11 COSMIC HEAVY ION TRACKS IN MESOSCOPIC BIOLOGICAL TEST OBJECTS.

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Since more than 20 years, when the National Academy of Siences and the National Research Council of the USA released their report on "HZE particle effects in manned spaced flight", it has been emphasized how difficult - if not even impossible - it is to assess their radiobiological impact on man from conventional studies where biological test organisms are stochastically exposed to 'large' fluences of heavy ions. An alternative, competing approach had been realized in the BIOSTACK experiments, where the effects of single - cosmic as well as accelerator - heavy ions on individual biological test organisms could be investigated. Although presented from the beginning as the preferable approach for terrestrial investigations with accelerator heavy ions too ("The BIOSTACK as an approach to high LET radiation research.") only recently this insight is gaining more widespread recognition. It has been claimed, e.g., that radiation protection for the workforce in the nuclear fuel cycle will rest on poorly understood grounds unless we can describe quantitatively the effects a single -particle may engender in the one lung cell which usually is irradiated. In part this delayed recognition may be due to the significantly more demanding techniques and procedures necessary for a successful application of the 'single particle effects' approach. This applies to the experimental techniques by which such data can only be gathered as well as to the statistical analysis required for their proper evaluation.

Whether recognized or not, this approach is the only feasible technique for meaningful investigations of the radiobiological effects of cosmic heavy ions. In space flight experiments, additional constraints imposed by the infrastructure of the vehicle or satellite further impede such investigations. Restrictions concern the physical detector systems needed for the registration of the cosmic heavy ions' trajectories as well as the biological systems eligible as test organisms. Test organisms must be able to endure immobilization for the duration of the space mission and the substantial time intervals of preparation and storage before and after the mission itself. Since the possibilities of 'life support' are minimal, biological systems in a dormant state or phase of their life cycle are preferred test objects. For investigations adressing the basic biophsysical mechanisms of track structure and radial dose distributions, microscopic and rather radiation resistant test systems are the preferred choice. For biological endpoints more pertinent to radiation protection, such as e.g. chromosome aberrations or genetic 'late' effects, only more complex test organisms are suited. In every instance the experimental techniques to establish the geometrical correlation between the ions' trajectories and the 'sensitive' parts of the chosen test organisms have to be adapted to their size, shape and structure.

Such optimized procedures and techniques were developed for the investigations on chromosome aberrations induced by cosmic heavy ions in cells of the stem meristem of lettuce seeds (Lactuca sativa) and for the investigation of the radiobiological response of Wolffia arriza, which is the smallest flowering (water) plant. The biological effects were studied by the coworkers of the Russian Institute of Biomedical Problems (IBMP) which in cooperation with the European Space Agency ESA organized the exposure in the Biosatellites of the Cosmos series. Since biological investigations and physical measurements of particle tracks had to be performed in laboratories widely seperated, the preferred fixed contact between biological test objects and the particle detectors until the geometrical correlation between tracks and organisms has been established could not be maintained.

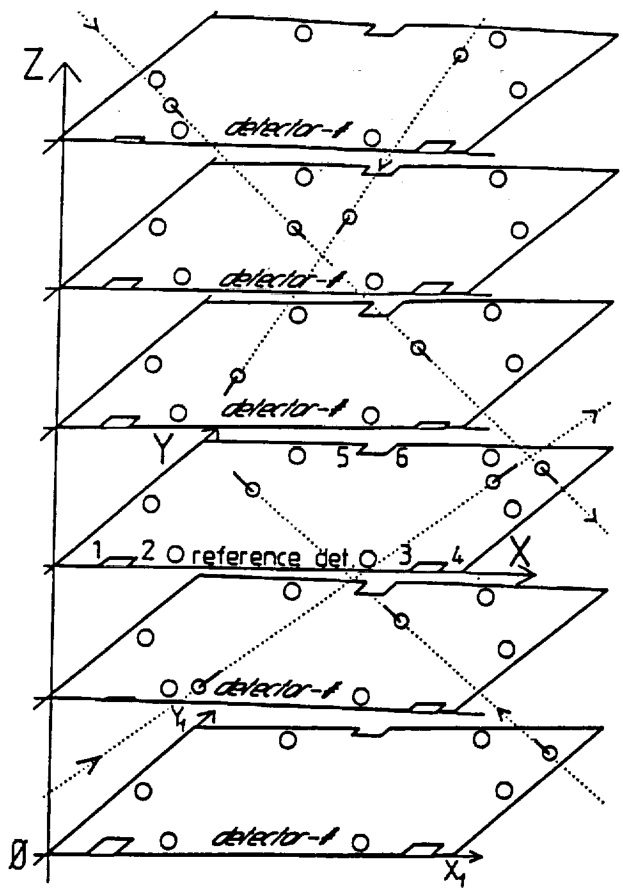

Figure 1: Relation between cosmic ray particle trajectories, etch tracks in coordinate systems of individual detectors, and between the stack- and detector-systems as displayed by the positions of grooves in the detector-system.

