PRODUCTION OF RADIONUCLIDES IN ARTIFICIAL METEORITES IRRADIATED ISOTROPICALLY WITH 600 MeV PROTONS

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The understanding of the production of cosmogenic nuclides in small meteorites (R<40 cm) still is not satisfactory. The existing models for the calculation of depth dependent production rates, e.g. /1-6/, do not distinguish between the different types of nucleons reacting in a meteorite. They rather use general depth dependent particle fluxes to which cross sections have to be adjusted to fit the measured radionuclide concentrations. Some of these models not even can be extended to zero meteorite sizes without logical contradictions. Therefore, a series of three thick target irradiations was started at the 600 MeV proton beam of the CERN isochronuous cyclotron in order to study the interactions of small stony meteorites with galactic protons. In contrast to earlier thick target experiments /7/, and references therein, and to recent experiments for the simulation of the GCR irradiation of large meteorites /8/, in these new experiments a homogeneous 4π-irradiation of the thick targets is performed. The irradiation technique used provides a realistic meteorite model which allows a direct comparison of the measured depth profiles with those in real meteorites. Moreover, by the simultaneous measurement of thin target production cross sections one can differentiate beween the contributions of primary and secondary nucleons over the entire volume of the artificial meteorite.

In most earlier thick target experiments only limited aspects of the production of cosmogenic nuclides were studied, i.e. some special radioisotopes or a particular rare gas was measured. In contrast, the new experiments shall provide an universal simulation for a wide variety of cosmogenic nuclides. For this purpose an international collaboration of ∿10 laboratories was initiated /9/ providing all necessary scientific and technical means. So radionuclide production is measured by γ-spectrometry instrumentally and by low-level counting and accelerator mass spectrometry after chemical separation, while the rare gases from He to Xe are studied by static mass spectrometry. The measurements are supported by Monte Carlo calculations of the nuclear cascades in the thick targets. Model calculations using the thus derived nucleon fluxes and experimental thin target excitation functions in combination with all the measured thick target production depth profiles then will provide a unification of the classical thin target and thick target approaches for the description of the production of cosmogenic nuclides in small meteorites.

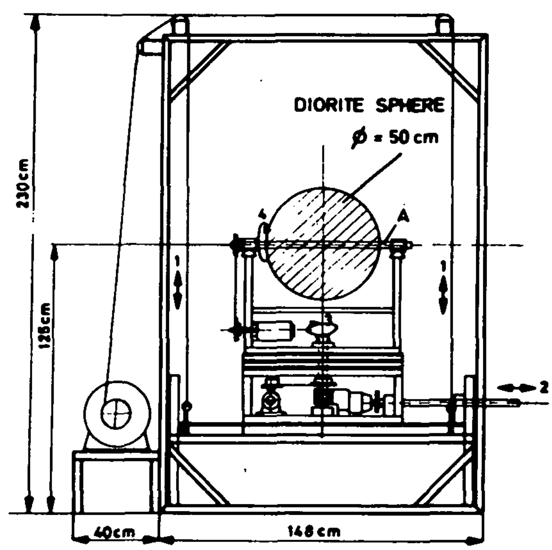

Fig. 1: Experimental set up used for the irradiation of an artifical meteorite with 50 cm diameter. The length of the arrangement was 126 cm.

In the first experiment in Feb. 1983 an artificial meteorite with 10 cm diameter was irradiated and a GCR irradiation age of about 76 My was simulated. A description of this experiment and first results are given elsewhere /10-12/. But the measurements and evaluations are still going on.

In the second experiment an artificial meteorite of 50 cm diameter was irradiated for 12 h with a proton flux of 2.5 μA in Dec. 1983. The homogeneous 4π-irradiation of the target was achieved by a machine (fig. 1) performing 4 independent movements of the artificial meteorite in the beam. Two translational movements (1) and (2) moved the sphere in the indicated directions by 50 cm, each, with velocities of 3.3 cm/min (vertical) and 11. cm/min (horizontal). They simulated a parallel homogeneous proton rain over a 50x50 cm^2 plane. Further the stony sphere made two rotations (3) and (4) with 2 and 5 rpm respectively, thus resulting in a perfect 4π-irradiation. The primary proton flux through the sphere was measured by a 50 cm x 50 cm Al-foil which also made the translational movements and which shadowed the artificial meteorite during irradiation. By the investigation of this Al-foil the homogeneity of the parallel proton rain was proved.

