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**PARTICLE REGISTRATION IN DIELECTRIC MATERIALS:
A BIBLIOGRAPHY**

Richard V. Griffith

April 9, 1974

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PARTICLE REGISTRATION IN DIELECTRIC MATERIALS:

A BIBLIOGRAPHY

ABSTRACT

A bibliography containing 872 references on techniques and applications of registration of nuclear particles in dielectric materials, as well as 30 track registration patents, has been compiled with cross-reference lists by author and key word. About two-thirds of the references include abstracts.

INTRODUCTION

Research and applications involving various aspects of track registration in dielectric materials has been increasing rapidly in recent years. Fleischer *et al.* (134) have indicated that papers on applications of track etching have been published at a rate that has doubled every two to two and one-half years over the last ten years. From the work presented here we find that, based on data from Nuclear Science Abstracts alone, we can expect more than 90 papers to be published in 1973.

In conjunction with a recent survey on track registration (145), this bibliography has been compiled as an aid to those who are becoming involved with track registration. It does not include all of the published work on the subject, but does include the majority of papers dealing with track registration since the early 1960's. The data has been obtained from Nuclear Science Abstracts, reference lists from recent publications by Becker (N10) and Fleischer *et al.* (134), and a set of references from miscellaneous sources provided by Dr. P. L. Van Velze of Luxembourg.

I have made a cross reference of the bibliography by author and by the key words which I felt would be useful. In some cases, references may be cross referenced with a number of key words which do not appear in the title or abstract. This is because I have personal knowledge of the information contained in the paper, or I have access to the abstract which I could not include because of copyright considerations.

I hope that this bibliography will be useful to those with interest in this field. Sources such as Nuclear Science Abstracts can be used to help keep the reference list up to date. Nuclear Science Abstracts has recently changed the key-word list to include specific use of headings for "Dielectric Detectors."

I would like to thank Dr. Van Velze for contributing his reference list to this bibliography.

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A. BASIC TRACK REGISTRATION RESEARCH

A1 OBSERVATIONS OF CHARGED-PARTICLE TRACKS IN SOLIDS. P. B. Price and R. M. Walker (General Electric Research Lab., Schenectady, N.Y.), *J. Appl. Phys.*, 33: 3400-6 (Dec. 1962).

The characteristics of tracks produced by fission fragments are studied by transmission electron microscopy in the following layer structure materials: molybdenite (MoS_2); talc; clinocllore; jefferisite; and various micas, including biotite, phlogopite, muscovite, and synthetic fluor-phlogopite. The measured track widths show little correlation with the decomposition temperatures and it is concluded that the track formation cannot be described by a simple-thermal-spike model. The absence of any new rings or spots in the electron diffraction pattern of a heavily irradiated sample leads to the conclusion that the tracks themselves consist of a disordered region and not of a definable new crystalline phase. In many of the materials the tracks fade during observation in the beam. Although this fading can be eliminated by using a cold stage, it is not caused simply by the thermal instability of tracks; some materials exhibiting rapid track fading retain tracks to higher temperatures in external annealing experiments than do those in which no fading occurs. Annealing experiments also show that tracks serve to nucleate the high temperature decomposition of natural micas. The results of experiments in which A1 absorbers are placed between a fission source and mica samples are interpreted as indicating that only particles with masses ≥ 30 are capable of forming visible tracks. This conclusion is consistent with the negative results of other irradiations in which mica samples are bombarded with 4-Mev alpha particles, 150-Mev oxygen nuclei, and 3-Bev protons. Experimental observations of the interaction of dislocations with tracks are also presented.

A2 A NEW TRACK DETECTOR FOR HEAVY PARTICLE STUDIES. P. B. Price and R. M. Walker (General Electric Research Lab., Schenectady, N.Y.), *Phys. Letters*, 3: 113-15 (Dec. 15, 1962).

When a slab of mica is bombarded with heavy particles and then heavily etched with acid, the particle paths show up as "tracks" which are easily observable in an optical microscope. The quality of these tracks is superior to that produced in conventional nuclear emulsions and the mica is simpler to process and

more rugged than emulsions. Examples are presented of particle tracks produced by fission fragments and by recoils induced by 150 Mev O^{16} ions on mica. Because the mica does not register particles with masses ≤ 30 , the observed tracks in the latter experiment are due to the heavy nuclear reaction products of O^{16} nuclei with the constituents of mica. The results indicate a compound nucleus formation cross section between 0.15 and 0.3 that of the geometrical cross section for elements with mass ~ 30 . The use of this new track registration technique as a method of dating natural mineral crystals and also for measuring low uranium concentrations is briefly discussed. It is pointed out that the particle tracks afford a simple explanation of anomalous etch pits which have been observed in natural mica.

A3 ELECTRON MICROSCOPE OBSERVATION OF ETCHED TRACKS FROM SPALLATION RECOILS IN MICA. P. B. Price and R. M. Walker (General Electric Research Lab., Schenectady, N.Y.), *Phys. Rev. Letters*, 8: 217-19 (Mar. 1, 1962)

Tracks in mica, resulting from recoil nuclei produced in spallation reactions of 3.0-Bev protons, were observed using an electron microscope. Decay events may be observed on a shorter time scale, and observation of "fossil" cosmic-ray events may become possible. A chemical etching treatment providing a demonstration of localized radiation-induced corrosion was used.

A4 THE STUDY OF IRRADIATION DAMAGE IN URANIUM BY ELECTRON MICROSCOPY. M. J. Makin (Atomic Energy Research Establishment, Harwell, Berks, Eng.), W. H. Chatwin, J. H. Evans, B. Hudson, and E. D. Hyam. p.45-51 of "Uranium and Graphite." London, Institute of Metals, 1962.

The bulk physical properties of α -uranium are quite severely affected by several different phenomena during neutron irradiation, and it has been shown that the scale of the damage responsible is such that in many cases it is observable only by electron microscopy. A fairly detailed account of the various electron-microscope techniques used in the U.K.A.E.A. Laboratories and some of the more notable results obtained are given. The replication of polished and etched surfaces has been extensively used to study the distribution of fission gas bubbles in uranium irradiated under

various conditions and has given much valuable information on the swelling problem. The replication of fractured surfaces has revealed the formation of grain-boundary cavitation during irradiations in which large temperature variations have occurred. Extraction replicas have been used to study the precipitates formed when iron and aluminium are added to uranium to control the grain size and which appear also to influence the distribution of gas bubbles. Recently the thin-film transmission technique has been successfully applied to uranium and has revealed the formation of dislocation loops on certain crystal planes during irradiation. The strains produced by these loops are believed to constitute the mechanism of the irradiation-growth phenomenon.

A5 INVESTIGATIONS OF CHARGED PARTICLE TRACKS IN SOLIDS. R. M. Walker and P. B. Price. (General Electric Research Lab., Schenectady, N.Y.). p.G-4 of "Electron Microscopy. Vol. 1." New York, Academic Press, 1962.

Mica was irradiated with U^{235} fission fragments, oxygen nuclei, α particles, and protons. Results showed that only nuclei with masses ≥ 30 produce tracks visible under an electron microscope. This indicates that high doses of light particles can be used to produce nuclear reactions involving visible heavy fragments without the light particles contributing background. Nuclear reactions using both 3-Bev protons and 150-Mev oxygen nuclei as bombarding particles were observed. The possibility of observing, "fossil" tracks produced by natural radiation processes is suggested.

A6 NUCLEAR PARTICLE TRACKS IN SILICON. D. P. Miller and H. L. Taylor (Texas Instruments, Inc., Dallas). Appl. Phys. Letters, 2: 33-4 (Jan 15, 1963).

Silicon (111) slices were obtained from spin-pulled crystals doped with 10^{17} B atoms cm^{-3} . The dislocation densities were below 10^4 cm^{-2} . The crystals also contained approximately 10^{18} O atoms cm^{-3} . Small disks of 0.125 in. diameter and 0.015 in. thickness were etched thin in the central 0.0625 in. diameter region. These disks were sufficiently thin for electron transmission (1000-1500 Å) yet firmly supported by a thick ring. These sample disks were inserted next to the core of the Battelle research reactor (swimming pool) and exposed to bombardment by 5×10^{14} fast neutrons cm^{-2} . Electron micrographs revealed damage tracks produced by the bombardment. Most tracks exhibit a central high-contrast image with surrounding low-contrast image cloud. Possible particles that could have produced the tracks were dis-

cussed. Atoms present in significant quantity in or nearby the film were Si, O, B, N, C, and H. The characteristics of the tracks eliminated most the particles in question. It was thought most probable that the track was produced by a primary knock on Si atom either inside the film or at the surface. The track was thought to be a temperature spike produced by the knockon atom.

A7 CHARGED PARTICLE TRACKS IN GLASS. R. L. Fleischer and P. B. Price (General Electric Research Lab., Schenectady, N. Y.). 5p.

From American Physical Society Meeting, St. Louis, Mar. 1963.

Heavily ionizing particles passing through crystalline solids produce trails of damage that can be seen either directly by electron microscopy or indirectly, by means of preferential chemical dissolution of the damaged material. Where both methods were used, it was shown that the method of chemical attack is the more sensitive. This method of revealing irradiation effects is able also to display the paths of heavy particles in a great many noncrystalline materials, in this instance glass. It is shown that fission fragments from Cf^{252} leave damage trails in glass that may be etched to give conical pits. In some glasses the cone angles are small, so that the direction taken by the moving particles may be followed. Fission tracks can also be revealed in certain glasses by preferential precipitation of a metal such as silver along the damaged regions. This method has the advantage that a track does not have to intersect a free surface to be revealed.

A8 TRACKS OF CHARGED PARTICLES IN HIGH POLYMERS. R. L. Fleischer and P. B. Price (General Electric Research Lab., Schenectady, N. Y.). Science, 140: 1221-2 (June 14, 1963).

Heavily ionizing particles create trails of damage as they move through materials. In both addition and condensation polymers these trails can be selectively dissolved so that the sites and the directions taken by the moving particles are revealed. These materials thus serve as simple detectors of heavily charged particles.

A9 TRACK REGISTRATION IN VARIOUS SOLID-STATE NUCLEAR TRACK DETECTORS. R. L. Fleischer (General Electric Research Lab., Schenectady, N.Y.), P. B. Price, R. M. Walker, and E. L. Hubbard. Phys. Rev., 133: A1443-9 (Mar. 2, 1964).

In a number of materials energetic, heavy nuclear particles leave trails of radiation-damaged material that can be selectively attacked by chemical reagents to

produce tracks visible in the optical microscope. The track-registration characteristics of three such materials — muscovite mica, Lexan polycarbonate, and cellulose nitrate — were investigated using fission fragments and various heavy ions from argon down to helium, each over a wide range of energies. Curves of energy-loss rate dE/dx versus particle energy were calculated for each solid, and the experimental results were displayed on the dE/dx curves. It was found that for each detector there is a fairly narrow range of dE/dx values over which the track-registration efficiency varies from unity to zero. This rapid drop in efficiency with dE/dx makes it reasonable to define a critical energy-loss rate $(dE/dx)_{crit}$ for each detector, which appears to be independent of energy and atomic number. Crude estimates of particle masses can be made using several detectors with different $(dE/dx)_{crit}$. For example, for particles with energies less than ~ 3 Mev/amu, the mass must exceed 3, 12, and 28 amu if tracks register in cellulose nitrate, Lexan polycarbonate, and muscovite, respectively. For particles such as fission fragments, with initial $dE/dx \gg (dE/dx)_{crit}$, the track lengths are a fair approximation of the particle ranges. Particles incident at a very small angle to a detector surface are registered in mica but not in plastics or glasses. Solid-state track detectors presently offer unique advantages when heavy particles must be studied in the presence of a high background flux of light particles.

A10 ION EXPLOSION SPIKE MECHANISM FOR FORMATION OF CHARGED-PARTICLE TRACKS IN SOLIDS. Fleischer, R. L.; Price, P. B.; Walker, R. M. (General Electric Co., Schenectady, N. Y.). *J. Appl. Phys.*, 36: 3645-52 (Nov. 1965).

Massive charged particles create regions of intense damage (tracks) by passing through bulk samples of insulating materials. These tracks are shown to result from the positively charged region created by ionization. An approximate model of an "ion explosion spike" is proposed in which the mutual repulsion of the positive ions ejects them into the surrounding lattice. This model is shown to be generally consistent with a wide range of experimental fact. An additional damage mechanism appears to apply to polymers, in some of which tracks are produced by light projectiles such as α particles. The data here are shown to be consistent with tracks consisting primarily of broken bonds caused by decay of directly excited electrons.

A11 COMPARISON OF THE REGISTRATION OF TRACKS OF HEAVY IONS IN IONOGRAPHIC EMULSIONS AND IN VARIOUS SOLID

MATERIALS. Pfohl, Raymond; Monnin, Michel; Debeauvais, Monique (Centre de Recherches Nucleaires, Strasbourg; Univ. Paris, Clermont, France). *Compt. Rend.*, 261: 2216-18 (Sept. 13, 1965). (In French)

The registration of tracks of heavy ions in ionographic emulsions and various solid materials was compared from the viewpoint of their length and the intrinsic sensitivity of the detecting material. A mechanism for the formation of tracks in these two types of detectors based on the emission of δ rays was proposed.

A12 (USNRDL-TR-917) CHARGED PARTICLE TRACKS IN POLYMERS. NUMBER 1. DELINEATION AND MEASUREMENT OF SUB-SURFACE TRACKS. Collier, M. M.; Benton, E. V.; Henke, R. P. (Naval Radiological Defense Lab.; San Francisco, Calif.). *Oct. 4, 1965. 20 p.*

A technique for the delineation of sub-surface charged particle tracks by a successive chemical removal of surface material is presented. A method of measuring the approximate range of heavily ionizing charged particles in polymers is given. The techniques are applied to the observation and measurement of low-energy ^4He -ion tracks in cellulose nitrate.

A13 DISLOCATIONS AND NUCLEAR PARTICLE TRACKS IN SILVER CHLORIDE CRYSTALS. Childs, C. B.; Slikin, L. M. (Univ. of North Carolina, Chapel Hill). *Brit. J. Appl. Phys.*, 16: 771-7 (June 1965).

Defects such as dislocations and the tracks left by energetic charged particles may be made visible inside large crystals of silver chloride by a photoelectric technique, the net result of which is the deposition of metallic silver along the imperfections. The main advantage of this procedure in the study of dislocations is that large regions of the crystal may be observed in the cold-worked state. For the study of cosmic rays and nuclear events, a convenient and distortion-free detector is offered which may be of use in specialized applications.

A14 METHODS FOR HIGH ENERGY EXPERIMENTS ON HEAVY NUCLEI USING MICA DETECTORS. Brandt, Reinhard (Max-Planck-Institut fuer Kernphysik, Heidelberg. CERN, Geneva). *Nukleonik*, 8: 235-9 (May 1966). (In German).

It is shown that 18-Mev protons leave no etchable traces in mica. Negligibly small etchable traces ($A > 30$) are produced by the interaction with impurities in mica for $< 10^{13}$ p/cm². A mica-pack-("sandwich")-method was developed in which a very thin metal layer (about

10 $\mu\text{g}/\text{cm}^2$ uranium on 200 $\mu\text{g}/\text{cm}^2$ aluminum) was pressed between two mica foils. These packs were irradiated and the particle traces were etched out in an acid bath. Single traces were observed under an ordinary optical microscope, which were produced by spallation phenomena. Further, two traces spatially associated with one another were seen, which result from a fission phenomena. Occasionally three associated traces were observed, whose origin is possibly a nuclear three-body fission process. The mica-pack method is suitable for determining the fission interaction cross-section as a function of energy and mass more exactly than previous determinations.

A15 ANNEALING OF TRACKS FROM SPONTANEOUS FISSION OF URANIUM IN MICA CRYSTALS AND GLASS. I. G. Berzina, I. V. Vorob'eva, Ya. E. Geguzin, and I. M. Zlotova. Dokl. Akad. Nauk SSSR 171(6), 1313-16 (1966) (Russ.).

A16 AUGABEN ÜBER GLIMMER NACH DER SPUR DER URANSPLITFRAGMENTE. I. G. Berzina. (Doklady Akad. Nauk SSSR 170, 681-83, 1966; Vsesojuznyj naučno-issledovatel'skij inst. jadernojo geofiz. i geochimii Ministerstva geol. SSSR; russ.)

A17 THEORY FOR THE DEVELOPMENT OF TRACK HOLES IN SOLID STATE NUCLEAR TRACK DETECTORS. Somogyi, Gyorgy. ATOMKI (At. Kut. Intez.) Közlem., 9: 77-89 (June 1967). (In Hungarian).

A general theory is described for the development of track holes in solid state nuclear track detectors. Based on this theory the existence of a correlation between the diameters of track holes and the energy of particles was proven. A sandwich technique was applied for direct demonstration of the effect in case of fission fragments entering into glass. The theory is extended to the particles entering at any angles into the detector, and the validity of the theoretical function for diameter of the track hole versus the entering angle of particles is proved experimentally.

A18 ORIENTATION ANISOTROPY OF TRACKS OF URANIUM NUCLEI FISSION FRAGMENTS IN LITHIUM FLUORIDE SINGLE CRYSTALS. Ya. E. Geguzin, I. G. Berzina, and I. V. Vorob'eva (Khar'kovsk. Gos. Univ. im. Gor'kogo, Kharkov). Fiz. Tverd. Tela 9 11, 3350-2 (1967) (Russ.).

A19 A STUDY OF THE REGISTRATION OF ARSENIC AND IODINE IONS IN OLIVINE AND HYPERSTHENE CRYSTALS. P. Horn, M. Maurette

and W. von Oertzen. Z. Naturforsch. (Germany), Vol. 22A, No. 11. 1793-8 (Nov. 1967).

A20 (JINR-P13-3585) REGISTRATSIYA ZARYAZHENNYKH CHASTITS S POMOSHCH'YU NITRATA TSELLYULOZY. (Charged Particle Detection With the Aid of Cellulose Nitrate). Abdullaev, Kh.; Perelygin, V. P.; Tretyakova, S. P.; Shadieva, N. Kh. (Joint Inst. for Nuclear Research, Dubna (USSR); Lab. of Nuclear Reactions). 1967, 9p. (In Russian).

The technique for detection of light charged particles with the aid of cellulose nitrate is developed. The threshold of response of cellulose nitrate to α -particles is determined to be ≤ 2.2 MeV, and the detection efficiency — $(90 \pm 7)\%$. The possibilities of using the cellulose nitrate detectors for the detection of heavy charged particles and for measurement of Li and B contents in matter are considered.

A21 DETECTION OF LIGHT NUCLEI WITH CELLULOSE NITRATE. Jones, W. D.; Neidigh, R. V. (Oak Ridge National Lab., Tenn.) Appl. Phys. Lett., 10: 18-20 (Jan. 1, 1967). (ORNL-P-2730).

It was shown experimentally that light nuclei, including protons having energies as low as 55 keV, can produce etchable damage in cellulose nitrate. Comparison of experimental results with theory indicates that the threshold for track registration is about 0.35 MeV per $\text{mg}\cdot\text{cm}^{-2}$.

A22 INTERACTION OF HEAVY IONS IN MATTER. Kobetich, Edward John. Lincoln, Nebr., Univ. of Nebraska, 1968. 146 p. Thesis.

The spatial distribution of ionization energy about the path of a rapidly moving ion has been shown to be the parameter essential for describing the response of several media to heavy ion bombardment. To accommodate electron scattering and other problems arising in the calculation of this distribution, a simple empirical formulation was developed for the energy dissipation of normally incident electron beams onto slabs, in agreement with complex formulations and experimental data, over a wide range of energies and materials. Successful application was made to three detection and damage phenomena. In these applications, the response of the media is taken to be characterized as a one-hit or many-hit (threshold) process; the media are taken as homogeneous; a point target approximation is used; and the characteristic energy dosage is treated as an adjustable parameter. Values for this parameter range from 10^4 to 10^9 ergs/cm^2 , an appropriate to the characteristic "sensitive volume"

for the process. A model proposed for the response of NaI (TI) to heavy ions yields relative pulse heights in agreement with experimental data for ions of $Z > 5$ at $1 - 10$ MeV/amu, when the characteristic energy dosage is 4×10^7 ergs/cm³. The model proposed for the formation of etchable tracks in dielectric media predicts the formation or nonformation of etchable tracks in Lexan polycarbonate, cellulose nitrate, and mica, in agreement with published data. The model proposed for the width of ion tracks in emulsion gives excellent agreement with measured profiles for residual ion ranges less than 3000μ ($\beta < 0.3$). In view of the continuing search for magnetic poles, calculations based on these models have been made to establish criteria for pole detection using NaI(TI), dielectric, or emulsion detectors.

A23 DURATION OF SENSITIVE PERIOD FOR TRACK RECORDING IN MICA. Russell, F. M. (Rutherford Lab., Chilton, Eng.). *Nature* (London), 217: 51-2 (Jan. 6, 1968).

There is evidence which suggests that the tracks of muons and electrons from electron showers may leave detectable marks in muscovite mica during a sensitive period following crystallization. Charged particles of higher specific ionization, such as alpha particles and fission fragments, would also be expected to leave detectable records. It has been suggested that the observable tracks may be produced as a result of exsolution of excess iron content on nucleation centers formed by ionization by the charged particles. Decoration of such centers will then occur as a result of accretion of impurities, and the original nature of the initial precipitation will be considerably masked by the continued decoration. Most crystals contain trace amounts of naturally radioactive elements, and isolated regions showing decoration by iron impurity would be expected in mica specimens showing staining. If the occurrence of such decorated regions or spots can be related to radioactive impurity content then the duration of the sensitive period for recording the passage of charged particles can be found. Estimates of this period as about 10 years were made, making use of the trace concentrations of U and Th. Although fission fragments should also produce nucleation centers, the low probability for spontaneous fission relative to alpha decay makes this a negligible contribution. Only those decays that occur after exsolution has commenced can form recordable nucleation centers. From measurements on some mica samples from the Madras region of India, the duration of the sensitive phase was

found to be 16 ± 8 yr. It is unlikely that the sensitive time for the recording of muons exceeds that for alpha particles.

A24 (COO-1671-16) PARTICLE TRACKS IN EMULSION AND RELATED PHENOMENA. Katz, Robert; Kobetich, E. J. (Nebraska Univ., Lincoln. Behlen Lab. of Physics). [1968]. 37p.

From American Physical Society Meeting, Washington, D. C.

The structure of particle tracks in emulsion may be understood through the spatial distribution of ionization energy carried into the medium by δ -rays, through an analysis used earlier to find the cross section for inactivation of dry enzymes and viruses, and the response of NaI(TI) to heavy ions. A parallel analysis yields criteria for the production of etchable tracks in dielectrics. The assumption that emulsion responds to a 1-hit process to the mean energy dose deposited in an emulsion grain yields predictions of grain count, the blackness profile, and the width of heavy ion tracks in emulsion.

A25 FORMATION OF ETCHABLE TRACKS IN DIELECTRICS. Katz, Robert; Kobetich, E. J. (Univ. of Nebraska, Lincoln). *Phys. Rev.*, 170: 401-5 (June 10, 1968).