This gave rise to half a dozen of coordinate systems for different measurements which finally had to be related to a single stack reference system (Fig. 1).

For the first Biosatellite 8 mission the position and orientation of the seeds were determined visually from magnified shadowgraphs of the stack layers bearing the seeds. Classification of seeds as hit or non hit by heavy cosmic ions was determined by an overlay of these shadowgraphs with a map of heavy ion trajectories reconstructed for the corresponding layer (Fig. 2).

For the next Biosatellite 9 mission, the position and orientation of the seeds was determined from measurements in these shadowgraphs and in addition the location of the stem meristem was estimated by the biological specialist performing these measurements. This allowed the distance between particle trajectories and the estimated centre of the stem meristem - the impact parameter - to be estimated (Fig. 3). The quantitative uncertainty the particle trajectories could be reconstructed with was much smaller than the extension of the meristem (Fig. 4).

The Wolffia arrhiza plants had to be exposed in an environment which at least provided enough humidity to survive the exposure during the Biosatellite 10 mission. This humidity in turn was a new factor to be accounted for in the trajectory reconstruction since the

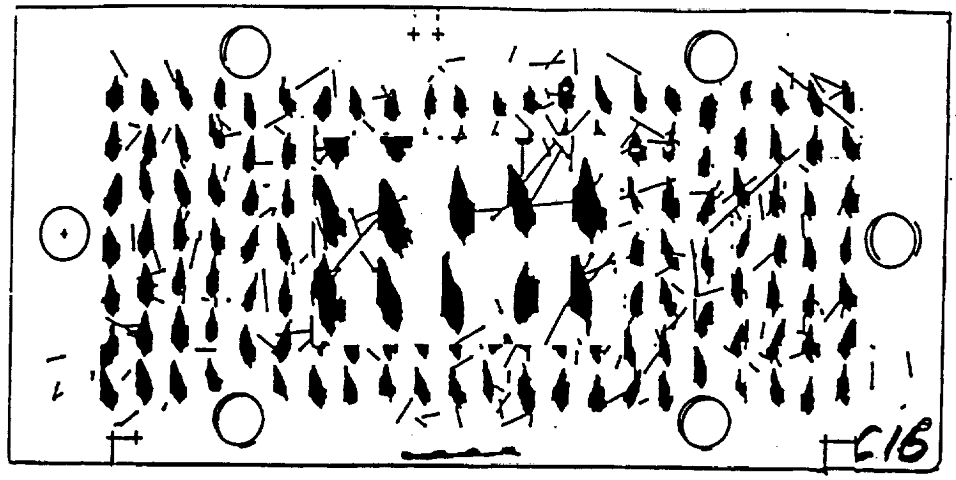

Figure 2: Map of projected particle transits through a biological layer overlain by its contact photography. The corners of the stack-reference grooves are marked by a (+) as well as the origin of the detector-system in the centre of the leftmost alignment hole. Magnified inset shows shadows of seeds and enlarged points of intersection of trajectories with the positive surface of the layer.

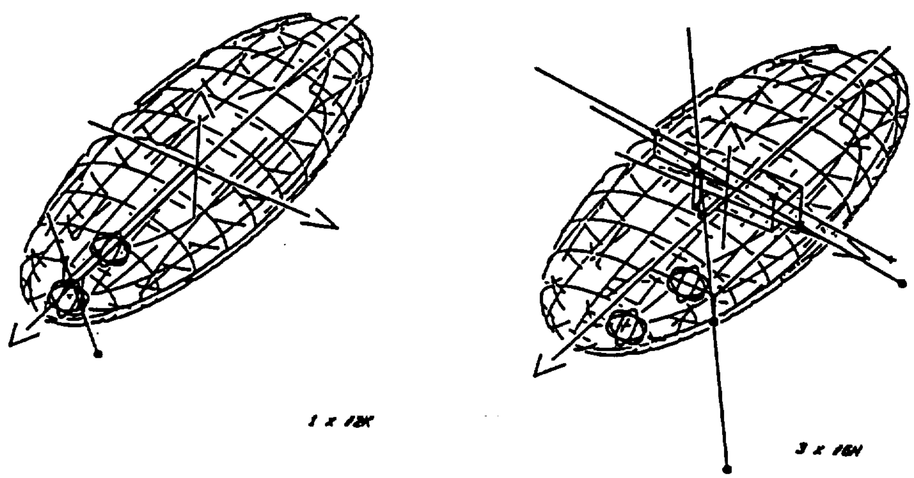

Figure 3: Threedimensional drawings of two seeds penetrated by 1 and 3 particles respectively. Root and stem meristems are appr. by spheres of 150 μm radius at the position, where they had been located in the shadowgraphs. Higher and lower ends of trajectories are marked by (+) or (0), respectively.