The sphere itself was made out of diorite slabs (ρ=3.0 g/cm^3, $H_2O \leq 10^{-3} g/g$. It contained a Fe tube (A) with an inner diameter of 1.9 cm. This tube contained 9 Al boxes which were filled with pure element target foils, some chemical compounds and carefully degassed samples of the meteorite JILIN. These targets covered the elements O, Mg, Al, Si, S, Ca, Ti, V, Mn, Fe, Co, Ni, Cu, Zr, Rh, La, Lu, Ba, Te, Au, and Pb. First results are shown in fig. 2. The artificial meteorite received a 600 MeV proton dose of 2.49 x 10^{14} cm^{-2} which is equivalent to a cosmic irradiation age of 4 My. The homogeneity of the irradiation can be seen from the results for Be-7 which - at least from Fe - is exclusively produced by primary particles. The Be-7 profiles from Al and Fe are constant over the entire artificial meteorite within 8.0 % and 3.5 %, respectively. For the other radionuclides the depth profiles show strong increases from the surface to the interior exhibiting important contributions of secondary particles. For Na-22 and Na-24 from Al the increase is by factors of 1.6 and 1.7, respectively. The profiles are fairly symetric. The production of Mn-54 and Co-56 from Fe increases by factors of 1.6 and 1.5.

Co-56 from Fe is of particular interest, since it is exclusively produced by proton induced reactions. Thus the depth profiles of Co-56 from Fe exhibits the action of secondary protons while for Mn-54 and other low energy products reaction of both, secondary protons and neutrons, have to be taken into account.

Generally, the production of Co-56 and Mn-54 from Fe in this meteorite model (fig. 2) are higher than in the sphere with 10 cm diameter (fig. 3). The depth profiles measured for the small sphere show a smaller but still significant increase from the surface to the interior by 20 to 30 %. The generally higher production rates of these nuclides in the big sphere surely are due to the larger amount of secondaries produced in the total targets. For Co-56, however, the maximum production rates are higher by 20 % in the big sphere than in the small one, while for Mn-54 the center production rates even are higher by a factor of 1.6 in the large meteorite model. These first results already demonstrate that in small meteorites the contributions of secondary protons and neutrons are changing with the meteorite sizes and that these