It is proposed that etchable damage is produced in dielectrics by energetic charged particles when a critical dosage of ionization energy is deposited at a critical distance from the ion's path by secondary electrons. Within the critical cylinder, molecular fragments more soluble than the parent molecule are formed. The radius of the critical cylinder is taken to be approximately $20 \text{ \AA}$, as is appropriate to the passage of the etchant along the track and the diffusion of reaction products back to the surface. At the critical radius the dosage approximates doses producing bulk damage under γ irradiation. The proposed criterion predicts the formation or nonformation of etchable tracks in Lexan polycarbonate, cellulose, nitrate, and mica, in agreement with published data. The calculations have been extended to magnetic monopoles to establish criteria for their detection in dielectric track detectors.

A26 CONTRIBUTION TO METHODS FOR STUDY OF THE DETECTION OF HEAVY IONS IN CELLULOSE NITRATE. Tripiet, Jacques; Debeauvais, Monique; Stein, Roland; Ralarosy, Jarno (Centre de Recherches Nucleaires, Strasbourg). *J. Microscop.*, 7: 811-24 (Nov. 1968). (In French).

The use of polymers to record ionizing particles was

investigated employing α particles (2.5 MeV) from ^{210}Po , oxygen ions accelerated in a Van de Graaff machine to 40 MeV, sulfur ions accelerated to 50 MeV, and fission fragments of ^{252}Cf with a mean energy of 90 MeV. Nitrocellulose films were prepared from amyl acetate solutions. It was shown that this material can be used to detect heavy ions. Ionizing particles give rise to damage in the molecular lattice along their range. This damage can be preferentially etched by means of a suitable chemical reagent. In this study oxidizing agents and strong bases were used to attack the degraded zones in the cellulose nitrate film. Thus by controlling the temperature and concentration of NaOH solutions the degree of etching could be varied. Details are given on track development parameters and the chemical etching process. The dependence of the track appearance on the energy loss of the ions was also investigated. For α particles, sulfur and oxygen ion tracks, and ^{252}Cf fission fragments, good discrimination for the different tracks registered in cellulose nitrate was obtained.

A27 THE RANGE OF CHARGED PARTICLES, SUCH AS FISSION PRODUCT TRACK, IN SOLIDS AND ITS APPLICATION. Sakanoue, Masanobu, (Kanazawa Univ., Kanazawa, Japan). *Radioisotopes (Tokyo)* 1968, 17(5), 212-29 (Japan).

A28 (COO-1671-17) PARTICLE TRACKS IN CONDENSED MATTER. Katz, Robert; Kobetich, E.J. (Nebraska Univ., Lincoln. Behlen Lab. of Physics). [1968]. 28p. From 2nd L. H. Gray Conference, Cambridge, England.

A proposed theory of track formation attributes observed effects to the spatial deposition of energy by secondary electrons. The theory is compared to experimental observations in a variety of fields, with good results. In contrast, linear measures of the interaction of charged particles with matter (LET, primary excitation, primary ionization, restricted energy loss) are unsuitable parameters through which to describe particle tracks, except in limiting cases, because many detection media are saturable. Energy deposited close to a particle's path often produces a disproportionately small response, because of overkill.

A29 RECORDING OF CHARGED PARTICLES WITH CELLULOSE NITRATE. Abdullaev, Kh.; Pereygin, V. P.; Tretyakova, S. P.; Shadieva, N. Kh. (Joint Inst. for Nuclear Research, Dubna, USSR). *Prib. Tekh. Eksp.*, No. 6, 64-6 (Nov.-Dec. 1968). (In Russian).

A method for recording light charged particles with cellulose nitrate is described. The threshold sensitivity of cellulose nitrate for alpha particles is ≤ 2.2 MeV and the efficiency of recording of such particles is $(90 \pm 7)\%$. The possibilities of using cellulose nitrate to record heavier particles is discussed. The effect of prolonged storage is also examined.

A30 A STUDY OF CHARGED-PARTICLE TRACKS IN CELLULOSE NITRATE. Benton, Eugene Vladimir. Stanford, Calif., Stanford Univ., 1968. 245 p. Thesis.

Both experimental and theoretical contributions are presented on the topic of dielectric charged particle track detectors. Cellulose nitrate was the principal track recording material. The study covers four areas: the chemical etch development of tracks; track registration criteria; range-energy calculations and comparisons with the etched track lengths; and charged particle detection.

A31 USNRDL-TR-68-14. A STUDY OF CHARGED PARTICLE TRACKS IN CELLULOSE NITRATE. Eugene V. Benton. Naval Radiological Defense Lab San Francisco, Calif. 22 Jan 68, 251 p.

A32 EVALUATION OF THE SPATIAL PARAMETERS K AND α IN EQUATIONS FOR FISSION TRACK URANIUM ANALYSIS. Kleeman, J. D.; Lovering, J. F. (Australian National Univ., Canberra). *Ref. J17.* (1969). pp III.100-113.

The equations describing fission track densities registered in solid state detectors contain some spatial parameters whose values are not well known. The product of K , a geometric factor approximately equal to the range of fission fragments in a solid, and α , the etching efficiency, is determined by simultaneously producing fission tracks from a glass of known uranium content, and monitoring the thermal neutron dose using gold foil. For tracks recorded in Lexan plastic and produced by aluminosilicate glass the value of this product is $8.1 (\pm 13\%) \cdot 10^{-4}$ cm, and for tracks etched in the glass matrix itself it is $3.7 (\pm 8\%) (\pm 8\%) \cdot 10^{-4}$ cm. This value is compared with analogous values calculated from other published data, and by speculating on the value of α for Lexan plastic, an estimate of K is made.

A33 LATENT TRACK FORMATION IN ORGANIC NUCLEAR CHARGED PARTICLE TRACK DETECTORS. Benton, E. V. (Naval Radiological Defense Lab., San Francisco). *Ref. J17.* pp II. 2-27. (1969)

The interaction of radiations with a polymer and subsequent events can be chronologically divided into three periods: energy absorption establishment of thermal equilibrium, and the establishment of chemical equilibrium. The ability to predict which particles will produce latent (etchable) tracks in a given polymeric system is a basic requirement to the practical utilization of the detectors. The parameters which influence track etching can be separated into five broad categories: the material parameters, the particle parameters, the irradiation environmental parameter, the pre-etch storage parameters, and the etching parameters. All of them are briefly reviewed.

A34 STUDY OF THE TRACK REGISTRATION IN THE REGION OF THE CRITICAL ENERGY.

Beaujean, R.; Meyerbroeker, H.; Enge, W. (Univ., Kiel). Ref. J17. pp II. 119-26. (1969).

A latent track in a plastic detector can be etched to a visible track if the ratio of the track etching rate v_t to the bulk etching rate v_b is greater than 1. The etching rate in a specific material for a given particle depends on the particle's energy. For a given particle the critical energy E_c is defined by $v_t(E_c) = v_b$. The track etching rate approaches the bulk etching rate near the critical energy in an asymptotic manner. The critical energy of cellulose nitrate was determined by using vertical incident alpha particles. The relation of the track diameter, the etching time and the energy of the particle can be calculated using the track and the bulk etching rate. In the region $E \geq 3$ MeV the curve $v_t(E)$ was unknown. For this calculation $v_t(E)$ was set to be $v_t = v_b$ for $E \geq 5$ MeV and as E decreases to 3 MeV $v_t(E)$ increases to $v_t(3 \text{ MeV}) = 2v_b$. Comparing the measured and the calculated curves the critical energy of alpha particles in cellulose nitrate was found to be higher than 5 MeV. The calculation predicts that the curves of track diameters as function of the etching time using the energy as parameter are parallel to each other as E increases beyond E_c . The measured curves are not parallel up to 6 or 7 MeV. The function $v_t(E)$ can be obtained by fitting the calculated curves to the measurements.

A35 FORMATION OF THE PARTICLE TRACKS.

Katz, Robert; Kobetich, E. J. (Univ. of Nebraska, Lincoln). Ref. J17. pp II. 28-45. (1969).

The formation of particle tracks, and such phenomena as the detection of charged particles and the damage produced by charged particles, are intimately related to the spatial distribution of ionization energy deposited by delta rays. Changes in the spectrum of

delta rays with the velocity of the primary particle imply that linear measures of the interaction of the primary particle with the medium, such as specific energy loss, or primary ionization, are unsatisfactory measures of effects produced in the medium, for they contain no knowledge of the spatial deposition of the lost energy.

A36 SOME RECENT ADVANCES IN PLASTIC DETECTORS. Enge, W. (Univ., Kiel); Momo, L. R.; Filz, R. C. Ref. J17. pp II. 108-13. (1969).

Some of the more interesting applications of plastic detectors involve nuclei of low Z , for which cellulose nitrate is particularly suitable. Heretofore, its use has been limited by the nonuniformity of commercially available sheet. This problem was overcome by the addition of certain metal-organic compounds and a casting solvent effect on sensitivity was obtained. By this means, an adjustment of sensitivity to a preferred range of Z is possible, and it now seems feasible to make a reliable discrimination between ^9Be and ^{10}Be . This difficult measurement can be greatly facilitated by use of the Nomarski system of differential interference microscopy.

A37 CHARGED PARTICLE DISCRIMINATION BY TRACK MEASUREMENT. Magdalena, E. (Univ., Clermont-Ferrand, France). Ref. J17. pp IV. 73-80. (In French)

Different tracks made by different particles in two identical samples developed in the same conditions of time, concentration, and temperature, were observed. The aim of this study was the control of the validity of the delta electron theory.

A38 TRACK FORMATION MECHANISM IN POLYMERS. Monnin, M. (Univ., Clermont-Ferrand, France). Ref. J17. pp II. 73-82. (In French). (1969).

The chemical changes produced by the irradiation of polymers result from ionization and electron excitation. The energy dissipated by the particle along its trajectory was determined. Two processes are involved: direct action of the particle leading to excitation and ionization, and the action of the secondary electrons produced.

A39 STUDY OF MUSCOVITE MICA IRRADIATED BY ARGON IONS, BY X RAY SCATTERING AT SMALL ANGLES. Lambert, M. (Paris Univ., Orsay, France); Levelut, A. M.; Maurette, M.; Heckman, H. Ref. J17. pp I. 41-58. (1969) (In French).

X ray scattering measurements showed that in mica high energy argon ions produce point defects and large

perturbed regions which play an important part in track formation by chemical etching. The electron density of these regions is similar to that of non-irradiated mica. They consist of a large number of defects grouped in a small region and are produced only when the particle energy loss per unit length is sufficiently high. An increase of temperature changes completely the state of the sample.

A40 DISCRIMINATION OF HEAVY PARTICLES IN PHOSPHATE GLASS AND MUSCOVITE MICA.

Perelygin, V. P.; Tretyakova, S. P.; Shadieva, N. H.; Cieslak, E. (Joint Inst. for Nuclear Research, Dubna, USSR). Ref. J17 pp I. 28-40 (1969)

Methods of selective annealing and weak etching for the discrimination of charged particle tracks in phosphate glass and mica were developed. Phosphate glass and mica were used to study the fission of the uranium nucleus, induced by ^{16}O , ^{20}Ne , ^{40}Ar , ^{40}Ca ions, and the formation of the compound nucleus in the reaction of ^{20}Ne with Ni nuclei.

A41 DIAMETER OF ETCHED FISSION FRAGMENT TRACKS IN SOLID STATE NUCLEAR TRACK DETECTORS AS A FUNCTION OF THE PARTICLE ENERGY. Fiedler, G.; Hoepfner, U. (Univ., Giessen, Ger.). Ref. J17 pp IV. 35-9 (1969)

Glass and several plastic materials have been vertically irradiated by fission fragments of known mass and energy. A correlation between fragment energy and the diameters of the etched fragment tracks is given. For sufficiently long etching times the method is well capable of an energy resolution of 3 to 5 MeV. A weak mass dependence of this effect exists. To test the method, a ^{252}Cf -fission fragment energy distribution has been measured which is in good agreement with corresponding solid state surface barrier detector data.

A42 INTERESTING TRACK DETECTOR: POLY-VINYL CHLORIDES. Monnin, M.; Sanzelle, S. (Univ., Clermont-Ferrand, France). Ref. J17. pp II. 127-31. (1969) (In French).

Polyvinyl chloride is a very sensitive polymer since it registers alpha particle tracks. Its great advantage is to separate very clearly, in time, different ion tracks.

A43 STABILITY OF LATENT TRACKS IN MICA. Widell, C.-O. (Aktiebolaget Atomenergi, Studsvik, Sweden). Ref. J17. pp I.24-7. (1969)

Latent tracks of fission fragments in muscovite mica are very stable. In order to investigate this stability, irradiated mica foils were placed for different lengths

of time in different temperatures. It was found that the critical time for the disappearance of the tracks could be given by the expression: $t = 10^{-15} \exp(2.8/kT)$ where k is the Boltzmann constant and T is the absolute temperature.

A44 COMMENT ON EXISTING PHYSICAL CRITERIA FOR ION TRACK REGISTRATION IN POLYMERS. Paretzke, H. G.; Burger, G. (Gesellschaft fuer Strahlenforschung mbH, Neuherberg). Ref. J17 pp II. 83-94 (1969)

It has been shown that there are severe discrepancies in the present delta ray criteria and the primary ionization criterion. Although it is possible, within the scope of all criteria, to fit most of the known experimental data, many of their physical assumptions are not satisfying and have to be revised in several points.

A45 MEASUREMENT OF CONE LENGTH AND RANGE IN ETCHED PLASTICS. O'Ceallaigh, C.; Daly, J. (Dublin Inst. for Advanced Studies). Ref. J17 pp IV. 81-91 (1969)

Two methods are presented and described for measuring the apparent depth of a cone-tip below the extinction point for the surface corresponding to the base of the cone.

A46 STUDY OF THE TRACK STRUCTURE OF HEAVY IONS IN CELLULOSE NITRATE BY ELECTRON MICROSCOPY. Tripier, J.; Debeauvais, M.; Stein, R.; Ralarosy, J.; Remy, G. (CNRS, Strasbourg). Ref. J17 pp III. 14-23. (1969) (In French).

Different heavy ion tracks were investigated with an electron microscope. The variation of the track diameter with the time, the concentration, and the energy loss was studied.

A47 EFFECTS OF O_2 , SO_2 , NO , AND N_2O ON TRACK REGISTRATION. Chave, A.; Monnin, M. (Univ., Clermont-Ferrand, France). Ref. J17 pp II. 102-7. (1969) (In French).

The effect of gases on track registration in polymers is important. Oxygen impedes cross-linking and favours degradation. The reactions in the presence of oxygen are reversible, and irreversible in the presence of sulfurous acid.

A48 (ORNL-4351) RADIATION CHEMICAL STUDY OF PLASTICS FOR CHARGED PARTICLE TRACK REGISTRATION. Pt. A. RADIATION CHEMISTRY OF CELLULOSIC CHARGED PARTICLE

TRACK DETECTORS. Pt. B. POSSIBLE METHODS OF ALPHA PARTICLE TRACK REGISTRATION WITH POLYTETRAFLUOROETHYLENE.

Sears, D. R.; Bopp, C. D. (Oak Ridge National Lab., Tenn.). July 1969. 35 p.

A radiation chemical investigation was performed on cellulose derivatives used for charged particle track registration. Studies of the radioinduced decomposition of cellulose and cellulose acetate, triacetate, and dinitrate during exposure to low LET gamma photons are reported. Among cellulosic films, pure viscose-regenerated clear cellulose film displayed the most extensive radiation damage, with the formation of CO₂ and carbonyl groups. The material may have promise as a particle track recorder. Gaseous products of γ radiolysis of bulk celluloses were identified as a function of ester groups, oxygen overpressure, presence of scavenger compound, and other parameters. A decomposition mechanism is proposed involving dehydrogenation of hydroxyl groups in cellulose and deacetylation in cellulose acetates. Some additional experiments that may help to identify processes occurring in actual latent track formation are suggested. Possible methods of registration of alpha particle tracks with polytetrafluoroethylene were studied. Schemes considered included chemical etching, decoration by crystallization, etching by vacuum volatilization, decoration by graft polymerization, and decoration by bubble formation. Only the first two schemes were attempted. A search for a suitable etchant for enlarging the tracks was unsuccessful. The lack of reproducibility obtained in attempts to decorate the tracks by crystalline growth makes this method unpromising.

A49 RANGE-ENERGY RELATIONS OF LOW-VELOCITY HEAVY IONS IN PLASTIC VISUAL DETECTORS. SPECIAL STUDY OF FISSION FRAGMENTS. Ralarosy, J.; Schmitt, R.; Mosinski, G.; Tripier, J.; Debeauvais, M.; Stein, R.; Remy, G. (Centre de Recherches Nucleaires, Strasbourg). *J. Phys. (Paris)*, 30: 1-13 (Jan. 1969). (In French).

To study the kinematic and mechanism of fission at high energy, two kinds of plastic visual detectors, cellulose nitrate and makrofol, were used. These studies require the knowledge of analytical relations between the particle momentum (or energy) and the particle range in the plastic. First, theoretical relations were determined and experimental verification made. A calculation method is presented giving particle range versus velocity in plastic detectors. These relations

and the knowledge of experimental α -particle range lead to momentum range relations for ions heavier than α particles. A special calculation concerning fission fragments leads to simple mathematical relations; all necessary experimental fits were made.

A50 RESTRICTED ENERGY LOSS CRITERION FOR REGISTRATION OF CHARGED PARTICLES IN PLASTICS. Benton, E. V.; Nix, W.D. (Naval Radiological Defense Lab.; San Francisco). *Nucl. Instrum. Methods*, 67: 343-7 (Jan. 15, 1969).

It was found that the restricted energy loss rate of charged particles can be used as a convenient criterion to predict the formation or non-formation of etchable tracks in plastics. The criterion allows sensitivity assignments, in absolute units, to each of the polymeric detectors. An experimentally determined parameter indicates that only electron energy transfer collisions of about 1.0 keV and less are important in track formation. The criterion is consistent with the known experimental observations of charged particle registration in plastics. It is proposed that latent (etchable) tracks are formed when the energy density (dose) in the immediate vicinity of the particle trajectory exceeds a critical value that is characteristic of the particular detecting material and the specific etching conditions.

A51 (NASA-CR-118657; SPP-20). COMMENTS OF A PAPER ON ELASTICALLY SCATTERED RECOIL NUCLEI IN SOLID STATE DETECTORS. Maurette, M.; Walker, R. M. (Washington Univ., St. Louis, Mo. Lab. for Space Physics). May 1969. 16 p.

The use of elastically scattered recoil nuclei to measure the registration characteristics of solid state track detectors is discussed. To support this, pictures of tracks in mica were attributed to elastically scattered K and Fe nuclei produced by an irradiation with 32 MeV ¹⁶O ions. It is shown that the measured characteristics of the tracks do not match the theoretically predicted features for elastic processes and that the experimental features are consistent with those predicted for inelastic (mostly compound nucleus) reactions. The possibility that they are produced by contaminant ions present in the incident beam is not ruled out.

A52 EVALUATION OF ETCHED SOLID-STATE TRACK DETECTORS BY ALPHA-PARTICLE ABSORPTION MEASUREMENTS. Doerschel, B. (Technische Univ., Dresden). *Kernenergie*; 12: 303-4 (Sept. 1969). (In German).

The measurement of the α absorption in mica foils

is a new method for the evaluation of solid-state track detectors. The number of α particles, which penetrate the material at the point of etching, is a direct measurement of the track density. The experimental studies made with ^{235}U and the results obtained are described. The results show that the α counting is a linear function of the track density.

A53 HEAVY PARTICLE RANGE-ENERGY RELATIONS FOR DIELECTRIC NUCLEAR TRACK DETECTORS. Benton, E. V.; Henke, R. P. (Naval Radiological Defense Lab.; San Francisco). Nucl. Instrum. Methods, 67: 87-92 (Jan. 1, 1969).

A method for the computation of multicharged particle range-energy and energy loss relations for dielectric nuclear track detectors is described. It is useful in the energy interval 0.1-1200 MeV/nucleon for heavy ions in materials of known atomic composition. The method extends the generalized expressions of Barkas and Berger to lower energies by using the range data of Whaling and the range extensions for emulsion of Heckman, et al., and Henke and Benton. The range calculations have been checked experimentally with the use of lithium drifted solid state detectors from 2 to 10 MeV/nucleon. It is also shown that the corrected length of etched tracks in dielectric track detectors can be used as an accurate measure of the stopping particle's energy.

A54 USE OF CELLULOSE NITRATE PLASTIC IN THE STUDY OF BLOCKING IN SINGLE CRYSTALS. Marsden, D. A.; Johansson, N. G. E.; Bellavance, G. R. (Atomic Energy of Canada Ltd., Chalk River, Ont.) Nucl. Instrum. Methods, 70: 291-7 (May 1, 1969).

Cellulose nitrate plastic has been used to record permanent track patterns of alpha particles back-scattered from various single crystals. These patterns show the orientation of the crystal surface and give quantitative information about the blocking phenomenon. The technique is shown to be useful in aligning single crystals (particularly in the "double alignment" type of experiment), and for the examination of crystal surfaces. This technique also holds promise for the study of the (p, α) reaction in aluminium single crystals, where the alpha particle yield is difficult to observe in the presence of a preponderance of scattered protons.

A55 DIAMETER OF ETCHED FISSION FRAGMENT TRACKS IN SOLID STATE NUCLEAR TRACK DETECTORS AS A FUNCTION OF THE

PARTICLE ENERGY. Hoepfner, U.; Konecny, E.; Fiedler, G. (Univ., Giessen, Ger.). Nucl. Instrum. Methods, 74: 285-90 (1969).

Glass and several plastic materials have been irradiated orthogonally with respect to their surfaces by ^{235}U fission fragments of known mass and energy. A correlation between fragment energy and the diameters of the etched fragment tracks is given. For sufficiently long etching times the method is well capable of an energy resolution of about 3 to 5 MeV. A weak mass dependence of this effect is existing. To test the method a ^{252}Cf fission fragment energy distribution has been measured which is in good agreement with corresponding solid-state surface-barrier detector data.

A56 ANNEALING OF TRACKS FROM FRAGMENTS OF FISSION NUCLEI IN SOLIDS. Geguzin, Ya. E.; Vorob'eva, I. V. (Kharkov State Univ.) Ukr. Fiz. Zh., 14: 1499-1505 (Sept. 1969). (In Russian).

A two-zone model of structure of tracks from fragments of heavy charged particles is given. Estimations are given of the track curing kinetics in supposition that the viscous flow or directed self-diffusion is the determining mechanism of mass transfer. The estimations presented are compared with the results of experiments on curing tracks in glasses and tectites. Such comparison testifies to the two-zone model of the track.

A57 SOLID DETECTORS FOR NUCLEAR PARTICLES. Blanc, D. Science, Progress Decouverte (F) Vol. 3420, pp. 21-31 (April, 1970). (In French).

A58 STUDY OF TRACK REGISTRATION IN THE REGION OF THE CRITICAL ENERGY. Beaujean, R.; Meyerbroeker, H.; Enge, W. (Institut fuer Reine und Angewandte Kernphysik, Kiel). Radiat. Eff.; 5: 47-8 (Aug. 1970).

