T H E S E S O F Ph.D. D I S S E R T A T I O N

Radon and Space Radiation Protection Measurements

Written by:

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I. Introduction

In this dissertation I deal with two radiation protection issues. The first part is about the protection of the crew of manned space flights against the exposure to cosmic ray charged particle irradiation in low Earth orbit. The second part deals with protection of the general population against exposure to inhaled radon and its decay products present in air in homes and in workplaces.

Crewmembers of spacecrafts on low Earth orbit receive effective dose around 1 mSv/day. Dose rate varies significantly both as a function of space and time. Much of the dose is received when the space vehicle crosses the so-called South Atlantic Anomaly. Protons, trapped in the Van Allen radiation belts contribute to the dose dominantly. In our experiments done in the Physics Research Laboratory of the University of San Francisco (San Francisco, California, United States) in 1991 and 1992, we have aimed at studying the flux and the linear energy transfer and directional distribution of cosmic ray charged particles collected in etched track detector stacks flown on the so-called Long Duration Exposure Facility satellite.

Inhalation of short-lived radon decay products, present in air of homes and of workplaces, contribute about 1 mSv/year effective dose to the exposure of the general population to the natural radiation environment. Indoor radon surveys showed that houses with high radon concentration could be found with startling frequency. Finding these houses and workplaces, and reducing radon (or risk) in them is the motivation of many efforts and is one of the indirect scope of our work in the Radon Group of the Institute of Nuclear Research (Debrecen, Hungary). On the other hand, efficient search strategies for radon-prone areas and efficient mitigation techniques require deep level of understanding of radon occurrence in nature, its origin, its transport in soil and its entry into houses. The scientific aim of our recent work is to develop a general physical-mathematical and computer model to describe the transport of radon in soil and its entry into houses, when all relevant influencing factors are taken into account.

II. Materials, instruments and methods

In the second part of the disseration I present the materials, instruments and methods that we have used in our experiments and measurements. Also in this part I show the results that I have obtained in developing instruments (Radamon etched track type ^{222}Rn and ^{220}Rn detector) and methods (exhalation rate measurement with AlphaGUARD ionization chamber radon monitor); in calibration and quality assurance measurements of etched track detectors (CR-39, polycarbonate) and radon monitors (Inverted cup, Radamon, Dataqua, AlphaGUARD); and in measuring the effects of storage time, vacuum, and carbon dioxide on the sensitivity of CR-39 etched track detector.

III. Results

I have grouped the main findings of the dissertation into three major thesis points.

1. *Instrument and method developments, calibrations*.

1.1 I have found that the response of CR-39 to alpha particles can be described by two parameters: the so-called etch induction time and the reduced etch rate ratio (sensitivity), both as a function of particle energy. I have found that, at room temperature, the sensitivity of CR-39 decreases as a function of storage time, even years after its production. On the other hand, I have found that the sensitivity of CR-39 does not depend on the time of the particle incidence, it depends only on the age of the detector at the time of etching.

I have found that irradiation of CR-39 in vacuum increases the etch induction time and reduces the sensitivity significantly if the detector is kept in vacuum at least for a few hours before and for a few minutes after irradiation. I have concluded that dissolved oxygen in the detector material plays an important role in latent track formation.

I have found that post-irradiation sensitization of CR-39 in CO_2 atmosphere increases both as a function of treatment time and as a function of partial pressure of CO_2. This sensitization did not depend on the age of the latent track nor on the energy of alpha particles. I have concluded that CO_2 plays a role in latent track transformation in CR-39.

1.2 I have developed and calibrated a passive, etched track type ^{222}Rn and ^{220}Rn concentration measuring detector, called Radamon. I have participated in two international intercomparisons and found that Radamon provided results within 7% of the nominal ^{222}Rn exposures reported by the organizers.

1.3 I have developed the multiple-etches technique to measure the high linear energy transfer (LET) portion of the LET spectra in CR-39 detector sheets that were exposed on the so-called Long Duration Exposure Facility (LDEF) satellite. I have developed the track anti-coincidence method to measure the mission fluence and directionality of arriving protons in an experiment on the LDEF satellite.

2. *Space radiation measurements*.

2.1 I have identified short range high-LET secondary particles, produced in interactions between trapped protons and the C and O nuclei of the experimental detectors, as a major contributor to the LET spectra for low Earth (LDEF type) orbits.

2.2 I have found that trapped protons collected in LDEF CR-39 detectors show strong directionality with more protons arrived from the west direction than from any surrounding directions. I have found that upper limit of mission fluence of trapped protons from the west direction is 6.3×10^6 at 25 MeV and 9.2×10^6 at 114 MeV proton energy.

2.3 I have found that directionality of LDEF mission fluence of relativistic Fe ions was slightly unisotropic with some extra particles coming from the south-west direction parallel with the surface of the Earth.

3. *Radon concentration measurements.*

3.1 From the analysis of indoor radon concentration data from a small scale national survey of 122 dwellings in 1985-1987 I have found that the arithmetic average radon activity concentration in Hungarian dwellings is 55 Bqm^{-3}. This value is about a factor of 2 smaller than that was obtained in a larger scale national survey of 998 dwellings done by I. Nikl and coworkers in 1993-1994. However, I have also found that it may be closer to the value that could be expected when comparing to the average of more than 6000 radon concentration measurements done by E. Tóth and coworkers in rural houses. I have concluded that an uncertainty of a factor of about 2 remains in the estimate of the average radon activity concentration in Hungarian dwellings.

3.2 I have found that annual effective dose received by tour guides of show caves, assistants of therapeutic caves and by the most active cavers from inhalation of radon decay products in cave air is in the order of 1 to 10 mSv, but significantly higher values may also occur. Because of the order of these doses and due to the known significant spatial and temporal (seasonal, weather front linked, and sometimes diurnal) variation of cave radon concentration I propose personal radon dosimetry for the most active cavers, tour guides and assistants of therapy. I also suggest to test all caves against radon at least for one year before opening to public or therapy or used otherwise by the same group of people.

3.3 I have found that the annual effective dose of staff of a dry carbon dioxide spa due to radon and its decay products, is a few mSv. I have found that the contribution of radon, that diffuses into the body through the skin, to the total effective dose due to radon and its decay products is significant for patient standing in the spa. Average cure effective dose of patients, however, is relatively low, it is around 1 mSv.

3.4 As a perspective of future radon studies, currently I have been working on a physical-mathematical model to describe the transport of heat, water, soil gas, and radon in the non-saturated zone of inhomogenous soils, and the entry of radon into houses when all relevant influencing (geological, meteorological) factors are considered. My preliminary calculations agreed relatively well (at least qualitative) with experimental measurements that we have done at our Mátraderecske and Erdőbénye (Hungary) radon test-sites. They do not agree, however, at all with measurements done by our collaborating partners at another radon test-site at Lamalou karst terrain (in southern France). I have concluded that in order to obtain better agreement between calculations and measurements the physical-geophysical part of the model should be more general.

IV. Relevant own publications

Regular Papers

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