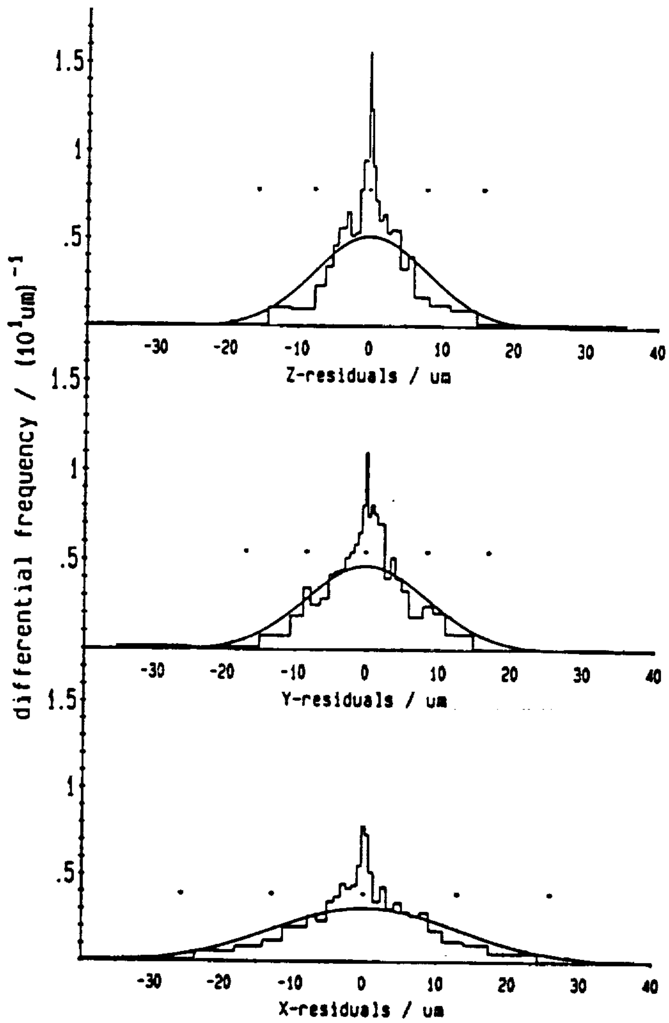

Figure 4: Quantitative precision of trajectory reconstruction as shown by the distribution of residuals between etch track coordinates and corresponding points on the trajectories.

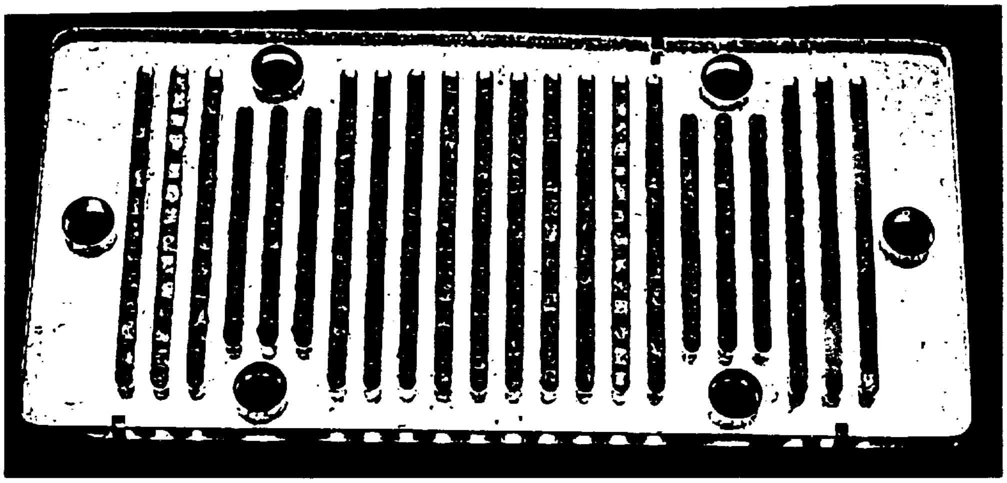

Figure 5: Wolffia arrhiza plants in their biological stack layer.

particle detectors significantly increased their size due to swelling of the plastic material. This time the position, orientation and size of the plants had to be determined immediately in the biological stack layers, where they had been fixed by small pieces of artificial sponge (Fig. 5). Despite the uncertainty added by the swelling the impact parameter to the budding zone of the plants could be determined with nearly the same precision.

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