A latent track in a plastic detector can be etched to a visible track, if the ratio of the track etching rate v_t to the bulk etching rate v_b is greater than 1. The etching rate in a specific material for a given particle depends on the particle's energy. For a given particle, the critical energy E_c is defined by $v_t(E_c) = v_b$. The track etching rate approaches the bulk etching rate near the critical energy in an asymptotic manner. The critical energy of cellulose nitrate was determined by using vertical incident alpha particles. The relation of the track diameter, the etching time, and the energy of the particle can be calculated using the track and the bulk etching rate. In the region $E \geq 3 \text{ MeV}$, the

curve $v_t(E)$ was unknown. For this calculation $v_t(E)$ was set to be $v_t = v_b$ for $E \geq 5$ MeV and as E decreases to 3 MeV, $v_t(E)$ increases to $v_t(3 \text{ MeV}) = 2v_b$. Comparing the measured and the calculated curves, the critical energy of α particles in cellulose nitrate was found to be higher than 5 MeV. The calculation predicts that the curves of track diameters as function of the etching time using the energy as parameter are parallel to each other as E increases beyond E_c . The measured curves are not parallel up to 6-7 MeV. The function $v_t(E)$ can be obtained by fitting the calculated curves to the measurements.

A59 (ORNL-TM-2826) MECHANISMS AND APPLICATIONS OF NUCLEAR TRACK REGISTRATION IN POLYMERS. Johnson, D. R.; Becker, Klaus (Oak Ridge National Lab., Tenn.). June 1970. 47 p.

The radiolytic damage mechanism for latent nuclear track formation in polymers has been corroborated using a stable free radical, DPPH, as a radical scavenging additive to sensitive cellulose nitrate and cellulose acetate foils. The G-value for free radical production has been measured as a function of linear energy transfer, and environmental effects on the track registration efficiency have been studied. For the automatic counting of etched alpha particle tracks and the imaging of their spatial distribution, a technique based on the local evaporation of a thin metal layer with electrical discharges occurring through perforations in cellulose nitrate foils has been developed. This method has been used for the evaluation of a newly developed radon progeny personnel dosimeter for uranium miners; for the ultrasensitive determination of quantity and distribution of fissile materials in biological and other samples (plutonium in bone, uranium in water and air) by neutron-induced autoradiography; and for increasing the sensitivity in quantitative alpha-autoradiography.

A60 MECHANISM AND APPLICATIONS OF NUCLEAR TRACK FORMATION IN POLYMERS. Johnson, Dennis Ray. Lawrence, Kan.; Univ. of Kansas (1970). 86p. University Microfilms Order No. 71-13, 321. Thesis.

A radiolytic damage mechanism for nuclear track formation in polymers was corroborated by studies that utilized a radical scavenger technique. The work was considerably simplified, both experimentally and statistically, by the successful adaptation of a spark counting technique for automatically counting etched alpha particle tracks in thin polymer films. In addition, a combination of the track etching and spark counting techniques resulted in several new dosimetric and

imaging applications of charged particle detection that included (1) a highly sensitive dosimeter for radon progeny in the uranium mining industry. (2) an improved method for the ultrasensitive determination of the quantity and distribution of fissile elements in liquids and solids; (3) a new, more sensitive method of alpha particle autoradiography, which permits automatic track counting and provides replicas as well as direct images; and (4) a new method of personnel neutron dosimetry, which utilizes automatic readout.

A61 SPATIAL DISTRIBUTION OF DEPOSITED ENERGY ALONG THE PATH OF HEAVY CHARGED PARTICLES. H. Paretzke and G. Burger. EURATOM Proc. of the 2d Symp. on Microdosimetry p.615-630. (Jan. 1970).

A62 SOME STUDIES ON THE CHEMICAL DAMAGE MECHANISM ALONG CHARGED-PARTICLE TRACKS IN POLYMERS. Boyett, R. H.; Johnson, D. R.; Becker, K. (Oak Ridge National Lab.; Tenn.). Radiat. Res. 42: 1-12 (Apr. 1970).

A number of experimental studies were carried out to obtain more information on the chemical damage mechanism along the tracks of charged particles of relatively low LET observed in the more sensitive organic plastics. For example, G-values for free radical production were measured using a radical scavenging technique; infrared spectroscopy and gas chromatography were used for qualitative and quantitative analysis of low molecular weight end products of radiolysis as a function of several parameters, and the stability of latent alpha particle tracks was measured at elevated temperatures. Effects of different agents (influence of oxygen partial pressure and humidity during exposure, and ultraviolet pre- and postirradiation treatment) on the track registration threshold and/or etching kinetics of cellulose nitrate and acetate were also examined. The possible interpretation of the results is discussed.

A63 STUDY OF THE STRUCTURE OF HEAVY-ION TRACKS IN NITROCELLULOSE BY ELECTRON MICROSCOPY. Tripiier, J.; Debeauvais, M.; Stein, R.; Ralarosy, J.; Remy, G. (Laboratoire de Physique Corpusculaire, Strasbourg-Cronenburg). Radiat. Eff. 3: 221-6 (June, 1970). (In French).

Electron microscope observations of heavy ion tracks registered in thin nitrocellulose foils and visualized by chemical etching lead to the following conclusions: (1) The revealing time of the tracks is a decreasing function of the energy loss (dE/dx) and

the development velocity is an increasing function of (dE/dx) . (2) The track structure depends on the variation of dE/dx along the ion path. (3) The etching rate inherent to the development seems to increase disparities in the initial structure. To perform a more careful study, thin foils were irradiated with sulphur ions at energies between 0 and 80 MeV. The diameter change was plotted against the energy loss (dE/dx) of the ion, the chemical reagent concentration, and the development time. In this way, an empirical law depending on those different parameters has been deduced.

A64 MEASUREMENT OF CONE LENGTH AND RANGE IN ETCHED PLASTICS. O'Ceallaigh, C.; Daly, J. (Inst. for Advanced Studies, Dublin). *Radiat. Eff.*; 5: 135-8 (Aug. 1970).

The measurement of track parameters in lexan sheets involves the location of the apparent top surface of the etched plastic, the location of the tips of the entrance and exit cones, and the location of the apparent bottom surface using a microscope. The apparent depth of a cone-tip below the extinction point for the surface may be estimated either with the cone-base uppermost, or the sheet inverted. The two ways differ by about 2 μ m, and possible causes of the discrepancy are examined. It is pointed out that thick supporting plates between the condenser and the sample should be avoided, and that the breath of the observer can produce movements of the lexan sheet.

A65 (COO-1671-28) UNIFIED TRACK THEORY. Katz, Robert (Nebraska Univ., Lincoln. Behlen Lab. of Physics). (1970).

From 7th International Conference on Corpuscular Photography and Visual Solid Detectors, Barcelona, Spain.

A theory for particle track formation in emulsion and other physical and biological media is discussed. It is attempted to couple the dose-response function of a material to gamma rays with the spatial distribution of dose from secondary electrons to yield the spatial distribution of response about the path of a charged particle. Measured and calculated data are presented for particle track formation in emulsion etchable track formation in dielectrics, the response of scintillation counters to heavy ions, and the inactivation of dry enzymes and viruses and cells by heavy ions.

A66 LATENT TRACK FORMATION IN ORGANIC NUCLEAR CHARGED PARTICLE TRACK DETECTORS. Benton, E. V. (Univ. of San Francisco). *Radiat. Eff.*; 2: 273-80 (Mar. 1970).

In recent years, in a number of laboratories throughout the world, a considerable amount of effort has gone into the development and the understanding of organic nuclear charged-particle track detectors. Even in their developmental stage, these detectors have found numerous applications in several scientific fields. A brief résumé is presented of some of the most important recent developments in this field. The scope is limited to the pre-etching phenomena; etching and post-etching treatments are covered by Medveckzy.

A67 MECHANISM OF TRACK FORMATION IN POLYMERS. Monnin, M. (Laboratoire de Physique Nucleaire, Clermont-Ferrand, France). *Radiat. Eff.*; 5: 69-73 (Aug. 1970). (In French).

The distribution of energy deposited around the trajectory of a heavy ion in a solid-state organic polymer is calculated. First, one calculates the energy deposited by secondary electrons, then the distribution of energy released directly by the incident particle. These distributions allow prediction of the maximal energy of recorded ions according to the fact that a minimal dose is required to induce sufficient damage.

A68 POLYVINYL CHLORIDE: AN INTERESTING TRACK DETECTOR. Monnin, M.; Sanzelle, S. (Univ., Clermont-Ferrand, France). *Radiat. Eff.*; 5: 125-8 (Aug. 1970). (In French).

It is shown that polyvinyl chloride is a polymer of sensitivity comparable to that of cellulose nitrate. In this polymer, the time when tracks appear depends critically upon ion energy and permits good discrimination.

A69 SOLID-STATE PRECIPITATION DETECTORS FOR NUCLEAR TRACKS: A DEVICE FOR GROWING LARGE SERIES OF DOPED MONOCRYSTALLINE AgCl SHEETS. Zenggeuel, F.; Hasse, G.; Henig, G.; Schopper, E.; Schott, J.-A. (Univ., Frankfurt am Main). *Z. Angew. Phys.*; 30: 316-20 (1970).

A device is described for growing series of sheets of AgCl crystals on quartz-glass plates in a definite gas atmosphere. The device allows the simultaneous production of a series of crystal sheets of various doping concentrations and of various doping components.

The single sheet is 25 X 15 mm² size and consists of several (up to ~8) monocrystalline areas, which originate from a polycrystal of about 10⁴ crystallites. Details of the procedure are given and micrographs of grown crystals are shown.

A70 EFFECT OF CHEMICAL FACTORS ON THE SENSITIVITY OF POLYMERIC DETECTORS. Veprik, Ya. M.; Pereygin, V. P.; Romanenko, V. P.; Tret'yakova, S. P.; Vinogradov, Yu. A. (Joint Inst. for Nuclear Research, Dubna, USSR). *Instrum. Exp. Tech. (USSR)* (Engl. Transl.); No. 4, 1015-17 (July-Aug. 1970).

Translated from *Prib. Tekh. Eksp.*: No. 4, 51-3 (July-Aug. 1970).

The effect of chemical factors on the change of sensitivity of nitrocellulose detectors to light charged particles was investigated. It was found that an increase of the content of camphor in nitrocellulose leads to an increase of detector sensitivity. Alpha-particles with an energy to 4.5 MeV were recorded in a detector made from a solution of 7% nitrocellulose and 2.5% camphor.

A71 DETERMINATION OF SENSITIVITY OF VARIOUS PLASTIC DETECTORS. Beaujean, R.; Enge, W.; Meyerbroeker, H. (Univ., Kiel). *Acta Phys. Acad. Sci. Hung.*; 29: Suppl. 4, 387-90 (1970).

Two methods have been developed to determine the sensitivity of various plastic materials for track registration. The sensitivity of a given material is defined as the critical energy up to which a given particle can be recorded. In plastic sheets which record alpha particles the sensitivity and the track etching rate in the region of the critical energy can be obtained using the track diameter curves for vertical incident alpha particles. Another method makes it possible to study less sensitive materials (e.g., polycarbonate sheets), too. After exposing the material to a high proton flux, pits can be etched which are probably produced by recoil nuclei. The number of these pits depends on the sensitivity of the material and the energy and flux of the protons.

A72 (IFA-PN-23) HEAVY ION REGISTRATION IN SOLID TRACK DETECTORS. Hasegawa, D. (Institutul de Fizica Atomica, Bucharest (Romania)). (Sept., 1971). 7 p.

A study is performed for pointing out the role of the primary and secondary ionization in the track formation mechanism in plastic detectors. The thin-down length was measured for ¹²C, ²²Ne, ³¹P, and

⁴⁰Ar and it was found to be inversely proportional to ²Z. This dependence is a function of the etching parameters. It is concluded that both of the two ionization orders contribute to track formation, their contributions being pointed out by a suitable choice of the etching conditions.

A73 NUCLEAR TRACKS IN SYNTHETICS. Paretzke, H. G. GSF-Bericht S138, May, 1971.

A74 KINETICS OF PHASE DECOMPOSITION AND ITS APPLICATION TO NUCLEAR PARTICLE DETECTION. Mahoney, Richard Warner. Washington, D. C.; Catholic Univ. of America (1971). 166 p. University Microfilms Order No. 72-3746. Thesis.

It was shown that the dramatic change in isothermal viscosity in a sodium borosilicate glass below the co-existence temperature can be explained on the basis of growth of the average microstructure size, $\bar{r}$. The environmental relaxation model of Macedo and Simmons best predicted the observed viscosity behavior when a value of 100 Å was used for the radius of the environment affecting a particular molecule. Comparison of the time dependence of the growth of $\bar{r}$ with that predicted by the theory of Lifshitz and Slyozov and of Wagner indicated that in the range $200 \text{ Å} \leq \bar{r} \leq 1000 \text{ Å}$, the growth of $\bar{r}$ is through diffusion-controlled ripening. Comparison of the activation energy for growth from the size measurements ($97 \pm 6 \text{ kcal/mole}$) with that for diffusion from the time shifts of the viscosity isotherms (103 kcal/mole) led to the conclusion that this activation energy corresponds to interdiffusion of SiO₂ through the silicate-poor matrix. The glass has an interconnected structure, and the viscosity measurements are essentially a measurement of the viscosity of the viscous phase. The average activation energy for interdiffusion for the viscous phase, computed from the viscosity shifts of the viscosity isotherms, was 137 kcal/mole, almost the value for self-diffusion in pure SiO₂ (140 kcal/mole). Thus it is concluded that this activation energy refers to diffusion of SiO₂ in the silicate-rich phase. An attempt was made to verify the proposition that phase decomposition preferentially takes place around radiation damage sites in glass. Thus heat treatment can be used to enhance radiation damage sites, making them large enough for electron microscope observation. A sodium silicate glass was used with two sources. Structure attributed to radiation appeared only on the irradiated surface of a glass sample after heat treatment. No such structure appeared regardless of thermal history if the glass was not irradiated. The similarity of radiation damage

structure from ^{252}Cf (which emits heavy fission fragments and alpha particles) and from ^{241}Am (which emits only alpha particles) led to the conclusion that alpha particles were being detected.

A75 GEOMETRY OF TRACKS IN DIELECTRIC NUCLEAR TRACK DETECTORS. Henke, R. P.; Benton, E. V. (Univ. of California, Berkeley). *Nucl. Instrum. Methods*; 97: No. 3, 483-9 (1971).

Dielectric nuclear track detectors are now being utilized in a variety of research applications involving registration of heavily ionizing charged particles. Many situations call for the identification of particle charge Z , energy E , and possibly the mass M . In these cases, a detailed knowledge of the etched track geometry is necessary to make possible computation of the relevant track parameters from the measured track features. Geometry of etched particle tracks can be quite complex. Some of the most relevant aspects of track geometry are derived and discussed in considerable detail. Two basic assumptions are made: the detector is isotropic and homogeneous, and the particle ionization rate remains constant over the etched portion of the track. Track specification and measurement parameters are developed for a variety of different situations.

A76 EXPERIMENTAL AND ANALYTIC STUDY OF THE RELATIONS BETWEEN THE ENERGY AND THE TRACK LENGTHS PRODUCED BY CHARGED PARTICLES IN A PLASTIC DETECTOR. Ralarosy, J.; Tripier, J.; Stein, R.; Remy, G.; Debeauvais, M. (CNRS, Strasbourg). *J. Phys. (Paris)*; 32: No. 10, 733-42 (Oct. 1971). (In French).

The detection threshold and the length of the visible tracks produced by heavy ions in Makrofol were studied. The physico-chemical etching conditions were maintained constant, and relations were determined between the chemical etching time and the specific critical energy loss. Empirical analytic expressions are given for the threshold and the visible range as a function of the specific energy loss of the incident ions for different etching times.

A77 (FRNC-TH-125) CHARACTERISTICS OF GLASS NUCLEAR TRACK DETECTORS. APPLICATION TO THE STUDY OF INDUCED FISSION OF MEAN MASS NUCLEI. Lecerf, Marc (Paris Univ., Orsay (France)). (1971). 57p. (In French). Thesis.

An accurate calibration of glass detectors revealed their regions of sensitivity. They were subsequently used to study fission fragments induced by 167-MeV α particles incident on thin targets with Z values be-

tween 29 and 79. The number of tracks produced with Au, In, Mo and Cu were counted and the total fission cross sections were determined. The experimental fissilities thus calculated are larger than those predicted by the statistical theory of de-excitation for these nuclei. Measurements on the diameters of the tracks led to total fission energies, which are in good agreement with values calculated from the liquid drop model. The angular distributions allowed the effective moment of inertia of Au and In to be calculated at the saddle point. The values obtained confirm the diminishing J_0/J_{eff} ratio for values of the fissionability parameter less than 0.67.

A78 MODELS OF TRACK CREATION OF CHARGED PARTICLES TRANSVERSING DIELECTRIC DETECTORS. Linscheid, Anna (Katedra Fizyki Wyzszej Szkoły Rolniczej, Krakow). *Postepy Fiz.*; 22: No. 5, 511-20 (1971). (In Polish).

The described models are the attempt at understanding the mechanism of creating tracks by massive charged particles in dielectric detectors. Fleisher and Price state that the massive charged particle passing through an insulating material causes a region of damage to occur. Their "ion explosion spike" model assumes that in this region the positively charged ions eject themselves into the surrounding lattice by mutual repulsion. Katz and Kobetich draw our attention to the fact that the mechanism of track creation can be different at different energies of the registered particle. At energies ~ 0.05 MeV/amu the author suggests that the track results from the interaction of δ -rays with the molecules of the medium. This picture justifies the fact that there exists a critical rate of energy loss $(dE/dx)_{\text{cr}}$ such that particles losing at least this value produce continuous tracks.

A79 RADIAL DISTRIBUTION WIDTH OF VOLUME ENERGY TRANSFER IN 4- TO 25-MeV α -PARTICLE TRACKS IN NaCl MONOCRYSTALS. Vaisburd, D. I.; Vorob'ev, A. A.; Komov, A. I.; Melikyan, L. A. (Tomsk Polytechnical Inst., USSR). *Izv. Akad. Nauk Arm. SSR, Fiz.*; 6: No. 2, 129-34 (1971). (In Russian).

The conditions are found for which the transformation of radiation-induced defects is used for the determination of effective crosswise particle-track dimensions in rigid bodies. The restoration reaction for F_2 -centers is found to be appropriate in a series of α bombardments of NaCl crystals. The experiments on the Tomsk cyclotron for the determination of the effective α -track radii gave the value of $(155 \pm 15) \text{ \AA}$.

The track radius as determined by this technique is shown to be the radial distribution width of volumetric energy transfer in α -particle tracks in NaCl on the 6.10^{19} eV/cm³ level.

A80 EFFICIENCY CALIBRATION OF SOLID STATE NUCLEAR TRACK DETECTORS. Khan, H.A.; Durrani, S. A. (Univ. of Birmingham, Eng.). Nucl. Instrum. Methods; 98: No. 2, 229-36 (1972).

The track registration efficiencies of various glasses, plastics and mica for fission fragments of various average energies and for alpha particles have been calculated on the basis of a series of new experiments in which exposures were made in "2 π " and other geometries. The effects of temperature and ultra-violet light on the registration efficiencies have been studied. Lastly, certain modifications in standard formulae for source-detector geometry, when applied to SSNTD, are proposed.

A81 TRACK LENGTHS OF HEAVY IONS IN MICA. Blak, H.; Kiely, F. M.; Pate, B. D. (Simon Fraser Univ., Burnaby, British Columbia). Nucl. Instrum. Methods; 100: No. 3 403-11 (1972).

The etching conditions under which visible tracks are developed in mica previously irradiated with heavy ions were studied. The registration threshold was found to lie between ion charge $Z = 10$ and $Z = 13$. Track lengths were measured for aluminum, nickel, argon, krypton, and gold ions in the energy range 0 to 1.0 MeV/nucleon. The data were compared with range predictions of Lindhard et al., and are consistent with etching for that part of the ion trajectory within which the stopping power exceeded a critical value of 10.1 MeV/mg/cm². The probability for registration of all ions studied heavier than neon, incident on the mica at 30° to the surface, was found to be indistinguishable from unity. (6 figures, 1 table)

A82 DAMAGE TRACK REGISTRATION RELATED TO THE THERMAL STABILITY OF THE POLYMERS. M. Marchetti, L. Tommasino, E. Casati. Laboratorio di Dosimetria e Standardizzazione, Comitato Nazionale Per L'Energia Nucleare, Centro di Studi Nucleari Della Casaccia, Rome, Italy. July, 1972.

A83 SPECIAL GLASSES AS ENERGY DETECTORS FOR FISSION FRAGMENTS. G. Fiedler and H. Schreck-Kollner (UNIV. Gießen-Germany); Transactions 1972. Annual Meeting of The American Nuclear Society, Vol. 15.

A84 TRACK ETCH REGISTRANTS FOR HIGH-TEMPERATURE APPLICATIONS. H. D. Kosanke (GE-Pleasanton); Transactions 1972 Annual Meeting of The American Nuclear Society, Vol. 15.

A85 FISSION TRACK ETCH KINETICS IN GLASSES. D. Storz (Max Planck Inst., Germany); Transactions 1972 Annual Meeting of The American Nuclear Society, Vol. 15.

A86 RECORDING REACTOR RADIATION WITH ALKALI HALIDE CRYSTALS. I. G. Berzina. Tr. II Koord. Soveshch. Dozim. Bol'shikh Doz 1965. 173-6. (Pub. 1966) (In Russian).

A87 EFFICIENCY OF TRACK DETECTORS FOR FISSION FRAGMENTS. Koroleva, T. V.; Kravtsov, S. N. This paper was summarized in At. Energ. (USSR); 31: No. 1, 52 (July, 1971) as paper No. 507/6039. (In Russian).

The efficiency for detecting fission fragments and neutrons with track detectors was calculated with the anisotropy of the fission process taken into account. The efficiency for detecting fragments is independent of the incident neutron energy for mica, whereas the anisotropy of the fission process in the range 0.5 to 10 MeV increases the efficiency by 10 to 20% relative to an isotropic angular distribution in the case of silicate glass; the isotropic distribution is encountered in fission processes involving thermal neutrons. For quartz glass the increase in efficiency was 4 to 7%. The efficiency for detecting neutrons was calculated; the curve reproduces the dependence of the fission cross section on the neutron energy for mica, but not for silicate and quartz glasses. The ratio of the efficiency for ²³⁵U fragment detection with a silicate glass detector to the efficiency for detection of thermal neutrons was measured; the calculated results agreed with this value. (2 figures)

A88 LATERAL DIMENSIONS OF TRACKS OF PROTONS AND ALPHA PARTICLES IN A CRYSTAL OF NaCl. Vaisburd, D. I.; Melikyan, L. A. (Tomsk Polytechnic Inst., USSR). Izv. Vysch. Ucheb. Zaved.; Fiz.; No. 5, 151-3 (1971). (In Russian).

Effective widths of proton and α -particle tracks were determined by the use of conversion kinetics of radiation defects. Plates of a monocrystal of NaCl were irradiated at room temperature with low-energy protons or α particles that penetrate to a given depth. Electron and hole color centers are formed; calculations are based on the F_1 and F_2 centers. The effective track

radius of a proton was found to be $74 \pm 5 \text{ \AA}$, that for an α particle $155 \pm 15 \text{ \AA}$.

A89 (RT/PROT-(73)17) REGISTRATION CHANGES OF DAMAGE TRACKS IN CELLULOSE DERIVATIVES. Casnati, E.; Marchetti, M.; Tommasino, L. (Comitato Nazionale per l'Energia Nucleare, Rome (Italy)). (June 1973). 17 p.

