunar mission. (Source: NASA)