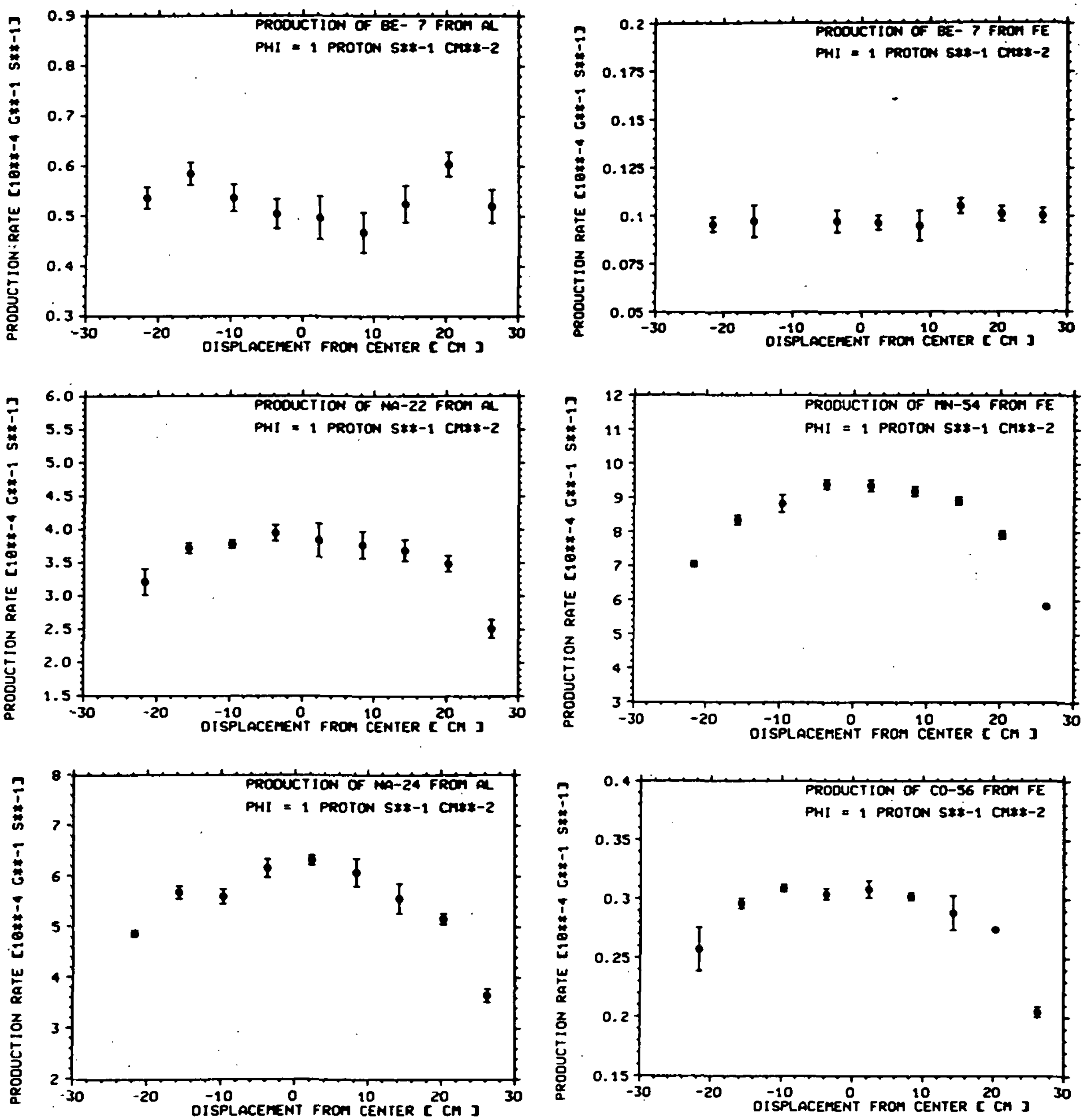

Fig. 2: Depth profiles for the production of radionuclides from Al and Fe in in an artificial meteorite (ρ=3 g/cm^3) with a diameter of 50 cm. The production rates are normalized to a 4π-integrated flux of primary protons of 1 cm^{-2}s^{-1}.

changes are depending on the types of the secondary nucleons.

Consequently, a model describing the production of cosmogenic nuclides in small meteorites has carefully to distinguish between the different types of reacting particles and their depth dependent fluxes. Such a model has to consider the contributions of primary and secondary galactic as well as of solar particles. The interaction of primary solar and galactic cosmic rays with

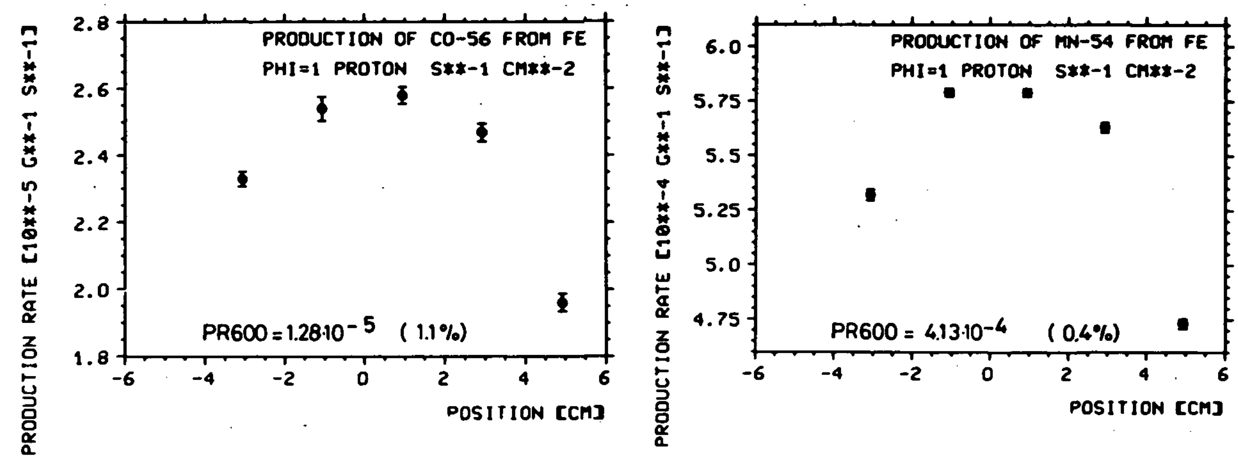

Fig. 3: Depth profiles for the production of Mn-54 and Co-56 from Fe in an artificial meteorite (ρ=3 g/cm^{-3}) with a diameter of 10 cm. The production rates are normalized to a 4π-integrated flux of primary protons of 1 cm^{-2} s^{-1}. The PR 600 values are the production rates due to primary 600 MeV protons only. The errors of these production rates are given in parentheses.

meteorites can be calculated with good a priori accuracy /13,14/. A description of the depth dependent contributions of secondary protons and neutrons will be possible on the basis of the experimental thick target production rates measured in the present simulation experiments.

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