The registration properties of the organic detectors depend on their morphological and chemical nature, which can be altered by uv and gamma exposures, thermal treatments, etc. The thermal treatment effects on damage track registration properties of the cellulose derivatives were studied. Data are presented to show how by simple thermal treatments it is possible to enhance the sensitivity of cellulose acetobutyrate and cellulose triacetate. When similar thermal treatments are applied to cellulose nitrate foils, they reduce mainly the bulk etching rate of such detectors. All these investigations indicate that the thermal history of these organic detectors represents an important parameter for their track registration characteristics.

A90 (NASA-TM-X-2440) HEAVY-ION PASSIVE DOSIMETRY WITH SILVER HALIDE SINGLE CRYSTALS. Childs, Charles B. (Univ. of North Carolina, Chapel Hill); Parnell, Thomas A. pp. 132-41. (Jan. 1972).

A method of detecting radiation damage tracks due to heavy particles in large single crystals of the silver halides is described. The tracks, when made visible with simple electrical apparatus, appear similar to tracks in emulsions. The properties of the crystals, the technique of printing out the tracks, and evidence concerning the threshold energy for registering particles indicate that this method may find application in heavy ion dosimetry. The method has been found to be sensitive to stopping the nuclei and relativistic M group cosmic rays. Some impurities strongly influence the "decoration" or printout of the tracks, and the effects of these impurities are discussed.

A91 EFFECTIVE CROSS SECTIONS OF PROTON AND ALPHA PARTICLE TRACKS IN IONIC CRYSTALS. Vaisburd, D. I.; Vorob'ev, A. A.; Melikyan, L. A. This paper was summarized in *At. Energ. (USSR)*; 30: No. 6, 538 (June 1971) as paper No. 502/5971. (In Russian).

Effective transverse sizes of proton (1 to 6 MeV) and α particle (4 to 25 MeV) tracks in NaCl monocrystals were determined from the transforma-

tion kinetics of electron color centers. The F_2 -center concentration follows the law $n = N[1 - \exp(-\Omega \nu)]$, where N is the saturation level of regenerated centers, Ω is effective track volume, and ν is instantaneous track concentration. The width of the radial distribution of energy transfer per unit volume is $4.5 \times 10^{19} \text{ eV/cm}^3$. The radius of a proton track is $74 \pm 5 \text{ \AA}$, while an alpha-particle track is $155 \pm 15 \text{ \AA}$.

A92 SOLID STATE DETECTORS FOR NUCLEAR TRACKS WITH ON- AND OFF-SENSITIVITY. Schopper, E.; Henig, G.; Schott, J. U.; Zoergel, R. (Univ., Frankfurt am Main). pp. 2511-15 of 12th International Conference on Cosmic Rays. Vol. 6. Hobart, Australia, International Union of Pure and Applied Physics (1971).

A new concept of trackforming solid state detectors is described. The detector alternatively either records the track of a nuclear particle — i.e. it accumulates tracks of particles for later revealing — or drops the track after the passage of the particle. The unrevealed latent tracks of particles in these detectors are unstable in time, unless they are not explicitly stabilized during the passage of the particle by irradiation with weak visible light. The detectors consist of 200 to 500 micron thick sheets of Cd-doped silver chloride-crystals on quartzglass. The tracks are revealed by irradiation with ultraviolet light. The facility of setting sensitivity thresholds by the doping conditions, and of triggering the recording of tracks on and off, enlarges the application of the visual solid detectors in combination with electronic devices. Examples are given of tracks of heavy ions and of primaries from cosmic radiation.

A93 POSSIBLE MECHANISM OF TRACK RECORDING FROM IONIZING PARTICLES BY CELLULOSE FILMS. Veprik, Ya. M.; Kartuzhanski, A. L.; Marenniy, A. M.; Popov, V. I. Zh. Nauch. Prikl. Fotogr. Kinetografi.; 17: No. 5, 349-53 (1972). (In Russian).

The structure of the cellulose molecule and of its nitrate and acetate derivatives is discussed with particular reference to breaking of various bonds by particles of different energies (5 to 15 MeV). The sensitivity of polymeric detectors in the form of cellulose films is related to the ether linkages between the monomeric units and the replacement of OH groups by nitro groups and to a lesser degree, by acetate groups. The ability of some types of ruptured bonds to recombine, in contrast to other types of bonds which lead to an irreversible disjunction of the polymer, is examined.

A94 PROGRESS IN SOLID STATE TRACK DETECTORS. Doke, Tadayoshi (Tokyo Univ.). *Radioisotopes* (Tokyo); 21: No. 2, 121-37 (Feb. 1972). (In Japanese).

Progress in solid state track detectors is described. The ion explosion theory and the electron thermal spike theory are in opposition to each other concerning track forming mechanism in the solid state detectors and neither theory is suitable for the mechanism in organic materials. The proposal of Benton and Nix to consider restricted energy loss (REL) as a criterion to decide the existence of formed tracks seems to be more universal. Since the mechanism of track formation by recoil nuclides accompanying α decay is entirely different, elucidation of formation conditions is required. Recently a new type of detector (glass chamber) using a mixed system of two kinds of liquid phase glass has been developed. Scanning techniques for large area detectors are also being developed, which are employed to improve statistical accuracy. Lately, the detectors have been widely utilized for the discrimination of nuclides, and application to research on cosmic rays and atomic nuclides is described.

A95 THERMAL STABILITY OF FISSION TRACKS IN THE STANDARD REFERENCE MATERIAL GLASS STANDARD (NATIONAL BUREAU OF STANDARDS). Reimer, G. M.; Wagner, G. A. (Univ. of Pennsylvania, Philadelphia). *Radiat. Eff.*: 15: No. 3-4, 273-4 (Aug. 1972).

The series of four NBS Standard Reference Glass samples contain 61 trace elements added to the base melt in differing nominal concentrations. The concentrations of several elements, including uranium, thorium, and boron, are certified in these glasses. After irradiation with thermal neutrons at various dose levels to induce tracks from ^{235}U fission, the samples were divided and annealed at a series of temperatures and times. The track densities were determined using an optical microscope. An equation is presented to express the ratio of post-annealing to pre-annealing track densities: as expected, the density decreases with increasing time and temperature. In addition, a decrease in track diameters was observed. It is concluded that glasses which are used as fission track references should be stored at 20°C as the tracks have a relatively low thermal stability.

A96 SOME CHARACTERISTICS OF THE TRACK REGISTRATION IN DIFFERENT PLASTIC DETECTORS. Enge, W.; Weber, R.; Beaujean, R.; Bartholoma, K. P. (Univ., Kiel). pp. 459-74 of *New*

Trends in Radiation Protection. Montrouge, France; Societe Francaise de Radioprotection (1972).

From sixth international congress on new trends in radiation protection; Bordeaux, France (27 Mar. 1972). See CONF-720328.

Three different plastic detectors were studied: Daicel cellulose nitrate (Japan), Kodak-Pathe cellulose nitrate (France), and the polycarbonate Lexan of General Electric (USA). These detectors were exposed to B and C ions having an energy of 10.2 MeV/nucleon from an accelerator and to cosmic radiation in high altitude balloon flights. The cellulose nitrate detectors were etched at different temperatures (20 to 65°C). The different etching rates are presented as a function of the energy loss experienced by the heavy ions. The Lexan polycarbonate plastic detectors were irradiated with ultra-violet radiation after being exposed to the ions. In this way their sensitivities were improved by a factor of between 4 and 40 (ratio of the track etching rate to the bulk etching rate). The improvements made to the recording characteristics of the detector are discussed.

A97 PARTICLE TRACK EVOLUTION IN DIELECTRIC TRACK DETECTORS AND CHARGE IDENTIFICATION THROUGH TRACK RADIUS MEASUREMENT. Paretzke, H. G. (Institut fuer Strahlenschutz, Neuberberg, Ger.); Benton, E. V.; Henke, R. P. *Nucl. Instrum. Methods*; 108: No. 1, 73-80 (1973).

The evolution of etched tracks in dielectric nuclear track detectors is considered for the case of normally incident particles taking into account the general case of the variable track etch rate. It is shown for the first time that measurement of track radii as a function of the amount of removed surface can be used for the determination of the differential track etch rate and for particle identification. This method is particularly applicable for particle tracks which lie in the region of the detection limit. The findings are also useful in estimating the degree of optical contrast and in understanding results obtained by integral light scattering devices such as in the case of track density evaluation.

A98 INFLUENCE OF THERMAL EFFECTS ON THE TRACK REGISTRATION CHARACTERISTICS OF PLASTICS. Somogyi, G. (Magyar Tudományos Akademia Atommag Kutato Intezete, Debrecen, Hungary). *Radiat. Eff.*; 16: No. 3-4, 245-251 (Oct. 1972).

Thermal effects can alter the physical and chemical parameters of the latent tracks and bulk material of

dielectric track recorders, and consequently those of the etched track pits too. A few characteristics of this thermal track-fading effect are studied in various plastic track detectors irradiated with lightly and heavily ionizing nuclear particles. Experimental data are given for the influence of different annealing conditions on the diameter of etch pits and the bulk etch rate of plastics. The possibilities of the eradication of alpha-particle background and the selective thermal track discrimination in cellulose nitrate, cellulose acetate, and polycarbonate detectors are studied. A few practical applications of the thermal track fading are also presented.

A99 EFFECT OF ENERGETIC ELECTRON IRRADIATION UPON CHARGED-PARTICLE TRACK REGISTRATION IN POLYCARBONATE FILMS. Goland, A. N.; der Mateosian, E. (Brookhaven National Lab., Upton, N.Y.). *Nucl. Instrum. Methods*; 106: No. 2, 295-299 (1973).

Samples of Lexan polycarbonate were exposed to 2-MeV electrons for short periods of time. The samples were also exposed to a ^{252}Cf source of fission fragments, and were subsequently etched to develop the fission-fragment tracks. The electron irradiation caused a marked change in the bulk etching rate of the plastic. The experiments leading to this conclusion and the consequences of the effect are discussed.

A100 (ORO-2854-14) STRUCTURAL RELAXATION IN LIQUIDS AND GLASSES. Scientific Final Report. Litovitz, T. A. (Catholic Univ. of America, Washington, D. C. Dept. of Physics). 14 May 1972. 9 p.

It is shown that particle track detection is feasible using a "glass chamber." However, the detection process is very sensitive to material composition of the detector, and further careful study is needed to establish the optimum conditions of composition and thermal treatment for which the rate of preferential nucleation of phase particles on track sites is maximized before the track damage is annealed out.

A101 GLASS DETECTORS. Lecerf, M.; Peter, J. (Laboratoire de Chimie Nucleaire, Orsay, France). *Nucl. Instrum. Methods*; 104: No. 1, 189-95 (1972). (In French).

Glass has been irradiated orthogonally with respect to its surface by ^{12}C , ^{16}O , ^{20}Ne , ^{40}Ar , Ni and ^{84}Kr ions of energy per nucleon ranging up to 1.1 MeV/amu. The diameter of the etched particle tracks was measured as a function of the mass and velocity of the particle. It increases with the mass and energy of the projectile. The increase with mass is greatest between O and Ar

and much smaller for heavier particles. The projectile detection threshold is found to occur in the vicinity of oxygen. Particles of mass greater than or equal to 10 and energy greater than 6 MeV are detected with 100% efficiency.

A102 EFFECT OF OZONE ATMOSPHERE ON THE DETECTING PROPERTIES OF PLASTIC TRACK RECORDERS. Somogyi, G. (Magyar Tudományos Akademia Atommag Kutato Intezete, Debrecen, Hungary). *Radiat. Eff.*; 16: No. 3-4, 233-243 (Oct. 1972).

The influence of ozone-containing atmosphere on the track-etching parameters of cellulose nitrate, cellulose acetate, polycarbonate, and polyvinyl chloride sheets was studied. Evidence of the increase of registration sensitivity was found for all plastics investigated. The effects of ozone treatment on the tracks of both lightly and heavily ionizing nuclear particles are discussed. Experimental data are given on the variations of the etching properties of bulk material and latent tracks as a function of storage times in ozone atmosphere. The observations indicate that in any effect where there is a possibility of ozone production (e.g., with plastic detectors placed in spark discharge or exposed to ultraviolet radiation) the sensitivity variation due to ozone effect cannot be neglected.

A103 CRYSTALLINE QUARTZ TRACK DETECTOR FOR HEAVY CHARGED PARTICLES. Sowinski, M. (Institut de Physique Nucleaire, Orsay, France); Stephan, C.; Czyzewski, T.; Tys, J. *Nucl. Instrum. Methods*; 105: No. 2, 317-22 (1972). (In French).

Plates made of crystalline quartz cut along the 100 plane of synthetic monocrystals were used as nuclear track detectors. Different calibrations were made with fission fragments. The influence of temperature on latent tracks and the effect on the detector of severe irradiation by neutrons were especially studied. (9 figures)

A104 CHARGED PARTICLE TRACKS IN GLASS. Fleischer, R. L. and Price, P. B. *J. Appl. Phys.*; 34, P.2903 (1963).

Abstract not available.

A105 PNCF 68-R19. ÉTUDE DE L'INTERACTION DES PARTICULES LOURDES IONISANTES AVEC LES MACROMOLECULES A L'ÉTAT SOLIDE. Monnin, M. (1968).

Abstract not available.

A106 PE-158, A SIMPLE MODEL FOR THE DEVELOPMENT OF TRACKS IN SOLID-STATE NUCLEAR TRACK DETECTORS. Tuyn, J. W. N., Kjeller, Norway (1968).

Abstract not available.

A107 CHARGED PARTICLE TRACKS IN SOLIDS. Dienes, G. J. *Stud. Radiat. Eff.*, Ser. A1 (1968).

Abstract not available.

A108 THE KINETICS OF HEALING FISSION FRAGMENT TRACKS IN THIN MICA SHEETS. Geguzin, Y. E., Berzina, I. G., and Varabeva, I. V. *Sov. Phys. Dokl.* 12, p. 814 (1968).

Abstract not available.

A109 JINR-P13-4848, RECORDING CHARGED PARTICLE TRACKS IN THE ALKALI-HALIDE CRYSTALS. Golovin, B. M., Nikanorov, V. I., and Piskarev, A. F. (1969).

Abstract not available.

A110 LET EFFECTS ON THE CHEMICAL RESISTANCE OF IRRADIATED POLYMERS. Boyett, R. H. and Becker, K. J. *Appl. Polym. Sci.* 14, p.1654 (1970).

Abstract not available.

A111 SOLID STATE PRECIPITATION DETECTORS: NUCLEAR TRACKS IN SILVER HALIDE SINGLE CRYSTALS. Haase, G.; Scheyper, E.; Henig, G.; Schott, J. U.; Zoergiebel, F. (*Univ., Frankfurt am Main*). (1970) Ref. J46, pp. 89-106.

In certain solid systems the disturbances, originating from the interaction of a charged nuclear particle on its path, can be used to initiate the precipitation of a new phase in the system, which leads to a visible track of the particle. The mechanism is briefly discussed. Well-known representatives of such systems are the silver halides, in particular silver chloride single crystals. The properties of these detectors and their response to ionizing particles strongly depend on impurities or on particular doping components respectively. A special procedure of growing thin sheets of AgCl monocrystals permitted to investigate a large amount of various elements, among which Cd and Pb proved favorable. The response of AgCl crystals as a function of the doping concentration, and the influence of temperature on the sensitivity and the stability of tracks are discussed as well as the simple procedure of revealing of the tracks by ultraviolet light. Examples of tracks and of applications are given. As an outlook from preliminary results the facility is mentioned to make visual

precipitation detectors in which the latent tracks are rapidly fading and can be revealed only by immediate triggering. Finally, the precipitation procedure for recording nuclear tracks seems to be realizable also with specially doped glasses. First results are encouraging.

A112 MICRODISTRIBUTION OF ABSORBED DOSE IN THE TRACK OF A HEAVY CHARGED PARTICLE. Kudryashov, E. I., Marennui, A. M., Popov, V. I., and Meshcheryakova, O. M. *Kosm. Biol. Med.* 4, p. 35 (1970). (*Engl. Transl. JPRS-52121*, p. 51)

Abstract not available.

A113 TRACK FORMATION MECHANISM IN MINERALS. Maurette, M. *Radiat. Eff.* 3, p149 (1970).

Abstract not available.

A114 INFLUENCE OF HUMIDITY ON TRACK REGISTRATION IN CELLULOSE NITRATE PLASTIC DETECTORS. Enge, W.; Beaujean, R.; Nicken, H.P. (*Univ., Kiel*). Ref. J46 pp. 175-180.

Dacel cellulose nitrate has been exposed to vertically incident alpha particles up to 5 MeV to study the influence of water on the etching process in 6N NaOH at 50°C. For this purpose two sets of samples exposed to alpha particles were studied, one was rinsed in 50°C hot water for 20 minutes immediately before etching, while the other one was kept dry. The track etching rate v_t and the bulk etching rate v_b of the "wet" samples grew to twice the rates of the "dry" samples. As the ratio v_t/v_b remained constant, there is no improvement of the sensitivity of the track registration; however, great attention has to be kept on this effect of the water on the etching process when precise etching is required.

A115 CHARGED PARTICLE TRACKS AND THEIR STRUCTURE. Mozumder, A. In "Advances in Radiation Chemistry" (M. Burton and J. L. Magee, eds.), Vol. 1, p. 3 Wiley (Interscience), New York (1970).

Abstract not available.

A116 HEAVY ION EFFECTS IN POLYMERS. Fain, J., Monnin, M., and Montret, M. *Proc. Symp. Radiat. Chem.*, 3rd, Tihany (1971).

Abstract not available.

A117 BIOMEDICAL MICROIMAGERY VIA ORGANIC FREE-RADICAL FILMS. Noffainger, E.B. *Photogr. Appl.*, January, p.25 (1971).

A118 CRITERION FOR REGISTRATION IN DIELECTRIC TRACK DETECTORS. Fleischer, R. I., Walker, R. M., and Hubbard, E. I. *Phys. Rev.* 156, p.353 (1967).

Abstract not available.

A119 METHOD OF FORMING FINE HOLES OF NEAR ATOMIC DIMENSIONS. Fleischer, R. L., Price, P. B., and Walker, R. M. *Rev. Sci. Instrum.* 34, p.510 (1963).

Abstract not available.

A120 NOVEL FILTER FOR BIOLOGICAL MATERIALS. Fleischer, R. L., Price, P. B., and Symes, E. M. *Science* 143, p.249 (1964).

Abstract not available.

A121 ETCHING OF SUBMICRON PORES IN IRRADIATED MICA. Bean, C. P., Doyle, M. V., and Entino, G. J. *Appl. Phys.* 41, p. 1454 (1970).

Abstract not available.

A122 TRACKS OF COSMIC RAYS IN PLASTICS. Fleischer, R. L., Price, P. B., Walker, R. M., Filz, R. C., Fukui, K., Friedlander, M. W., Holeman, E., Rajan, R. S., and Tamhane, A. S. *Science* 155, p187 (1967).

Abstract not available.

A123 Maurette, M., and Walker, R. M. *J. Phys. Paris* 25, p. 661 (1964).

Title and abstract not available.

A124 ELECTRON MICROSCOPE OBSERVATION OF TRACKS OF CHARGED PARTICLES REGISTERED IN IONOGRAPHIC EMULSIONS. Schmitt, R.; Demoulin, R.; Strebel, N. (Centre de Recherches Nucleaires, Strasbourg). *Ref. J46* p. 75-82. (1970). (In French).

The method of electron microscope observation of tracks in ionographic emulsions is too restricted to be of general use, but it could become irreplaceable in certain specific studies such as in the study of particles with very short lives such as hyperfragments or of particles of low energy that produce short tracks, such as recoil nuclei, or even a better discrimination of heavy ion tracks.

A125 SOLID STATE PRECIPITATION DETECTORS FOR NUCLEAR TRACKS: PROBLEMS IN PRODUCING AgCl SINGLE CRYSTAL SHEETS. Haase, G.; Schopper, E.; Henig, G.; Schott, J. U.; Zoerglebel, F. (Univ., Frankfurt am Main). *Ref. J46* pp. 107-115. (1970).

A method for growing AgCl single crystal sheets with an area of about 1 cm² for use as nuclear track detectors is described.

A126 SOME RECENT IMPROVEMENTS IN OUR EXPERIMENTAL UNDERSTANDING OF THE INTERACTION OF CHARGED PARTICLES WITH PLASTIC DETECTORS. Some Applications at the Laboratoire de Physique Corpusculaire de Strasbourg. Debeauvais, M.; Ralarosy, J.; Remy, G.; Stein, R.; Tripier, J. (CNRS, Strasbourg). *Ref. J46* pp. 147-168. (1970). (In French).

The study of heavy ion tracks using an electron microscope and an optical microscope is discussed; and track parameters such as specific energy loss, range, and development parameters are considered. The uses of plastic track detectors for dosimetry and for studying very heavy element fission induced by high-energy protons are discussed. Specific energy losses as a function of energy are given for sulfur and oxygen ions; the variation of the speed of development of Makrofol for different ions as a function of specific energy loss is shown graphically; a comparison of track lengths of different ions of different energies as a function of time of development is given; the ranges of different ions of different energies are plotted; and specific energy loss is plotted as a function of energy per nucleon for different ions.

A127 UTILIZATION OF POLY(VINYL CHLORIDE) AS SOLID TRACK DETECTOR. Monnin, M.; Montret, M.; Sanzelle, S.; Touzery, C. (Laboratoire de Physique Nucleaire Fondamentale et Developpement, Clermont-Ferrand, France). *Ref. J46* pp.169-173. (1970). (In French).

The effects of various additives (lead salts, tin salts, and mixed barium cadmium salts) on the track etching time and the performance for fission fragment detection are studied. Data are given.

A128 IMPROVEMENT OF THE PERFORMANCE OF CELLULOSE NITRATE FILM FOR RECORDING IONIZING PARTICLE TRACKS. Barbier, J. F. *Ref. J46* pp. 187-204. (1970). (In French).

A study of the anomalies in different cellulose nitrate track detectors and the development of detectors with more reproducible results are discussed. Characteristics of cellulose nitrate track detectors, track etching, and cellulose nitrate detectors for neutron radiography and thermal neutron dosimetry using lithium converter foils are discussed.

A129 COMPARATIVE STUDY OF THE EFFECTS OF THE GASES ON DETECTION CHARACTERISTICS. Chave, A.; Morrin, M. (Laboratoire de Physique Nucleaire Fondamentale et Developpement, Clermont-Ferrand, France). Ref. J46. pp.205-211. (1970). (In French).

The effects of various gases on track formation in poly(vinyl chloride) and polycarbonate track detectors for fission fragment detection were studied. The effects of gaseous atmospheres of SO_2 , N_2O , and I_2 were studied and results are given.

A130 RESPONSE OF CELLULOSE NITRATE TO LITHIUM AND OXYGEN IONS IN DIFFERENT ENERGY RANGES. Prohl, R. (CNRS, Strasbourg); Kaiser, R.; Schmitt, R.; Rios, C.; Gandia, V. Ref. J46. pp.219-231. (1970). (In French).

The detection of lithium-6 ions at 6 to 12 MeV at 15 to 30°C, lithium-7 ions at 12 to 20 MeV, and oxygen-16 at 33 to 52 MeV at 45°C using cellulose nitrate track detectors was studied. Results are presented and discussed.

A131 DIFFICULTIES IN THE EXPOSURE OF PLASTIC DETECTORS IN A VACUUM CHAMBER: METALLIZATION. Cordailat, A. (CERN, Geneva); Annoni, H. Ref. J46. pp.263-266. (1970). (In French).

Experiments on metallization of plastic detectors (cellulose nitrate and Makrofol) hindering degassing, were carried out with the view of using such detectors in an enclosure under vacuum. These investigations require a preliminary corrosion of the surface of the detector and a cleaning after use. These two operations have to be carried out without harm both to the registration of tracks as well as to the development of plastic detectors.

A132 MECHANISM OF CELLULOSE FILMS SENSITIVITY TO IONIZING PARTICLE TRACKS REGISTRATION. Veprik, Ya. M.; Kartuzhanskii, A. L.; Marenniy, A. M.; Popov, V. I. Ref. J46. pp. 287-296. (1970).

Characteristics of nitrate cellulose and acetate cellulose track detectors are discussed and compared. The radiation chemistry of the track formation in polymers is discussed and the necessity of the presence of oxygen for good sensitivity is explained.

A133 SOLID STATE PRECIPITATION DETECTORS FOR NUCLEAR TRACKS. III. Some Applications of AgCl-Detectors. Schopper, E.; Schott, J. U.; Henig, G.; Haase, G.; Palm, E.; Zoergiebel, F. (Univ., Frankfurt am Main). Ref. J47. pp. 461-468. (1970).

Some characteristics and uses of monocrystalline AgCl (Cd) track detectors in fission experiments are described. Particle discrimination properties are graphically depicted of the response of AgCl (Cd) detectors to particles of different specific ionization as a function of their cadmium content. Use for measuring the mean-life of the isomeric fissioning decay of plutonium-240 is described.

A134 SOME REGISTERING CHARACTERISTICS OF PLASTIC PARTICLE DETECTORS IN VACUUM AND IN GASEOUS MEDIA. Girshin, A. B.; Kartuzhanskii, A. L.; Martysh, G. G.; Privalova, V. E.; Shur, L. I. Ref. J47. pp. 825-836. (1970).

A study of the characteristics of plastic track detectors for α -particle and multicharged heavy-ion detection in vacuum and in gaseous media is described. The experiments were conducted at the A. F. Ioffe Phys. - Techn. Institute cyclotron.

A135 SOLID STATE TRACK DETECTOR: CELLULOSE TRIACETATE. Varelle, J. C.; Teyssier, J. L. (Univ., Limoges, France). Radioprotection; 7: No. 4, 215-228 (1972). (In French).

The utilization of cellulose triacetate (Bayer triafol T.N.) as a solid state track detector for charged particles (α particles, californium fission fragments) was studied. It was demonstrated that the etch rate ratio R_T increases with decreasing temperature and increasing etching reagent concentrations. The presence of a plastifier in the detector material increases R_T by a factor of 2.5. The activation energy for the potassium hydroxide/damaged zone reaction increases with decreasing linear energy transfer from the charged particle. The maximum α particle energy recorded was 4 MeV, the etching reagent being 4N KOH at 60°C. The discrimination between α particles of different energy can be made using this detector with a 500 keV resolution.

A136 DETECTION OF CHARGED PARTICLES BY POLYMER GRAFTING. Monnin, M. M.; Blanford, G. E. Jr. (Univ. Clermont, Aubiere, France). Science; 181: No. 4101, 743-744 (24 Aug. 1973).

Tracks of fission fragments from a californium-252 source have been revealed by graft copolymerization. A 15% solution of propenoic (acrylic) acid monomer was reacted with irradiated cellulose triacetate for 24 h at 55°C. Copolymer forms preferentially at the track sites and it can be dyed with rhodamine B because of its acid and hydrophilic properties. After the dyeing, the tracks were seen by using fluorescence microscopy.

A137 NEW PROCEDURE FOR DETECTING CHARGED PARTICLES. Monnin, M.; Blanford, G. (Clermont-Ferrand Univ., France). *Compt. Rend., Ser. A, B*; 276: No. 10, 389-391 (5 Mar. 1973).

A new procedure is presented for detecting charged particles by radiografting acrylic acid onto a basic polymer (cellulose triacetate) irradiated by ^{252}Cf fission fragments. The copolymer formed is colored with rhodamine B. Observations of the tracks are then made using optical transmission and ultraviolet fluorescence microscopy.

A138 MEASUREMENT OF HEAVY IONS USING SOLID-STATE GLASS DETECTORS. Siebert, G.; Fiedler, G.; Aschenbach, J. (Univ., Giessen, Ger.). *Z. Naturforsch., A*; 28: No. 3-4, 544-545 (1973). (In German).

A simple model for track formation in solid state nuclear track detectors is proposed. According to this model the area of an etch pit is proportional to the etching time and to the square root of the energy of the impinging particle. This conclusion is in agreement with experimental results.

A139 APPEARANCE TIME. I. Theoretical Considerations. Dragu, A. (Inst. of Atomic Physics, Bucharest). *Rev. Roum. Phys.*; 18: No. 3, 347-357 (1973). (In French).

The appearance time (the time necessary to etch out a track to a projected length in a dielectric track detector) is discussed.

A140 TRACK-DIAMETER KINETICS IN DIELECTRIC TRACK DETECTORS. Somogyi, G. (Inst. of Nuclear Research, Debrecen, Hungary); Szalay, S. A. *Nucl. Instrum. Methods*; 109: No. 2, 211-232 (1973).

The minor and major axes of track-pits of nuclear particles registered in dielectric solids are gradually varying in the course of the etching process. A general theoretical description of this variation (track-diameter kinetics) is given here for particles entering solids at arbitrary angles. The model has been extended to detectors with both isotropic and anisotropic etching properties. The determination of the formulas describing the variation of etch-pit axes during the etching process are separately discussed for constant and varying track etch rates. The characteristics of the model are illustrated for some particular cases. On the basis of the geometrical model of etch-pit evolution, new methods for the experimental determination of track parameters (track etch rate, entrance angle,

range) are proposed. These methods applying to etch-pits of spontaneous fission tracks registered in glass detectors may help, among others, in the search for super-heavy transuranic elements.

A141 (NASA-CR-123918; ITR-19). CHARGED PARTICLE TRACKS IN CELLULOSE NITRATE AND LEXAN. Interim Technical Report. Benton, E. V.; Henke, R. P. (San Francisco Univ., Calif. (USA). Dept. of Physics). (July 1972). 39p.

Investigations were performed aimed at developing plastic nuclear track detectors into quantitative tools for recording and measuring multicharged, heavy particles. Accurate track etch rate measurements as a function of LET were performed for cellulose nitrate and Lexan plastic detectors. This was done using a variety of incident charged particle types and energies. The effect of aging of latent tracks in Lexan in different gaseous atmospheres was investigated. Range distributions of high energy ^{14}N particle beamtrons in nuclear emulsion were measured. Investigation of charge resolution and Bragg peak measurements were carried out using plastic nuclear track detectors.

A142 COMMENTS ON "ELASTICALLY SCATTERED RECOIL NUCLEI IN SOLID-STATE DETECTORS". Maurette, M.; Walker, R. M. (Washington Univ., St. Louis). *Radiat. Eff.*; 19: No. 1, 15-18 (May 1973).

Horn and Von Oertzen (Earth Planet. Sci. Letters; 2: 280 (1967)) have shown that tracks in mica are produced by an irradiation with 32 MeV ^{16}O ions. These tracks were attributed to K and Fe recoils produced by elastic-scattering of the incident oxygen beam. An alternate explanation of their observations is offered. The measured characteristics of the tracks are shown to be compatible with theoretical predictions for production of tracks by inelastic (mostly compound nucleus) reactions with silicon and to be inconsistent with the previously proposed elastic scattering process. The possibility that the tracks are produced by contaminant ions in the beam cannot be ruled out.

A143 LET RESPONSE OF SOLID-STATE DETECTORS. A Review. Becker, K. (Oak Ridge National Lab., Tenn. (USA)). (1973). 22p. From fourth international symposium on microdosimetry; Verbania, Italy (27 Sept. 1973).

It is shown in a review of the LET response of various solid-state dosimeters such as TLD, RPL, TSEE,

and photographic film that most of them exhibit (as predicted by the model of trap saturation by low-energy delta rays in a cylindrical zone around particle tracks) a more or less pronounced decrease in sensitivity with increasing LET. The relationship between trap density (low LET saturation dose) and relative high LET (alpha particle) efficiency as well as some changes in the TL or TSEE curves can also be explained by this model. There are, however, apparently also some qualitative differences between the effects of low LET and high LET radiation, which indicate semi-permanent structural changes along high-LET particle tracks. It is concluded that both trap saturation and structural damage contribute to varying degrees, depending on lattice characteristics and the nature of the observed effect, to the detector response.

A144 ANNEALING OF LATENT DAMAGE TRAILS IN SOLID-STATE NUCLEAR TRACK DETECTORS. Khan, H. A.; Durrani, S. A. (Univ. of Birmingham, Eng.). Nucl. Instrum. Methods; 113: No. 1, 51-54 (1973).

Experiments have been carried out to gain some further insight into the annealing behaviour of latent damage trails in Solid State Nuclear Track Detectors (SSNTDs). The results indicate that on annealing, (a) a latent damage trail shrinks both radially and axially thus causing a decrease in the etchable range and an increase in θ_c , the critical angle of etching, and (b) the decrease in the number density of tracks in the initial stages of the annealing process is mainly due to the disappearance of oblique tracks.

A145 THERMAL STABILITY OF TRACKS IN PLASTICS AND SOME USES IN RADIOGRAPHY. Somogyi, G. (Inst. of Nuclear Research, Debrecen, Hungary). Isotopenpraxis, 9: No. 7, 249-251 (July 1973).

The eradication of alpha and fission tracks and the selective track discrimination by heat treatment have been studied in cellulose nitrate, cellulose acetate, and polycarbonate sheets. Some applications of the phenomena in alpha-graphy and fissionography are presented.

A146 (NP-19847) TRACKS DISCRIMINATION OF LOW ENERGY NUCLEI IN PLASTICS. Internal Note 458. Baroni, G.; Di Liberto, S.; Petrerà, S.; Romano, G.; Sgarbi, C. (Rome Univ. (Italy). Istituto di Fisica; Istituto Nazionale di Fisica Nucleare, Rome (Italy)). (17 April 1973). 29p.

The efficiency of nitrocellulose plastic sheets as external detectors was studied as a function of im-

pinging particle angle, energy loss rate, and other experimental conditions also in the presence of a high background of neutral and singly-charged particles. The discrimination among low-energy nuclei ($2 \leq Z \leq 6$) with a two step method of analysis was achieved with the definition of a parameter (w), connected with the measured etched length of the tracks, that assures their almost certain assignment to the various nuclear species.

A147 RANGE AND ENERGY LOSS RATE FOR HEAVY IONS IN MAKROFOL AND CELLULOSE NITRATE. Tripiet, J.; Remy, G.; Ralarosy, J.; Debeauvais, M.; Stein, R. and Huss, D. Nuc. Inst. Meth. 115, 29-46 (1974).

Abstract not available.

A148 (NASA-CR-124381). PARTICLE TRACK DETECTORS. Interim Report No. 27. Benton, E. V.; Gruhn, T. A.; Andrus, C. H. (San Francisco Univ., Calif. (USA). Dept. of Physics). (June 1973). 35 p.

Aqueous sodium hydroxide is widely used to develop charged particle tracks in polycarbonate film, particularly Lexan. The chemical nature of the etching process for this system has been determined. A method employing ultraviolet absorbance was developed for monitoring the concentration of the etch products in solution. Using this method it was possible to study the formation of the etching solution saturated in etch products. It was found that the system super-saturates to a significant extent before precipitation occurs. It was also learned that the system approaches its equilibrium state rather slowly. It is felt that both these phenomena may be due to the presence of surfactant in the solution. In light of these findings, suggestions are given regarding the preparation and maintenance of the saturated etch solution. Two additional research projects, involving automated techniques for particle track analysis and particle identification using AgCl crystals, are briefly summarized.

A149 USEFULNESS OF MICA AND QUARTZ TRACK DETECTORS AT HIGH ENVIRONMENTAL TEMPERATURES. Khan, H. A. (Univ. of Birmingham, Eng.). Nucl. Instrum. Methods; 114: No. 1, 61-63 (1974).

The track registration and retention characteristics of Muscovite mica and fused quartz (vitreosil) Solid-State Nuclear Track Detectors (SSNTDs) have been studied at high environmental temperatures. A particular emphasis has been laid on the improvement of genuine to background track densities so that the detectors can be used for even low yield experiments.

The experiments were carried out in the temperature range of 22°C to 900°C and the results show that fused quartz (vitreous) and mica (muscovite) SSNTDs can be used with an almost 100% efficiency up to temperatures of ~500 and 400°C respectively.

A150 STUDY OF THE ELECTRICAL CONDUCTIVITY OF CELLULOSE ACETATE IN RELATION TO ITS USE AS A SOLID TRACK DETECTOR. Bourdeaux-Pontier, M.; Roux, F.; Bernard, P. J.; Briand, C. (Aix-Marseille II Univ.). Radioprotection; 8: No. 1, 37-49 (1973). (In French).

An original method is proposed for determining the dose received by cellulose acetate irradiated with

fission fragments or α particles. The method is based on the alteration occurring in the transverse electrical conductivity of the detector after irradiation and subsequent etching with soda. Such techniques enable very high doses of irradiation to be measured.

A151 PLASTIC TRACK DETECTOR WITH HIGH SENSITIVITY. Lueck, H. B. (Zentralinstitut fuer Kernforschung, Dresden). Nucl. Instrum. Methods; 114: No. 1, 139-140 (1974).

The sensitivity of a novel plastic track detector prepared from cellulose nitrate has been investigated. The track etching rate was determined in relation to the primary ionization rate.

B. ETCH PARAMETER STUDIES

B1 ETCHING OF RADIATION DAMAGE IN LITHIUM FLUORIDE. D. A. Young (Atomic Energy Research Establishment, Harwell, Berks, Eng.). Nature 182., 375-7 (1958).

Single crystals of lithium fluoride were cleaved along the plane and fission fragments from a U_3O_8 film 1 mm distant were allowed to enter a portion of the crystal surface at room temperature. The crystals were then etched in an acid bath and photographed in a projection microscope. The damage produced in the crystals by recoiling fission fragments is demonstrated.

B2 CHEMICAL ETCHING OF CHARGED-PARTICLE TRACKS IN SOLIDS. Price, P. B. and Walker, R. M. (General Electric Research Lab., Schenectady, N. Y.). J. Appl. Phys., 33: 3407-12 (Dec. 1962).

When a heavy charged particle such as a fission fragment traverses certain materials it leaves a trail of radiation damage, which shows up as a track when a sample is viewed by transmission electron microscopy. If a sample of a silicate mineral containing such tracks is immersed in a suitable reagent, such as hydrofluoric acid, it is found that the tracks are very selectively attacked. Fine hollow channels are formed along the particle paths while the rest of the material is untouched. A study of this effect in various silicate minerals is reported as a function of etching reagent, etching temperature, and etching time. The minimum width of the etched channels is considerably less than the apparent widths of the tracks prior to etching. It is concluded that the track images result in large part from elastic strains surrounding a damaged core. The

etching effect also serves to "develop" and "fix" particle tracks, and hence increases the usefulness of silicate minerals as particle detectors.

B3 EFFECT OF OXYGEN AND HUMIDITY ON CHARGED PARTICLE REGISTRATION IN ORGANIC FOILS. Becker, K. (Oak Ridge National Lab., Tenn.). Radiat. Res., 36: 107-18 (1968).

The number and diameter of microscopically visible alpha-particle tracks which can be etched in the surface of sensitive plastic foils such as cellulose triacetate are increased by the presence of oxygen. Pre- or post-treatment of foils with water or humid air increases the etching speed but not the foils' sensitivity. Treatment of foils with diluted H_2O_2 increases the sensitivity slightly, but the etching speed considerably. Some parameters of the oxygen/humidity effect are described; its possible consequences for the interpretation of the latent track formation process and its practical applications are discussed briefly.

B4 (USNRDL-TR-68-136). CHARGED PARTICLE TRACKS IN POLYMERS No. 7: SENSITIVITY ENHANCEMENT OF LEXAN. Beiton, Eugene V.; Henke, Richard P. (Naval Radiological Defense Lab., San Francisco, Calif.). Nov. 22, 1968. 12p.

Ultraviolet radiation in the presence of oxygen has been used to greatly enhance track-etching rates in Lexan polycarbonate nuclear particle track detector. When irradiated detectors are stored in darkness, the slow variation of chemical track reactivity with the age of latent tracks can be explained as being caused by the presence of oxygen.

B5 ENHANCEMENT OF TRACK ETCHING RATES IN CHARGED PARTICLE IRRADIATED PLASTICS BY A PHOTO-OXIDATION EFFECT. Crawford, W. T. (General Electric Co., Pleasanton, Calif.). *Nature*, (London), 220: 1313-14 (Dec. 28, 1968).

Among dielectric solids useful for track etching applications are plastic films, notably cellulose and polyesters, which are very sensitive to a variety of energetic charged particles. Studies are described in which it was found that exposure of a charged-particle-bombarded polycarbonate film to UV energy in an oxidizing atmosphere resulted in a significant acceleration in the etching rate for the damage region along a track, permitting immediate processing and analysis. Polycarbonate film was irradiated in air at 10 to 15 torr to a density of 100 to 3,000 tracks/cm² with fission fragments from a ²⁵²Cf source, and then subjected to various UV exposure times in air, N₂, O₂, or CO₂. It was demonstrated that oxygen is essential to the chemical fixation of the debris remaining in the vicinity of the tracks. Mechanisms are discussed. The geometry of the "pores" formed on etching was also examined.

B6 SOME STUDIES ON THE CHEMICAL DAMAGE MECHANISM ALONG CHARGED PARTICLE TRACKS IN POLYMERS. Johnson, D. R.; Boyett, R. H.; Becker, K. (Oak Ridge National Lab., Tenn.). *Ref. J17*. pp II. 46-72. (1969).

A number of experimental studies have been carried out to obtain more information on the chemical damage mechanism along the tracks of charged particles of relatively low LET observed in the more sensitive organic plastics. For example, G-values for free radical production have been measured under different conditions using a radical scavenging technique. Infrared spectroscopy and gas chromatography have been used for qualitative and quantitative analysis of low molecular weight end products of radiolysis as a function of several parameters and the stability of latent alpha particle tracks has been measured at elevated temperatures. The effect of different agents (influence of oxygen partial pressure during exposure, humidity, H₂O₂ and ultraviolet pre- and postirradiation treatment) on the track registration threshold and/or etching kinetics of cellulose nitrate and acetate has also been examined. The possible interpretation of the results is discussed briefly.

B7 SENSITIVITY ENHANCEMENT OF PLASTIC NUCLEAR TRACK DETECTORS THROUGH PHOTO-OXIDATION. Henke, R. P. (Naval Radiological

Defense Lab., San Francisco); Benton, E. V.; Heckman, H. H. *Ref. J17*. pp II. 136-48. (1969).

A new method is presented for the sensitization of plastic track detectors. It has been found effective for cellulose, polycarbonates, and polyesters. Most of the reported data deals with Lexan. The method consists of irradiating plastics with ultraviolet radiation in the presence of oxygen. The sensitivity enhancement is found to increase exponentially with decreasing uv wavelength and increasing particle restricted energy loss rate, REL. This technique can be used to provide a continuously variable sensitivity from sample to sample, within a given sample, or from one etch to the next of a given sample. Greater spatial resolution is possible because of the increase in the ratio τ_r/τ_g . Better charge resolution is possible because of the stronger dependence of the track etch rate, τ_r , on REL. Long term measurements show that samples stored in the dark in an O₂ atmosphere show a small increase in τ_r with time. In inert atmospheres a negligible increase is observed, and in a vacuum τ_r decreases.

B8 TRACK ETCHING PARAMETERS FOR PLASTICS. Blanford, G. E. Jr.; Walker, R. M.; Wefel, J. P. (Washington Univ., St. Louis). *Ref. J17*. pp III. 27-41. (1969).

A series of experiments was performed to study the effect of types of etchant, concentration of etchant, etchant temperature and other parameters on track development in cellulose nitrate, polycarbonate resin, cellulose tri-acetate, and cellulose acetate butyrate plastic. This work has led to a set of preferred etching conditions for each of these plastics. For example, although there were only slight differences in general etching rate when LiOH, KOH, and NaOH were used as track etchants for cellulose nitrate the alpha particle registration sensitivity was greatest when NaOH was used. Also in cellulose nitrate the general etching rate and the particle registration sensitivity did not change significantly with increasing concentration for hydroxide solutions >6 normal. This was in marked contrast to other plastics which showed a strong concentration dependence.

B9 INFLUENCE OF ETCHING PARAMETERS ON THE SENSITIVITY OF PLASTICS. Somogyi, G. (Magyar Tudományos Akadémia Atommag Kutató Intézete, Debrecen, Hungary); Medveczky, L.; Varnagy, M. *Ref. J17*. pp III. 86-99. (1969).

It seems that the critical rate of primary ionization for the track registration must depend on the etching

conditions, too. Simple experimental methods are presented to show a possible change in the registration sensitivity as a function of the chemical parameters. It was proved from the investigations of alpha tracks, that the sensitivity of a cellulose acetate detector can considerably depend on the concentration and sort of etching reagent. Quantitative data are given on the ratio of the rate of chemical etching along the track and on the detector surface as a function of concentration of solution NaOH for tracks of fission fragments registered in plastics of cellulose acetate, polycarbonate, and polythepthalate.

B10 STUDIES OF ENVIRONMENTAL EFFECTS UPON TRACK ETCHING RATES IN CHARGED PARTICLE-IRRADIATED POLYCARBONATE FILM. De Sorbo, W.; Humphrey, J. S. Jr. (General Electric Co., Schenectady, N. Y.). Ref. J17. pp II. 132-5. (1969).

Wide variations in the effects of environmental gases and up upon the track registration characteristics of the polycarbonate detector were observed. These results cannot be interpreted at this time within the framework of any responsible scheme of plausible chemical reactions.

B11 SENSITIVITY ENHANCEMENT OF LEXAN NUCLEAR TRACK DETECTOR. Benton, E. V.; Henke, R. P. (Naval Radiological Defense Lab., San Francisco), Nucl. Instrum. Methods, 70: 183-4. (April, 1969).

Ultraviolet radiation in the presence of oxygen has been used to greatly enhance track-etching rates in Lexan polycarbonate nuclear particle track detectors. When irradiated detectors are stored in darkness, the slow variation of chemical track reactivity in Lexan with the age of latent tracks can be explained as being caused by the presence of oxygen.

B12 SENSITIVITY ENHANCEMENT OF PLASTIC NUCLEAR TRACK DETECTORS THROUGH PHOTO-OXIDATION. Henke, R. P. (Univ. of San Francisco); Benton, E. V.; Heckman, H. H. Radiat. Eff.; 3: 43-9 (May 1970).

A new method is presented for the sensitization of plastic track detectors. It has been found effective for celluloses, polycarbonates, and polyesters. Most of the reported data deals with Lexan. The method consists of irradiating plastics with ultraviolet radiation, uv, in the presence of oxygen. The sensitivity enhancement is found to increase exponentially with decreasing uv wavelength and increasing particle restricted energy

loss rate, REL. This technique can be used to provide a continuously variable sensitivity from sample to sample, within a given sample, or from one etch to the next of a given sample. Greater spatial resolution is possible because of the increase in the ratio r_t/r_p . Better charge resolution is possible because of the stronger dependence of the track etch rate, r_t , on REL. Long term measurements show that samples stored in the dark in the O₂ atmosphere show a small increase in r_t with time. In inert atmospheres a negligible increase is observed, and in a vacuum r_t decreases.

B13 INFLUENCE OF ETCHING PARAMETERS ON SENSITIVITY OF PLASTICS. Somogyi, G. (Inst. of Nuclear Research, Debrecen, Hungary); Varnagy, M.; Medveczky, L. Radiat. Eff.; 5: 111-16 (Aug. 1970).

It seems that the critical rate of primary ionization for track registration must also depend on the etching conditions. Simple experimental methods are presented to show a possible change in registration sensitivity as a function of the chemical parameters. It was proved, from investigations of α -particle tracks, that the sensitivity of a cellulose acetate detector can considerably depend on the concentration and type of etching reagent. Quantitative data are given on the ratio of the rate of chemical etching along the track and on the detector surface as a function of concentration of NaOH solution for tracks of fission fragments registered in plastics of cellulose acetate, polycarbonate, and polyethylene-terephthalate.

B14 STUDIES OF ENVIRONMENTAL EFFECTS ON TRACK-ETCHING RATES IN CHARGED PARTICLE-IRRADIATED POLYCARBONATE FILM. DeSorbo, W.; Humphrey, J. S. Jr. (General Electric Research and Development Center, Schenectady, N. Y.). Radiat. Eff.; 3: 281-2 (June, 1970).

An investigation was made of combined uv-gas environmental effects on the track etchability of Makrofol polycarbonate tape exposed to fission fragments from ²⁵²Cf. It was found that 3-min uv exposures in conjunction with N₂O increases the time to first pore breakthrough, while if O₂ or NO is used, the breakthrough time is reduced. The wavelength dependence of the uv-O₂ effect was studied; the breakthrough time increases in going from 304 to 366 nm.

B15 DEVELOPMENT OF TRACKS WITH SOLVENTS. Sanzelle, S.; Moanin, M. (Univ., Clermont-Ferrand, France). *Radiat. Eff.*; 3: 279-80 (June, 1970). (In French).

Some tracks are obtained in several plastics using an organic solvent track etching procedure. The described results are those obtained with ethyl alcohol. The samples (PMMA) are submitted to pure alcohol, then to water. In this way, one can get 6 MeV α -tracks but the phenomenon is not reproducible. The most frequent observations are described.

B16 IMPROVEMENT IN PARTICLE TRACK ETCHING IN LEXAN POLYCARBONATE FILM. Peterson, D. D. (General Electric Research and Development Center, Schenectady, N. Y.). *Rev. Sci. Instrum.*; 41: 1252-3 (Aug. 1970).

An improvement in the process of particle track etching in Lexan polycarbonate film has been made leading to smoother track profiles. The improvement is based on the findings that, in aqueous sodium hydroxide, the bulk etching rate increases with an increase in the concentration of etch products in solution. The bulk etching rate as a function of etch product concentration is graphed.

B17 TRACK ETCHING PARAMETERS FOR PLASTICS. Blanford, G. E. Jr.; Walker, R. M.; Wefel, J. P. (Washington Univ., St. Louis). *Contracts Z-80058T; NAS 9-8352. Radiat. Eff.*; 3: 267-70 (June 1970).

A series of experiments was performed to study the effect of types of etchant, concentration of etchant, etchant temperature, and other parameters on track development in cellulose nitrate, polycarbonate resin, cellulose triacetate, and cellulose acetate butyrate plastic. This work has led to a set of preferred etching conditions for each of these plastics. For example, although there were only slight difference in general etching rate when LiOH, KOH, and NaOH were used as track etchants for cellulose nitrate, the alpha particle registration sensitivity was greatest when NaOH was used. Also in cellulose nitrate the general etching rate and the particle registration sensitivity did not change significantly with increasing concentration for hydroxide solutions $> 6 N$. This was in marked contrast to other plastics which showed a strong concentration dependence.

B18 (NP-19211) EFFECT OF ETCHING INTERRUPTIONS ON TRACKS FORMATION IN PLASTICS. Note No. 321. Baroni, G.; Di Liberto, S.; Romano, G.;

Sgarbi, C.; Tabasso, M. C. (Rome Univ. (Italy). Istituto di Fisica. Istituto Nazionale di Fisica Nucleare, Rome (Italy)). (June, 1971). 24 p.

The effect of etch interruptions on track formation was studied in nitrocellulose plastic sheets by using α -particle tracks. The "step effect" is remarkable on some parameters of the tracks; while on others, as the lengthening with development time (that is the most useful in identification of high ionizing tracks), it seems to be absent. An attempt is made to interpret this effect on the basis of the known dissolution properties of polymers. (5 figures, 3 tables).

B19 (RT/PROT-(71)1) ELECTROCHEMICAL ETCHING OF DAMAGED TRACK DETECTORS BY H. V. PULSE AND SINUSOIDAL WAVEFORMS. Tommasino, L. (Comitato Nazionale per l'Energia Nucleare, Rome (Italy)). (Jan. 1971). 18p.

It is known that the etching reagents rapidly diffuse in the fine channels produced in insulators by the passage of the charged particles. Conductive paths are thus produced, which penetrate the insulating foils. By applying H. V. square or sinusoidal waveforms through the irradiated insulator, currents are produced in the conductive paths, delivering energy mostly along the tracks. This type of etching enables us to increase the sensitivity of alpha particle registration on cellulose Acetate-Butyrate, to produce well defined and elongated alpha particle tracks and to enlarge the damaged tracks at will.

B20 EFFECT OF ETCHING INTERRUPTIONS ON TRACKS FORMATION IN PLASTICS. Baroni, G.; Di Liberto, S.; Romano, G.; Sgarbi, C.; Tabasso, M. C. (Univ., Rome. Istituto Nazionale di Fisica Nucleare, Rome). *Nucl. Instrum. Methods*; 98: No. 2, 221-7 (1972).

The effect of etching interruptions on track formation has been studied in nitrocellulose plastic sheets using α -particle tracks. The "step effect" is remarkable on some parameters of the tracks while on others, as the lengthening with development time (that is the most useful in identification of high ionizing tracks) it seems to be absent. An attempt is made to interpret this effect on the basis of the known dissolution properties of polymers.

B21 PROLONGED ETCHING FACTOR IN SOLID STATE TRACK DETECTION AND ITS APPLICATIONS. Khan, H. A.; Durrani, S. A. (Univ. of Birmingham, Eng.). *Radiat. Eff.*; 13: No. 3-4, 257-66. (April, 1972).

It was observed that the number density of etch pits resulting from spontaneous or induced fission within a solid state track detector (SSTD) is a function of the duration of etching, other conditions being constant. As the etching proceeds, the net number of etch pits observed per unit area continues to increase. This necessitates a modification of the conventional equations governing the observed etch-pit densities in SSTD. A prolonged etching factor $f(t)$ is defined, and its value measured as a function of time under various specific etching conditions, in a number of materials of interest, including "reference glass". Furthermore, the theoretical relationship of this factor with the general velocity of etching in a given material, and with the average range R of fission fragments in it, is utilized in deriving self-consistent and very satisfactory values of R in the above-mentioned materials.

B22 TRACK-DIAMETER KINETICS IN SOLID STATE NUCLEAR TRACK DETECTORS. Somogyi, G.; Szalay, A. S. (Eötvös Loránd Univ., Budapest). *ATOMKI (At. Kut. Intez.) Közlem.*; 14: No. 3, 113-160 (1972). (In Hungarian).

The diameters (generally minor and major axes) of etch-pits in dielectric nuclear track detectors are gradually increasing while being etched. The general theoretical description of this phenomenon (track-diameter kinetics) is given, considering particles entering the detector at arbitrary angles. The model has been extended to both isotropic and anisotropic detector solids. Formulas describing the variation of track-diameters during the etching process in the case of constant and varying etching rate along the particle trajectory are discussed. The characteristics of the model are illustrated with special cases. On the basis of these theoretical results some new methods for the experimental determination of particle parameters (etching rate along trajectory, entrance angle, and range) are suggested. These methods, applied to studying etch-pits of spontaneous fission fragments registered in detectors like glass, can help in hunting for superheavy transuranic elements.

B23 ETCHING OF POLYCARBONATE CHARGED PARTICLE DETECTORS BY AQUEOUS SODIUM HYDROXIDE. Paretzke, H. G. (Institut fuer Strahlenschutz, Neuherberg, Ger.); Gruhn, T. A.; Benton, E. V. *Nucl. Instrum. Methods*; 107: No. 3, 597-600 (1973).

The chemical composition of the reaction products of polycarbonate film and aqueous NaOH has

been studied. This system is widely used for the development of charged particle tracks. The principal organic component of the aqueous phase is the anion of Bisphenol A. When large amounts of plastic have been decomposed the anion of phenol may become a major species. A method employing ultra-violet absorbance is suggested for monitoring the concentration of the etch products in the solution. The composition of an etching solution becomes more complicated with increasing age as a result of air oxidation. A remarkable difference between the polycarbonate types Lexan and Makrofol KG has been found since the bulk etching rate of Makrofol KG is independent of etch product concentration. Studies of this type are aimed towards a more fundamental understanding of the bulk and track etching processes.

B24 ETCH KINETICS OF HEAVY ION TRACKS IN SOLID STATE TRACK DETECTORS. Haegeman, D. (Inst. of Atomic Physics, Bucharest). *Rev. Roum. Phys.*; 17: No. 9, 1023-9. (1972).

The variation of the track attack rate, v_r , with respect to the Restricted Energy Loss of the bombarding particle is obtained starting from the hypothesis that the track diameter is due only to the bulk rate v_b . It is concluded that the track diameter is not a parameter depending on the particle ionization. The length of the entrance cone, which is due to the unsaturated etchant, is found to depend on both the charge of the particle and the temperature of the etchant.

B25 JUL-787-ST. FESTSTELLUNG GUNSTIGER ATZBEDINGUNGEN ZUR NICHTOTOGRAFISCHEN KERNSPURREGISTRIERUNG. Heinzelmann, W., and Haschke, W. Jülich, Germany. p159. (1971).

Abstract not available.

B26 IMPROVEMENT IN PARTICLE TRACK ETCHING IN LEXAN POLYCARBONATE FILM. Peterson, D. D. (General Electric Research and Development Center, Schenectady, N.Y.) *Ref. J46*. pp. 181-185. (1970).

An improvement in the process of particle track etching in Lexan polycarbonate film has been made leading to smoother track profiles. The improvement is based on the findings that in aqueous sodium hydroxide, the bulk etching increases with an increase in the concentration of etch products in solution. The rate reaches a maximum value at the etch product solubility limit, and remains at this value in the

presence of etch product precipitation. Using an etchant saturated with etch products, the track profile is smooth compared with the irregular profile obtained with an unsaturated etchant. Alternatively, the saturated etchant can be prepared by adding the compound Bisphenol A to aqueous sodium hydroxide. Using a saturated etchant, the etched track length (L) is given by $L \sim R^{-\alpha}$, where R is the residual range and $\alpha \approx 1$, for heavy cosmic rays that come to rest in a stack of thin Lexan films.

B27 CHEMICAL DEVELOPMENT OF TRACKS IN ORGANIC NUCLEAR TRACK DETECTORS. Benton, E. V. (Univ. of San Francisco). Ref. J46. pp. 127-146. (1970).

In recent years organic nuclear track detectors have found wide application in several different scientific fields including physics, geophysics, and biophysics. They are utilized for the selective recording of very heavily ionizing, energetic, charged particles. Particle tracks are observed after a chemical etching treatment of the irradiated detectors. This serves to enlarge the particle damage trails to optically visible dimensions. A variety of chemical etchants and techniques have been proposed and utilized. The most commonly used of the chemical etchants, as utilized with the most important track detecting materials, are reviewed. For track development, the etchant must have access to the latent track region. Since etchants do not readily diffuse through the bulk material, only latent tracks that cross the detector surface are developed. For certain applications this has been a serious shortcoming. A technique is presented which allows the

development of tracks within the volume of the detector. This technique will be useful in a variety of applications that require the visualization of complete sets of tracks (such as nuclear "stars"), or visualization of tracks deep in the detector volume away from external surfaces. The increased number of visible tracks will in turn result in the enhancement of detector sensitivity, i.e., make possible the measurement of infrequently occurring events.

B28 IMPORTANT PRECAUTION IN THE ETCHING OF SOLID STATE NUCLEAR TRACK DETECTORS. Khan, H. A. (Univ. of Birmingham, Eng.) Eng. J. Nucl. Instrum. Methods; 109: No. 3, 515-519 (1973).

The effects of etch product layer on (a) the etch pit diameter and (b) the general etching velocity, V_g , have been studied in a number of Solid State Nuclear Track Detectors. Observations were made under various etching conditions and attempts were made to reduce the adverse effects of the etched product layer. The results show that (a) the effect of the etch product formation is more serious in the case of oblique tracks (as compared with perpendicular or near perpendicular ones) and (b) the method of mechanical brushing of the detector surface during the etching process is quite effective in removing this layer.

B29 ETCHING BEHAVIOUR OF A CELLULOSE NITRATE PLASTIC DETECTOR UNDER VARIOUS ETCHING CONDITIONS. Eage, W.; Grabisch, K., Benjean, R. and Bartholme, K. P. Nuc. Inst. Meth. 115, 263-270. (1974).

Abstract not available.

C. ETCH TRACK ENHANCEMENT AND COUNTING

C1 SEMI-AUTOMATIC MICE-2 MICROSCOPE FOR MEASURING GEOMETRIC PARTICLE TRACK PARAMETERS IN NUCLEAR EMULSIONS. Raguzin, R. M.; Sharygin, N. V.; Fedorova, N. M. (Leningrad Joint Optical-Mechanical Plants). Prib. Tekh. Eksp., No. 2, 51-5 (Mar.-Apr. 1966). (In Russian).

A semi-automatic device for determining and recording X, Y, and Z coordinates is described. Further determination of geometric parameters was carried out with the universal computing machines according to the preliminary design program using group numbers in the computer. The precision of the X and Y coordinate determination is 0.005 and 0.0001

mm and 0.001 and 0.0002 mm for Z, depending on the method of determination on the table or in the microscope field. The plate dimensions ranged from 60 X 40 to 120 X 220 mm².

C2 (ANL-TRANS-599) AUTOMATIC EVALUATION OF NUCLEAR TRACK PLATES AND SOLID DETECTOR PLATES. Bitter, F.; Fiedler, G.; Wolnik, H. Translated by Elmer K. Weip (Argonne National Lab., Ill.), from Nucl. Instrum. Methods, 51: 241-4 (1967). 9 p.

An orthogonal mechanical scanner is described which makes the time consuming and tedious tasks of

visual scanning of nuclear emulsions and solid detector plates in special cases obsolete. With this instrument in about 120 min a plate of 2.5 X 7.5 cm² can be scanned completely in 10 μ m wide stripes with a velocity of 2.8 cm/sec. The advantage of this instrument is the electronic pulse-length discrimination which makes it unnecessary to use several photomultipliers and several channels of discriminators. The handling of the instrument as well as the particle identification thus is very much simplified. The instrument is used to scan the mass spectrum of fission particle tracks in nuclear emulsions as well as in solid detectors.

C3 (KAPL-3412) TRACK DENSITY MEASUREMENT IN DIELECTRIC TRACK DETECTORS WITH SCATTERED LIGHT. Schultz, Warner W. (Knolls Atomic Power Lab., Schenectady, N.Y.). (Jan. 1968). 13 p.

Fission track densities in glass and in Lexan polycarbonate resin have been measured using light scattered from the tracks as a measure of the track density. Scattered light was found to be proportional to track density up to the point where tracks begin to overlap. For the two track detector materials tested, a scattering angle was found at which optimum signal-to-background ratios are obtained.

C4 AUTOMATIC OPTICAL REGISTRATION AND COMPUTER ANALYSIS OF ETCHED ION-TRACKS IN POLYMER FOILS. Abmayr, W.; Gruenauer, F.; Burger, G. (Gesellschaft fuer Strahlenforschung MBH., Neuberberg, Ger.). Ref. J17. pp III.46-55. (1969).

The improvements of the ion track registration technique in insulating solids requires the development of suitable methods for automatic track analysis. The basic idea of the method discussed is to digitalize the electronic information obtained from a microscopic pattern by an optical scanning device, and to feed it into a computer. Then, it is possible to perform every desirable pattern analysis by suitable programming. This method of software analysis is evidently most efficient when on-line techniques can be used.

C5 RAPID READING TECHNIQUE FOR NUCLEAR PARTICLE DAMAGE TRACKS IN THIN FOILS. Cross, W. G.; Tommasino, L. (Atomic Energy of Canada Ltd., Chalk River, Ont.). Ref. J17. pp III. 73-85. (1969).

The low background of damage track detectors allows them to measure low integrated fluxes of charged particles or neutrons. When good statistical accuracy is desired, the long times required for visual

track counting under the microscope may seriously limit the number of measurements, particularly when the track density is low. A technique has been developed for automatically counting etched tracks that pass through a thin film. Very simple and inexpensive equipment is required. The insulating film is placed between a plane, high-voltage electrode and a thin layer of Al. A spark, passing through the film along a damage track, evaporates a hole in the Al. A second spark is prevented from starting through the same hole, so that the discharge passes successively along each track and then stops. Sparks are counted with a scaler. The patterns of holes in the Al provides a visible replica of the pattern of tracks. Track densities from background level to 3000 tracks/cm² can be measured. Areas up to 100 cm² are usually counted in less than 10 seconds, with an error of a few percent in the number of tracks. The technique has been applied to neutron dosimetry and to measurements of angular distributions in photofission.

C6 IMPROVEMENTS OF TRACK VISUALIZATION BY USING AN INTERFERENCE CONTRAST METHOD. Piech, E. (Kernforschungszentrum, Karlsruhe, Ger.). Ref. J17. pp III. 66-72. (1969).

For the purpose of solid-state dosimetry, when no geometrical analysis of nuclear tracks is necessary, the interference contrast equipment shows several advantages for nuclear track counting including a brilliant relief image of etch pits, a good discrimination of the etch pits to the background, and the possibility to improve the contrast by changing the color of the image. Color slides demonstrate different applications of track counting by means of the interference contrast method including nuclear track counting of fission fragments in phosphate glass and mica and alpha particles in plastic foils.

C7 ENHANCEMENT OF TRACK ETCHING BY A SPARK DISCHARGE. Blanford, G. E. Jr.; Walker, R. M.; Wefel, J. P. (Washington Univ., St. Louis). Ref. J17. pp II. 95-101. (1969).

It was found that the rate of track etching of heavy-ion tracks in Lexan polycarbonate is greatly increased when the track-containing plastic is stored in a container in which a spark-discharge is occurring. A series of simple experiments, using a Tesla coil as the spark source, that have led to the opinion that the effect is caused by the interaction of excited gas species with the stored tracks is described. It does not appear to be caused either by a direct electrical effect of the dis-

charge or by light given off by the spark. This new effect can potentially be used as a method to both sensitize and stabilize plastics containing charged particle tracks.

C8 ENHANCEMENT OF TRACK ETCHING BY A SPARK DISCHARGE. Blanford, G. E. Jr.; Walker, R. M.; Wefel, J. P. (Washington Univ., St. Louis). Ref. J17, pp III, 42-45. (1969).

An interesting effect has been observed in the development of charged particle tracks in Lexan polycarbonate. The rate of track etching is greatly increased when the irradiated plastic is stored in a container with a spark-discharge. Several simple experiments indicated that chemical species formed by the spark-discharge react with the damage sites caused by the charged particle. The effect of this reaction is to increase the hydrolysis rate of the plastic material along the track. The experiments which lead to these conclusions are discussed and some of the experiments which have been done or are being planned to specify the chemical causing track etching enhancement are mentioned.

C9 OBSERVATION OF FLUORESCENT TRACKS. Parizet, M. J.; Monnin, M. (Univ., Clermont-Ferrand, France). Ref. J18, pp IX, 6. (1969). (In French).

A method using fluorescence was developed in order to reduce background noise and measure nuclear tracks to a greater accuracy. The method utilizes the fact that the tracks are hollow canals.

C10 TRACK VISUALIZATION WITH SOLVENTS. Sanzelle, S.; Monnin, M. (Univ., Clermont-Ferrand, France). Ref. J17, pp III, 24-6. (1969). (In French).

Several plastics, and particularly methyl polymethacrylate, were studied. After irradiation the samples were immersed in ethanol at 70°C during 1.5 min. Then they were treated by boiling water during 30 sec. The results of these experiments are given.

C11 TRACK REVEALING AND VISUALIZATION. Medveczky, L. (Magyar Tudományos Akadémia Atommag Kutató Intézete, Debrecen, Hungary). Ref. J17, pp III, 2-13. (1969).

Procedures suitable for rendering tracks visible with an optical microscope are presented. Methods facilitating the observation of the tracks with a microscope and their visualization by other means are discussed. (37 references).

C12 (AECL-3430; PR-B-82). BIOLOGY AND HEALTH PHYSICS DIVISION PROGRESS REPORT. 1 Apr. - 30 Jun. 1969. Atomic Energy of Canada, Ltd., Chalk River (Ontario). 47 p. (30 Jun. 1969).

C13 SPARK SCANNING FOR FISSION FRAGMENT TRACKS IN PLASTIC FOILS. Lark, N. L. (Univ. of Copenhagen). Nucl. Instrum. Methods, 67: 137-40 (Jan. 1, 1969).

A new technique is described for detecting fission-fragment tracks in thin foils of polycarbonate plastic (Makrofol). First, a sodium hydroxide solution is used to selectively etch away the damaged material along the track, producing microscopic holes through the foil. Then, a spark gap is used as a fast scanning device for detecting the holes and enlarging them to a size visible to the unaided eye.

C14 HOLE DETECTION IN POLYMER FILMS AND IN PLASTIC TRACK DETECTORS. Blok, J.; Humphrey, J. S. Jr.; Nichols, G. E. (General Electric Research and Development Center, Schenectady, N. Y.). Rev. Sci. Instrum., 40: 509 (Mar. 1969).

A method for rapidly detecting the holes due to the charged particle in thin sheets of plastic track detectors is described. The method consists of placing the polymer in contact with a sheet of Ozalid paper and passing the pair slowly through the ammonia stage of a conventional Ozalid machine.

C15 PARTICLE TRACK ENHANCEMENT IN CELLULOSE NITRATE BY APPLICATION OF AN ELECTRIC FIELD. Crannell, Hall; Crannell, Carol Jo; Kline, F. J.; Battist, Lewis (Catholic Univ. of America, Washington, D. C.). Science, 166: 606-7 (Oct. 1969).

The number and length of etchable tracks, created by alpha particles in a cellulose nitrate sheet, are significantly enhanced by the application of an electric field across the cellulose nitrate.

C16 COMPUTER-CONTROLLED MICROSCOPE FOR SCANNING FISSION TRACK PLATES. Cohn, Charles E.; Gold, Raymond; Pienias, Thaddeus W. (Argonne National Lab., Ill.). Trans. Amer. Nucl. Soc., 12: 68 (June 1969).

From 15th Annual Meeting of the American Nuclear Society, Seattle, Wash.

C17 ENHANCEMENT OF ALPHA PARTICLE TRACKS IN CELLULOSE NITRATE USING ELECTRIC FIELDS. Crannell, Carol Jo; Crannell,

Hall; O'Sullivan, Colm (Catholic Univ. of America, Washington, D.C.). IEEE (Inst. Elec. Electron. Eng.), Trans. Nucl. Sci.; NS-17: No. 3, 337-9 (June 1970).

We have observed that the application of an electric field across samples of cellulose nitrate during irradiation by alpha particles enhances the formation of etchable tracks. The track formation efficiency has been studied as a function of the strength of the electric field for alpha particles energies from 2.75 to 5.0 MeV. Both the number of etchable tracks and the amount of damage along individual tracks have been found to be enhanced by the application of an electric field. Approximately the same enhancement is observed either if the field is applied during irradiation by alpha particles or if the field is applied, then turned off before the irradiation is initiated. It is hypothesized that phenomena, associated with corona discharge in the air near the surface of the dielectric sample, is responsible for the observed enhancement. The present results are dominated by chemical effects which elapse any indication of enhancement due directly to the application of an electric field.

C18 RAPID-READING TECHNIQUE FOR NUCLEAR PARTICLE DAMAGE TRACKS IN THIN FOILS. Cross, W. G.; Tommasino, L. (Chalk River Nuclear Labs., Ont.). Radiat. Eff.; 5: 85-9. (Aug. 1970).

The low background of damage track detectors allows them to measure low integrated fluxes of charged particles or neutrons. When good statistical accuracy is desired, the long times required for visual track counting under the microscope may seriously limit the number of measurements, particularly when the track density is low. A technique has been developed for automatically counting etched tracks that pass through a thin film. Very simple and inexpensive equipment is required. The insulating film is placed between a plane, high-voltage electrode and a thin layer of Al. A spark, passing through the film along a damage track, evaporates a hole in the Al. A second spark is prevented from starting through the same hole, so that the discharge passes successively along each track and then stops. Sparks are counted with a scaler. The pattern of holes in the Al provides a visible replica of the pattern of tracks. Track densities from background level to 3000 tracks/cm² can be measured. Areas up to 100 cm² are usually counted in less than 10 seconds, with an error of a few per cent in

the number of tracks. The technique has been applied to neutron dosimetry and to measurements of angular distributions in photofission.

C19 SENSITIVE AUTOMATIC COUNTING OF ALPHA PARTICLE TRACKS IN POLYMERS AND ITS APPLICATION IN DOSIMETRY. Johnson, D. R.; Boyett, R. H.; Becker, K. (Oak Ridge National Lab., Tenn.). Health Phys.; 18: 424-7 (Apr. 1970).

Following the successful use of the spark counting technique for automatically counting fission fragment tracks in polymer films, investigations have been carried out to extend this simple technique to counting alpha tracks in cellulose nitrate. The counter and the counting system are described. Details of the preparation of cellulose nitrate thin films are given. The use of the technique for dosimetry of radon daughters in the uranium mining industry; for conventional autoradiography; for fast neutron dosimetry using (n,f), (n, alpha), and recoil reactions; as an imaging system for neutron radiography; and for neutron-induced autoradiography of fissile elements such as plutonium and uranium is discussed.

C20 TRACK REVEALING AND VISUALIZATION. Medveczky, L. ATOMKI (At. Kut. Intez.) Kozlem.; 12: 11-15 (June, 1970).

The procedures for revealing the particle tracks in dielectric track detectors in order to make them visible under an optical microscope are described including direct observation in an electron microscope; decoration-forming an optically-distinguishable phase layer of material along the damaged track; and chemical etching. (37 references)

C21 USING A PHOTOELECTRIC COLORIMETER FOR COUNTING CHARGED PARTICLE TRACKS ON THE SURFACE OF GLASS DETECTORS.

Khovanovich, A. I.; Pikalov, G. L.; Kryvokrysenko, I. F. This paper was summarized in *Ac. Energ. (USSR)*; 29: No. 5, 367 (Nov. 1970), as paper No. 443/5530. (In Russian).

A method for counting tracks using the type FÉK-M photoelectric colorimeter is examined. This method is based on the dependence of the change in the optical density of the detector on the number of tracks and the regimes of its chemical processing. The method is simple, dependable in practice, and does not require large time expenditures for scanning the detectors. The range of measured track densities depends on

the etching regime and equals $5 \cdot 10^3$ to 10^7 cm⁻². The root-mean-square error of a single measurement of track densities with a confidence coefficient of 0.7 is not greater than $\pm 8\%$.

C22 ENHANCEMENT OF TRACK ETCHING BY A SPARK DISCHARGE. Blanford, G. E. Jr.; Walker, R. M.; Wefel, J. P. (Washington Univ., St. Louis). *Contracts Z-80058T; NAS 9-8352. Radiat. Eff.*; 3: 263-6. (June, 1970).

It is found that the rate of track etching of heavy-ion tracks in Lexan polycarbonate is greatly increased when the track-containing plastics are stored in a container in which a spark-discharge is occurring. A series of simple experiments, using a Tesla coil as the spark source, were conducted that have led to the view that the effect is caused by the interaction of excited gas species with the stored tracks. It does not appear to be caused either by a direct electrical effect of the discharge or by light given off by the spark. This new effect can potentially be used as a method to both sensitize and stabilize plastics containing charged-particle tracks.

C23 DUAL MICROSCOPE COMPARATOR FOR FISSION TRACK STUDIES. Dooley, J. R. Jr.; Taylor, R. B.; Jurceka, F. J. (Geological Survey, Denver). *Rev. Sci. Instrum.*; 41: 887-8. (June, 1970).

Two monocular microscopes have been simply combined, making use of a single stage and adjustable specimen holder, to facilitate uranium distribution studies by the induced fission track method. The sample and Lexan fission track detector can be readily compared at magnifications from about 25 to 400 X. The dual microscope comparator is a practical instrument for rapid visual correlation of fission tracks with their uranium bearing source with a precision approaching the etched track length in Lexan ($\approx 14 \mu$).

C24 SOLID TRACK DETECTORS: ANALYSIS OF DATA AFTER DEVELOPMENT. Blanc, Daniel (Toulouse Univ., France). *Radioprotection*; 5: 115-46. (1970). (In French).

The different methods used for the counting of developed tracks and the studies in spectrometry by solid track detectors are presented. A mechanism of track formation and development is established.

C25 AUTOMATIC SYSTEM FOR COUNTING ETCHED HOLES IN THIN DIELECTRIC PLASTICS. Congel, F. J. (Macalester Coll., St. Paul); Roberts, J. H.; Strait, E. N.; (and others). *Trans. Amer. Nucl. Soc.*; 13: 524. (Nov. 1970).

C26 COUNTING OF HEAVILY ETCHED FISSION FRAGMENT TRACKS IN POLYCARBONATE.

Gilliam, D. M.; Knoll, G. F. (Univ. of Michigan, Ann Arbor). *Trans. Amer. Nucl. Soc.*; 13: 526. (Nov. 1970).

C27 AUTOMATIC COUNTING OF SOLID-STATE FISSION TRACK RECORDERS. Oosterkamp, W. J. (Kernforschungszentrum, Karlsruhe, Ger.); Schaar, J.; Van Velze, P. L. *Trans. Amer. Nucl. Soc.*; 13: 526-7. (Nov. 1970).

C28 USE OF SPARKING TECHNIQUES TO ENHANCE TRACK-ETCH RADIOGRAPHS. Oltman, B. G. (Argonne National Lab., Ill.); Congel, F.; Lapinski, N. P.; Berger, Harold. *Trans. Amer. Nucl. Soc.*; 13: 531-2. (Nov. 1970).

C29 CONTRAST IMPROVEMENT OF IMAGES OBTAINED IN CELLULOSE NITRATE FILM BY TRACK-ETCH METHODS. Barbier, J. (Kodak-Pathe Research Lab., Vincennes, France). *Trans. Amer. Nucl. Soc.*; 13: 530. (Nov. 1970).

C30 SEMI-AUTOMATIC SCANNING OF TRACKS IN PLASTICS. Khen, H. A. (Univ. of Birmingham, Eng.). *Radiat. Eff.*; 8: No. 1-2, 135-8. (Mar. 1971).

Light scattering (spot density) was found to be a good method of counting tracks in 127- μ m thick plastic foils which were exposed to ²⁵²Cf fission fragments and alpha particles and then etched in 6.25 N KOH. The effects of etching time were studied, and foils of Lexan, Macrofol, and cellulose acetate (T-Cellit) were calibrated for a method for semi-automatic scanning of tracks. The reproducibility of the method was determined in tests. For very low fluxes, a red dye method was devised which results in easily seen impressions of the holes; 10- μ m thick Macrofol foils gave almost quantitative yields for 25 or 65 fission fragments.

C31 METHOD FOR DEVELOPMENT OF VOLUME TRACKS IN DIELECTRIC NUCLEAR TRACK DETECTORS. Beaton, E. V. (Univ. of California, Berkeley). *Nucl. Instrum. Methods*; 92: 97-9. (1971).

For track development in dielectric nuclear track detectors, the etchant must have access to the latent track region. Since etchants do not readily diffuse through the bulk material, only latent tracks that cross the detector surface are developed. This inability to develop volume-tracks, those that do not cross a detector surface, is perhaps the single, most serious shortcoming of these detectors. A special technique for the development of volume tracks is presented.

C32 ANALYSIS OF AUTOMATIC FISSION TRACK SCANNING DATA. Gold, Raymond; Cohn, Charles E. (Argonne National Lab., Ill.). *Trans. Amer. Nucl. Soc.*; 14: No. 2, 500 (Oct. 1971).

From Joint meeting of the American Nuclear Society; Miami Beach, Fla. (17 Oct. 1971).

C33 ANALYSIS OF AUTOMATIC FISSION TRACK SCANNING IN SOLID-STATE NUCLEAR TRACK RECORDERS. Gold, Raymond; Cohn, Charles E. (Argonne National Lab., Ill.). *Rev. Sci. Instrum.*; 43: No. 1, 18-28 (Jan. 1972).

A computer controlled microscope has been developed for the automatic scanning of fission tracks in solid-state track recorders. Emphasis has been placed on the attainment of absolute accuracy comparable to that already demonstrated in manual track scanning. Analysis of automatic fission track data is considered in detail. It is demonstrated that track overlap or pileup can be accurately described within the framework of the paralyzable counter model. Absolute calibration of this system has been successfully carried out for Makrofol solid-state track recorders. Absolute fission rate measurements by automatic track scanning of Makrofol have been established with at least as high an accuracy as that of manual track scanning. Limitations due to effects of nonuniformity in fission track density have been estimated. Extension of these precise capabilities to mica solid-state track recorders has been attempted. In contrast with Makrofol, unresolved difficulties have been encountered in the automatic scanning of mica.

C34 AUTOMATIC SYSTEM FOR COUNTING ETCHED HOLES IN THIN DIELECTRIC PLASTICS. Congel, F. J. (Macalester Coll., St. Paul); Roberts, J. H.; Dreis, D.; (and others). *Nucl. Instrum. Methods*; 100: No. 2, 247-52. (1972).

The rapid determination of track densities in dielectric plastics is desirable for many experiments. A fast spark discharge counting system similar to that described by Cross and Tommasino has been built for use with thin polycarbonates exposed to fission fragments. Experimental details concerning construction, calibration, and use of this system are discussed and the accuracy of the system is evaluated. An efficiency of about 80% was determined for this apparatus. This system is very useful in investigations where track densities less than 100 tracks/cm² are encountered and where a reproducibility of $\pm 10\%$ is acceptable.

C35 COMPUTER-CONTROLLED MICROSCOPE FOR AUTOMATIC SCANNING OF SOLID-STATE NUCLEAR TRACK RECORDERS. Cohn, Charles E.; Gold, Raymond (Argonne National Lab., Ill.). *Rev. Sci. Instrum.*; 43: No. 1, 12-17. (Jan. 1972).

An optical microscope having computer control of specimen motion in three dimensions, via stepping motors, has been developed and used for automatic scanning of solid-state nuclear track recorders. Programming for this system includes provisions for detection and area measurement of individual tracks as well as automatic adjustment of focus.

C36 IMPROVED METHOD FOR LOCATING CHARGED PARTICLE TRACKS IN THIN PLASTIC SHEETS. Geisler, Fred; Phillips, P. R. (Washington Univ., St. Louis). *Rev. Sci. Instrum.*; 43: No. 2, 283-4. (Feb. 1972).

A new electrical method is presented for locating tracks of charged particles in very thin plastic sheets. Short high voltage pulses are employed rather than the steady voltages used previously. The method is applicable to plastic sheets of large area and of thickness down to 3.5 μ . The background is low and the efficiency greater than 85%.

C37 MAKING OF GRIDS ON PLASTIC DETECTORS. Birabeau, J. P.; Cordaillat, A.; Mendola, O. (CERN, Geneva). *Nucl. Instrum. Methods*; 99: No. 2, 355-7. (1972). (In French).

In order to facilitate the locating of tracks of charged particles in cellulose nitrate and polycarbonate (Makrofol, Lexan) foils, a method was developed for the photodeposition of translucent coordinate grids on these materials. The grids are resistant to the strongly caustic solutions used in developing tracks in plastic foils. (2 figures)

C38 PRECISE COORDINATE CONTROL IN FISSION TRACK URANIUM MAPPING. Haines, E. L. (California Inst. of Tech., Pasadena). *Nucl. Instrum. Methods*; 98: No. 1, 183-4. (1972).

The problem of locating minute mineral grains by fission track uranium mapping solved by means of a congruent transformation of the track detector's coordinate system.

C39 (EURFNR-953) WORK ON SOLID STATE TRACK RECORDERS. Guenther, Gudrum (Kernforschungszentrum, Karlsruhe (West Germany). Institut fuer Angewandte Reaktorphysik). Translation of report KFK-1461. 28 p.

Investigations for the routine application of solid state track recorders for measurements in SNEAK are described. A polycarbonate foil (Lexan) was chosen as a detector material satisfying all requirements. In this type of material fission products leave tracks which can be enlarged by etching until they are visible in a light microscope. A simple model of the etching process was compared to experimental results. In order to increase the contrast of the tracks against the background they were colored using a felt pen. The evaluation is performed with the image analyzer CLASSIMAT, an apparatus designed to count single particles. The operation of the CLASSIMAT was tested and calibration curves were taken. Using some experimental results the principle of operation was demonstrated. A modification of the CLASSIMAT is planned in preparation of a completely automated image analysis using a computer.

C40 (CEA-R-4063) CONSTRUCTION OF A SEMI-AUTOMATIC DEVICE FOR MEASURING NUCLEAR TRACKS. APPLICATION TO NEUTRON SPECTROMETRY AROUND THE LOW- AND MEDIUM-ENERGY ACCELERATORS AT SACLAY. Delsaut, Romeo. (Commissariat a l'Energie Atomique, Saclay (France). Centre d'Etudes Nucleaires). 91 p. (Oct. 1970). (In French).

Amongst the various methods commonly used for neutron spectrometry around accelerators, the use of nuclear emulsions is particularly interesting. This technique presents two major difficulties due to the fact that the analysis of the emulsions is lengthy and tedious, and that the neutrons measured around accelerators do not have a preferred direction. In order to solve these difficulties, a semiautomatic device for analyzing the emulsions was developed, which gives results used directly by a computer. The fixed emulsion was replaced by a mobile system of two emulsions perpendicular to each other. The validity of these methods was verified by measuring the spectrum of neutrons emitted by reaction $D(d,n)^3\text{He}$; the practical application is the determination of the spectrum of neutrons emitted by a plutonium fluoride source, and that of neutrons emitted in the Van de Graaff tandem chamber at Saclay. The results obtained are very satisfactory and indicate that the two techniques proposed make it possible to widen the field of application of nuclear emulsions to the spectrometry of neutrons having an unknown incident direction, and also improve the conditions in which the emulsion is analyzed.

C41 ELECTRONIC COUNTING AND PROJECTION OF ETCHED TRACKS IN SOLID STATE NUCLEAR TRACK DETECTORS (SSNTD). Khan, H. A.; Durrani, S. A. (Univ. of Birmingham, Eng.). Nucl. Instrum. Methods; 101: No. 3, 583-7. (1972).

A surface barrier detector coupled with a thin plastic SSNTD has been used to determine moderately high fission fragment fluences, employing beams of alpha particles as probes. An attempt has also been made to use the system for estimation of fission fragment average energies. Also, etched tracks in glasses and thin mica sheets have been optically projected to facilitate visual counting of low track densities.

C42 STUDIES OF NUCLEAR TRACK VISUALIZATION IN SYNTHETICS. Paretzke, H. G. TU Munchen. (1972).

C43 FISSION TRACK OBSERVATION BY THE REFLECTIVE SURFACE TECHNIQUE. Seitz, M., et al. Earth Planet Science Letters in Press.

C44 NEW READING SYSTEM FOR AN IONOGRAPHIC DETECTOR. Chapuis, A. M. (CEN, Fontenay-aux-Roses, France); Soudain, G.; Gerard, N. Radioprotection; 7: No. 1, 13-20. (1972). (In French).

The track density may be obtained from an ionographic detector from measurements of the light transmitted by the detector, which incorporates a thin film of colored cellulose nitrate in which holes correspond to the particle tracks. Results obtained with a U source and radioactive aerosols are presented.

C45 IMPROVEMENT IN THE PERFORMANCE OF CELLULOSE NITRATE FILMS FOR THE DOSIMETRY OF IONIZING PARTICLES. Barbier, J.; Renard, G. (Societe Kodak-Pathe, Paris). pp 475-86 of New Trends in Radiation Protection. Montrouge, France; Societe Francaise de Radioprotection. (1972). (In French).

The Kodak LR 115 experimental film consists of a $10\ \mu$ thick film of α sensitive cellulose nitrate on an inert polyester substrate. It was discovered that the latent images of tracks recorded on this film are subject to considerable fading at high temperatures (70°C); this fading can exceed 60% in one hour. As the recommended development procedure involves treating the irradiated film with 2.5 N sodium hydroxide at 60°C for 90 minutes, it was suggested that the development process competes with the tendency of the track image to fade. It was suggested that low temperature development would reveal more information.

This assumption was proved valid. An improvement was made in the discrimination between the irradiated areas and the background by modifying the development process: 75 hours at 25°C instead of 90 minutes at 60°C. A simultaneous reduction in the background level was obtained because of the improved discrimination between irradiated and non-irradiated areas. This new method of utilizing the LR 115 film is of considerable interest in the dosimetry of weak α sources (10^{-15} Ci).

C46 DETERMINATION OF TRACK PARAMETERS BY DIFFRACTION METHOD USING LASER LIGHT.

Varnagy, M.; Szabo, J.; Juhasz, S.; Csikai, J. (Kossuth Univ., Debrecen, Hungary). Nucl. Instrum. Methods; 106: No. 2, 301-305. (1973).

Measurements were performed for determining the diameter of tracks by the Fraunhofer-diffraction method. A ≈ 1 mW He-Ne gas laser as a light source as well as cellulose acetate track detectors irradiated with alpha particles at different energies were used. The diameter of tracks determined by the diffraction method as well as those measured by microscope are in good agreement with each other.

C47 EVALUATION OF DIELECTRIC TRACK DETECTORS WITH DIFFRACTED LASER LIGHT.

Platzer, H. (Technische Univ., Munich); Abmayr, W.; Paretzke, H. G. Atonkernenergie; 20: No. 2, 162. (Feb. 1972).

A method for readout of dielectric track detectors based on the Fourier transform analysis of laser light diffraction patterns is discussed. The experimental setup is briefly described.

C48 INCREASING THE IMAGE CONTRAST OF PLASTIC DETECTORS WITH FLUORESCENT STAIN.

Fink, D. (Hahn-Meitner Institut fuer Kernforschung, Berlin). Nucl. Instrum. Methods; 107: No. 3, 615-616. (1973). (In German).

Plastic detectors were etched and rubbed in with fine grain fluorescent powder. Under dark field illumination with ultraviolet light, the irradiated zones showed up brightly with good contrast to unirradiated areas.

C49 (EUR-4896 (Vol. 1), pp 283-301) IMPROVEMENTS IN THE SPARK-COUNTING TECHNIQUE FOR DAMAGE-TRACK NEUTRON DOSIMETERS.

Cross, W. G.; Tommasino, L. (Chalk River Nuclear Labs., Ont.). (Sept. 1972).

Parameters governing spark counting of etched damage tracks in thin insulating foils were studied

with the objective of understanding the conditions that give more accurate and reliable counts. Variables investigated were foil thickness, track diameter, applied voltage, polarity of the thin electrode, air pressure, and time between sparks. The main cause of nonreproducible track counting was found to be double sparking in a track rather than failure of some tracks to pass a spark. The length and slope of the plateau in the curve of counts vs. voltage was improved by varying the air pressure during counting in such a way that all sparks occur at nearly the same voltage, by using positive polarity for the thin Al electrode and by controlling the time between sparks. For insulators 10 microns thick, slopes of 1%/100 volts, from 400 to 800 volts, were obtained and the reproducibility of repeated counts with the same insulator was about 0.5% (standard deviation for 10 measurements). The relation found between minimum sparking voltage and air pressure $\times$ distance, and between spark energy and the amount of aluminium evaporated, can explain the length of the plateau obtained under varying conditions. Improved track resolution and higher maximum hole densities were obtained in a sparking atmosphere of He. Percentage counting losses were proportional to hole density up to 5000 tracks/square cm, when 10% of the holes were missed.

C50 Monnin, M., Besson, H., Sanzelle, S., and Avan, L. C. R. Acad. Sci. Ser. B263, p1337 (1966).

Title and abstract not available.

C51 Monnin, M., Besson, H., Sanzelle, S., and Avan, L. C. R. Acad. Sci. Ser. B264, p1751 (1967).

Title and abstract not available.

C52 ELECTRICAL DETECTION OF FISSION FRAGMENT TRACKS FOR FAST NEUTRON DOSIMETRY.

Cross, W. G., and Tommasino, L. Health Phys. 15, p196. (1968).

Abstract not available.

C53 TRACK DENSITY MEASUREMENT IN DIELECTRIC TRACK DETECTORS WITH SCATTERED LIGHT.

Schultz, W. W. Rev. Sci. Instrum. 39, p1893 (1968).

Abstract not available.

C54 SPUREN IONISIERENDER TEILCHEN IN CD-DOTIERTEN AGCL-KRISTALLEN.

Breuer, K., Schopper, E., Haase, G., and Zorgiebel. Photogr. Korresp. 104, p 76. (1968).

Abstract not available.

C55 SEMI-AUTOMATIC SCANNING OF TRACKS IN PLASTICS. Khan, H. A. (Univ. of Birmingham, Eng.). Ref. J47. p 681-710. (1970).

Two attempted automatic scanning methods for particle tracks in dielectric track detectors for very high and very low fluences of fission fragments and alpha particles are described. One method is based on the scattering of visible light by the etched tracks; the other method is based on the dyeing of tracks by red ink. Results are presented and discussed.

C56 ELECTROCHEMICAL ETCHING OF DAMAGE TRACK DETECTORS BY PULSE AND SINUSOIDAL WAVEFORMS. Tommasino, I. (CNEN, Rome). Ref. J46. p 213-231. (1970).

An electrochemical etching process for increasing the sensitivity of dielectric track detectors is described. The irradiated plastic foil is placed between two Teflon cells containing etching reagent, usually 30% KOH in water. The output of the high-voltage function generator, which gives sinusoidal or positive square pulse waveforms is applied through the irradiated dielectric by two platinum electrodes placed directly in the reagent. Results are discussed.

C57 ANWENDUNG DER INTERFERENZ-KONTRAST-MIKROSKOPIE ZUR KERNSPURREGISTRIRUNG IN FESTKÖRPERN. Piesch, E. Zeiss Inform. 18, p58. (1970).

Abstract not available.

C58 DETERMINATION OF THE LENGTH OF ETCHED LOW ENERGETIC HEAVY ION TRACKS IN QUARTZ GLASS BY MEANS OF AN INTERFERENCE TECHNIQUE. Kraetschmer, W. (Max-Planck-Institut fuer Kernphysik, Heidelberg). Ref. J46. p 121-126. (1970).

From 7th international conference on corpuscular photography and visual solid detectors; Barcelona, Spain (7 July 1970).

Quartz glass was bombarded with various heavy ions (Cl, Fe, Br, I, U) in the energy range between 10 and 100 MeV. Under fixed etching conditions the lengths of the particle tracks were measured as a function of particle energy. The track lengths were determined from the interference pattern of the etchpits using a reflection interference microscope. By this technique an energy resolution of ± 2 MeV in the investigated energy region was achieved. For Br and heavier ions it was found that above 30 MeV the track length is a linear function of particle velocity. Com-

bined with diameter measurements, the track length gives information about nuclear charge and energy of the track forming particle.

C59 AUDIOVISUAL DISCRIMINATION FOR TRACK MEASUREMENTS IN EMULSIONS. Medveczky, L. (Inst. of Nuclear Research, Debrecen, Hungary). Ref. J47. pp. 671-674. (1970).

A semiautomatic digital microscope for readout of nuclear emulsion particle tracks is briefly described.

C60 Z-COORDINATE MEASUREMENTS IN PLASTIC-DETECTORS. Fukui, K. (Cambridge Research Labs., Bedford, MA); Beaujean, R.; Enge, W. Ref. J47. pp. 675-679. (1970).

From 7th international conference on corpuscular photography and visual solid detectors; Barcelona, Spain. (7 July 1970).

A study to determine the reliability of the reading of the z-coordinate of the tip of a track cone in dielectric track detectors is described. Direct measurements of the coordinate of the tips from the side view of the track were made.

C61 SOLID VISUAL DETECTORS: AUTOMATIC COUNTING OF TRACKS AND LAW OF LOSSES BY OVERLAPPING. Ruegger, B.; Richmond, R.; Zuercher, W. (Institut Federal de Recherches en Matiere de Reacteurs, Wuerenlingen, Switzerland). Ref. J47. pp. 723-728. (1970). (In French).

It has been shown that the amount of fission can be measured by means of plastic track detectors, the density of tracks being obtained with a Quantimet 720. The following have been established: the reproducibility of measurements to be better than 1%, a law of losses by overlapping, and the measurement of the distribution of the amount of fission of ^{235}U in a fuel cluster agrees very well with the results obtained by gamma counting. The method can thus be used for the general study of fission, relative and absolute, in the lattices of nuclear reactors.

C62 INSTRUMENTS FOR COUNTING TRACKS ON THE SURFACE OF SOLID TRACK DETECTORS. Zaichik, V. E. (Inst. of Medical Theology, Obninsk, USSR). Instrum. Exp. Tech. (USSR). (Engl. Transl.); 15: No. 6, 1669-1671. (1972). Translated from Prih. Tekh. Eksp.; 15: No. 6, 48-50. (1972).

An instrument has been developed for the automatic measurement of the numerical density of tracks on microsectors of the surface of detectors. The principle of operation of the instrument is based on

recording the light scattered by the detector surface. It is shown that for a diameter of α -tracks equal to 2 to 3 μ a linear dependence is observed between the photocurrent and the numerical density of the tracks in the range of $6 \cdot 10^5$ to $2.4 \cdot 10^7$ α -tracks/cm².

C63 CONDUCTIMETRIC STUDY OF CELLULOSE NITRATE AS A SOLID-STATE TRACK DETECTOR. Roux, F.; Bourdeaux Pontier, M.; Bisset, J. P.; Briand, C. (Univ., Marseille). *Int. J. Appl. Radiat. Isotop.*, 24: No. 9, 501-508. (Sept. 1973). (In French).

The different methods for the reading of solid-state track detectors are considered. An original method determining the dose received by cellulose nitrate irradiated by fission fragments or α particles is suggested. The technique depends on a change in electrical conductivity of the detector after being irradiated and etched by soda. It is possible to determine very high doses of irradiation by this rapid and precise method.

C64 IMPROVEMENT OF THE CHARGE RESOLUTION OF LEXAN POLYCARBONATE PLASTIC DETECTORS BY ULTRAVIOLET IRRADIATION. Enge, W.; Schmitt, H. O.; Bartholomae, K. P.; Beaujean, R. (Univ., Kiel). pp 2913-2918 of Twelfth International Conference on Cosmic Rays. Vol. 7.

Hobart, Australia; International Union of Pure and Applied Physics (1972).

The effect of ultraviolet irradiation on heavy-ion tracks in Lexan-polycarbonate was studied. Irradiations with wavelengths longer than 3000 Å keep the bulk etching rate v_b nearly constant whereas the track etching rate v_t increases strongly with increasing energy loss and with longer irradiation times. Thus the sensitivity v_t/v_b was increased by a factor of 4 to 40, i.e. the charge resolution on heavy ions can be improved by a factor of two to three applying irradiation in the order of days.

C65 RADIATION DETECTION THROUGH SOLID TRACK DETECTORS IN THE SCANNING MICROSCOPE. Paul, D. (Institut fuer Polymerenchemie, Berlin); Somogyi, G.; Haufe, G. *Isotopenpraxis*; 9: No. 4, 133-134. (Apr. 1973). (In German).

A cellulose acetate foil of 100 μ m thickness was irradiated by a planar 3 MeV alpha source. After exposure, the foil was etched for one hour in a solution of 20 g NaOH, 16 g KOH, 4.5 g KMnO₄, and 90 g H₂O at 70°C. Subsequently, the foil was coated with a 20 nm thick film of gold and placed into the scanning electron microscope. The alpha tracks appeared as holes with a mean diameter of 5.5 μ m. Both diameter and depth of the holes depended on the etching conditions.

D. FISSION FRAGMENT DETECTION

D1 EXAMINATION OF FISSION FRAGMENT TRACKS WITH AN ELECTRON MICROSCOPE.

Silk, E. C. H., and Barnes, R. S. (Atomic Energy Research Establishment, Harwell, Berks, Eng.). *Phil. Mag.* (8) 4, 970-2. (Aug. 1959).

Thin sheets, removed by cleavage from the surface layers of mica exposed to fission fragments from uranium, were examined in transmission in the electron microscope. Fission fragment tracks which are less than 300 Å in diameter and greater than four microns in length were seen superimposed upon a general background introduced by associated neutron bombardment. The nature of the tracks is discussed. The technique can be used to study radiation induced atomic displacements and the nature and behavior of the particles with high resolution.

D2 ELECTRON MICROSCOPE OBSERVATIONS OF FISSION FRAGMENT TRACKS IN THIN FILMS OF UO₂. Noggle, T. S., and Stiegler, J. O. (Oak Ridge National Lab., Tenn.). *J. Appl. Phys.*, 31: 2199-2208. (Dec. 1960).

Electron microscope studies of the tracks produced by fission fragments in thin films of UO₂ established a 100% detection efficiency for fission events in films 100 Å or less in thickness. A background texture decreases the efficiency in thicker films. The tracks register in the films primarily as a result of a redistribution of surface material arising from the disturbance produced by the continuous loss of energy of the fragment by electron excitation and ionization. The minimum rate of energy loss which registers as a track in the film is on the order of 1000 eV/Å. Track length

distributions, however, suggest that as yet unrecognized free surface effects may also contribute to the track registration.

D3 (AFOSR-981) ELECTRON MICROSCOPE INVESTIGATION ON THE NATURE OF TRACKS OF FISSION PRODUCTS IN MICA. Technical Note No. 3. G. Bonfiglioli, A. Ferro, and A. Mojoni (Turin. Istituto Elettrotecnico Nazionale Galileo Ferraris). (May 1961). 17 p.

To clarify some aspects of the damage caused to crystals by fission products, specimens of different micas were examined using the electron microscope, after suitable bombardment. Biotite, muscovite, and artificial fluorophlogopite and muscovite annealed at 900°C were observed after covering with a thin evaporated uranium layer and irradiation in a reactor up to an integrated flux of 10^5 thermal neutrons/cm². Tracks appeared on every specimen but biotite. The respective diameters of the tracks can be put into correspondence with their different resistance to thermal decomposition: larger in muscovite (240 Å), thinner in fluorophlogopite (150 Å), and still smaller in dehydrated muscovite (115 Å). These features supported the view that the mechanism of damage occurs through the heat that is released by the heavy ionizing particles. No tracks were observed in biotite, likely because of too rapid recovery effects. Some recovery effects were also observed in muscovite.

D4 FISSION FRAGMENT TRACKS IN METAL FILMS. Noggle, T. S., and Stiegler, J. O. (Oak Ridge National Lab., Tenn.). *J. Appl. Phys.*, 33: 1726-30. (May, 1962).

Fission fragment tracks observed in electron microscope studies of platinum and palladium films are interpreted in terms of thermal processes involving melting and vaporization. The results require that the energy lost by the fragment be converted into thermal energy over the entire volume of the track in a time short enough that little of it is conducted away. A model in which free electrons disperse the energy over this volume is used to account for the widths and structures of the tracks.

D5 (AERE-R-4066) THE NATURE OF FISSION FRAGMENT TRACKS IN URANIUM DIOXIDE. Whapham, A. D., and Makin, M. J. (Atomic Energy Research Establishment, Harwell, Berks, Eng.). p.G-5 of "Electron Microscopy, Vol. 1." New York, Academic Press, 1962.

Fission fragment tracks observed in single crystal

sheets of UO₂ were quite different from evaporated furrows observed in vacuum deposited films of UO₂ with a grain size of ~ 30 Å. The type of track formed seemed to depend upon the grain size of the material. Examination of films of various grain sizes by electron microscopy showed that only a few indistinct tracks are visible when the grain size is 100 Å, and no tracks can be seen in material with 150 Å grains. A possible explanation of the grain size effect is offered.

D6 FISSION-FRAGMENT TRACKS IN METAL AND OXIDE FILMS. Merkle, K. L. (Argonne National Lab., Ill.). *Phys. Rev. Letters*, 9: 150-2. (Aug. 15, 1962).

An isolated-particle model is presented to explain track formation in fission-fragment-irradiated thin films. Experimental evidence to support the model is based on observations on Au and Al films. The tracks are explained on the basis that fast-moving fission fragments lose energy mainly by electronic excitations causing localized particle heating and vaporization. Energy transfer processes are discussed for both the metal and metal oxide particle films.

D7 RECORDING OF NUCLEAR FISSION BY MEANS OF AMORPHOUS MEDIA WITH SiO₂. Perelygin, V. P., Tret'yakova, S. P., and Zvarz, I. (Joint Inst. for Nuclear Research, Dubna, USSR). *Pribery i Tekhn. Eksperim.*, No. 4, 78-80. (July-Aug. 1964). (In Russian).

A method of registering fragments from fission of nuclei in amorphous media containing SiO₂ is described. The method is based on etching the surfaces of the irradiated media by hydrochloric acid solutions.

D8 ETCHING AND ENLARGING OF FISSION FRAGMENT TRACKS BY ATMOSPHERIC MOISTURE. Caspar, P. E. (Cambridge Univ., Eng.). *Nature*, 201: 1203-4. (7 - 1964).

The preferential etching and enlarging of fission fragment tracks in nickel chlorides and bromides by atmospheric water vapor is reported.

D9 FACTORS CONTROLLING THE PRODUCTION OF FISSION-FRAGMENT TRACKS IN THIN METAL FILMS. Kelsch, J. J., Goland, A. N., and Paskin, Arthur (Brookhaven National Lab., Upton, N.Y.). *Phys. Chem. Solids*, 26: 203-7. (Jan. 1965).

The results of a quantitative investigation of the role of resistivity and film thickness in track production are reported. Using thin evaporated palladium films it was demonstrated that films whose resistivity approaches bulk values do not show evaporation tracks,

and that those whose resistivities are in excess of ten times bulk value do show such tracks. It was further demonstrated that tracks are not produced in films whose thickness is much in excess of the crystallite dimensions, even when the resistivity is high.

D10 SOME PRELIMINARY RESULTS OF THE DETECTION OF PRODUCTS OF FISSION AND OF FRAGMENTATION OF DIFFERENT AVERAGE AND HEAVY METALS UNDER THE EFFECT OF 3-GeV PROTONS BY DETECTION IN NEW SOLID DETECTORS. Debeauvais, Monique; Cueser, Pierre. (CRN, Strasbourg). *Compt. Rend.*, 261: 2633-6. (Oct. 1965). (In French).

The forward-backward ratio of heavy ion tracks produced by the action of protons on targets of natural U, Pb, Au, Ag and Cr were compared for the ion tracks recorded in micas and Makrofol. This ratio was higher than 1 in all cases except in Makrofol in the case of elements with low Z where it is <1.

D11 REGISTRATION OF FISSION FRAGMENT TRACK ON SOLID SURFACE. Kikuchi, Takeo (Japan Atomic Energy Research Inst., Tokyo). *Japan. J. Appl. Phys.*, 4: 386-7. (May, 1965).

Fission-fragment tracks were previously observed on a fractured surface of sintered UO_2 and on a surface of a LiF crystal. Relations between the two cases are considered. The relation between a dimension of a damaged region and a depth from which a track is registered on a surface is discussed.

D12 PRODUCTION BY FISSION FRAGMENTS OF LARGE TRACKS IN CRYSTALS. Caspar, P. E. (Cambridge Univ., Eng.). *J. Appl. Phys.*, 37: 427-30. (Jan. 1966).

Thin crystals of two nonmetallic compounds were irradiated with uranium fission fragments and the resulting damage investigated using the electron microscope. The light-contrast tracks observed were wider by a factor of over two than any previously reported and appeared to be directly produced by the passage of the fission fragments. Considerations of the rate of energy loss strongly suggest that the damage was produced by an ionization mechanism and that even these track widths are not the maximum which may be observed.

D13 FISSION-FRAGMENT DAMAGE IN EPITAXIAL FILM OF URANIUM DIOXIDE. Nasu, Shoichi; Shiozawa, Ken-ichi; Kikuchi, Takeo (Japan Atomic Energy Research Inst., Tokyo). *Jap. J. Appl. Phys.*, 5: 248 (Mar. 1966).

Electron microscope observations of irradiated epitaxial uranium dioxide films were made in order to examine the effects of factors such as the crystallography or film thickness on fission fragment track registration. A transmission electron micrograph of an epitaxial film after irradiation is shown. The mosaic or island structure of the epitaxial film is considered significant in the registration of the fission fragment tracks.

D14 (UCRL-17075) PROCEDURES FOR FINDING FISSION TRACKS IN MICA AND MYLAR. Kleppe, Lowell M.; Mary Roger, R. S. M. (California Univ., Berkeley. Lawrence Radiation Lab.). (Aug. 1966). 16 p.

A procedure is described for recording, etching, and counting the tracks of fission fragments in mica and Mylar resulting from the neutron bombardment of various heavy elements. Sensitivity comparisons as well as annealing and etching conditions for both mica and Mylar are described in detail. Tracks of fission fragments in mica and Mylar can be used to locate uranium and thorium in thin rock sections; mica and Mylar can be used with metals as threshold detectors for neutrons of different energies.

D15 ÄTZFIGUREN DER SPUREN VON U-SPALTUNGSRESTEN IN GLIMMERN. Krylov, I. N., Šukoljukov, Ju. A. and Ovcinnikova, G. V. (*Zap. vses. mineralog. Obšč.*) No. 2, 95, 450-53. (1966). (In Russian).

D16 SOME URANIUM FISSION FRAGMENT TRACK DATA FOR MICAS. Berzina, I. G. *Dokl. Acad. Sci. U.S.S.R., Earth Sci. Sect.*, 170, 143-145, 3 figs., 1966. Transl. from *Dokl. Akad. Nauk SSSR*, 170, 681-683. (1966).

D17 IDENTIFICATION OF ETCH FIGURES ON TRACKS OF FISSION FRAGMENTS IN IONIC CRYSTALS. Berzina, I. G., and Berman, I. B. (*All-Union Sci.-Res. Inst. Nucl. Geophys. and Geochem.*); *Soviet Phys.-Doklady*, Vol. 12, pp 484-486. (Nov. 1967).

D18 STRUCTURE AND HEALING OF TRACKS FROM NUCLEAR FISSION FRAGMENTS IN SINGLE CRYSTALS OF LiF AND $CaCO_3$. Geguzin, Ya. E.; Vorob'eva, I. V.; Suslova, A. G.; Demyanov, L. D.; Selina, L. S. (Kharkov State Univ.). *Dokl. Akad. Nauk SSSR*, 182: 552-4. (Sept. 1968). (In Russian).

The kinetics of the healing of tracks generated in crystals by the spontaneous or induced fission of heavy nuclei depends on the crystal structure, i.e., the distribution of defects within the limits of the track. Investigation of this problem in the case of LiF and

CaCO_3 crystals resulted in a new concept of the structure and the thermal stability of the tracks. The tracks in the LiF crystals were generated by the fragments of the ^{245}Cm nucleus at the rate of 10^4 tracks/ cm^2 per hour of irradiation; the CaCO_3 preparation with a ^{235}U was exposed to a flux of 10^4 n/ cm^2 in a thermal column. The tracks were developed by etching, using a saturated aqueous solution of FeCl_3 and formic acid for LiF and CaCO_3 , respectively; the angles were determined interferometrically. An increased level of defect distribution was noted in certain portions of the crystals similar to those resulting from stress in mica. This specific distribution of defects near the tracks is noticed especially during the healing process in LiF single crystals. It is concluded that during high-temperature annealing, these crystals become ordered, i.e., the degree of defects with a given depth as a function of time decreases.

D19 (SGAE-M-23) DETERMINATION OF DISTRIBUTION AND DEPTH OF PENETRATION OF FISSION FRAGMENTS IN METALS [BESTIMMUNG DER VERTEILUNG UND EINDRINGTIEFEN VON SPALTFRAGMENTEN IN METALLEN] Tutschek, E. and Koss, P. Oesterreichische Studiengesellschaft fuer Atomenergie G. m. b. H., Seibersdorf, Reaktorzentrum. 15 p. Refs. (1968). (In German).

D20 MASS AND ENERGY DISTRIBUTION OF FISSION FRAGMENTS FROM THEIR RANGES IN SOLID STATE DETECTORS. Alt-Salern, M.; Gerhardt, H.; Goennenwein, F.; Hipp, H.; Paap, H. (Univ., Tuebingen, Ger.). Nucl. Instrum. Methods, 60: 45-51. (Feb. 1968).

A method is given to take mass and kinetic energy distribution of fission fragments with solid state detectors. The target material is evaporated on two detector foils (acetylcelluloid in the present experiment) and the foils arranged to form a sandwich during irradiation and scanning under the microscope. This allows to measure simultaneously the ranges of the two correlated fragments in binary fission. An empirical range-energy relation for heavy ions in several stopping materials has been set up. Using this relation and — apart from minor corrections — mass and momentum conservation, the mass and energy of the fission fragments are calculated event by event. The results of an experiment on $^{238}\text{U}(n,f)$ induced by 15.3 and 4.65 MeV neutrons are compared with the findings obtained by other techniques. From the comparison range straggling data are found.

D21 MICA TARGETS WITH NEARLY A 4pi GEOMETRY FOR FISSION STUDIES. Boes, A. H.; Brandt, R.; Starke, K. (Univ., Marburg, Ger.). Ref. J18. pp VIII. 9-14. (1969).

A target system which allows the study of ternary fission of heavy elements with different bombarding particles approaching the 4pi geometry as close as possible is studied. Narrow holes are produced in mica by etching fission tracks. These holes are filled with a uranium compound. After irradiation the newly formed fission fragments can be made visible as fine tracks emerging from the original holes. The present status of this method is given.

D22 INVESTIGATIONS ON TERNARY PHOTO-FISSION WITH TRACK RECORDERS OF DIFFERENT SENSITIVITY. Medveczky, L.; Somogyi, G. (Magyar Tudományos Akademia Atommag Kutatási Intézete, Debrecen, Hungary). Ref. J18. pp VIII. 65-82. (1969).

The existence of the ternary photofission of ^{232}Th , ^{238}U and ^{239}Pu induced by a 27.5 MeV bremsstrahlung beam was studied simultaneously with track detectors of different threshold. In sandwiches prepared from both muscovite mica and plastic Melinex O about 1.5 million binary fission events were scanned. Data are given for the frequency of three prong events, two-prong events with a space angle smaller than 180° , and recoil events produced by the fission fragment scattered on ^{39}K and ^{16}O occurring in the material of the mica and plastic detectors, respectively. For the two first cases the range and angular distributions are presented. Results obtained in mica and plastic are compared. A background consisting of short tracks was discovered in plastic sandwiches containing ^{239}Pu . The track density shows a correlation with the concentration of target nuclei and the storage time before etching. A possible origin of these tracks is discussed.

D23 STUDY OF THE FISSION AND FRAGMENTATION OF HEAVY NUCLEI BY HIGH ENERGY PROJECTILES. Stein, R.; Romy, G.; Ralrosy, J.; Triplex, J.; Debeauvais, M. (Univ., Strasbourg). Ref. J18. pp VIII. 83-94. (1969). (In French).

The fission of heavy nuclei by alpha particles of energies up to 100 MeV was studied using the Makrofol as a detector. Using some rather involved techniques, it is easy to obtain accurate values for certain cross sections and mass and energy distributions. Events whose probabilities of occurrence are small may be counted, indexed, and studied kinetically and dynamically providing the different geometric parameters are known.

D24 DETERMINATION OF THE EFFICIENCY OF REGISTERING FISSION FRAGMENT TRACKS IN VARIOUS MATERIALS. Berman, I. B. (USSR). *Tr., Vses. Nauch.-Issled. Inst. Yad. Geofiz. Geokhim.* No. 7, 221-5. (1969). (In Russian).

D25 A POSSIBLE METHOD FOR MEASURING THE FISSION-FRAGMENT ENERGY BY MEANS OF SOLID-STATE DETECTORS. Solov'ev, S. M.; Eismont, V. P. (Radium Inst., Leningrad). *Izv. Akad. Nauk SSSR, Ser. Fiz.*, 33: 116-19. (Jan. 1969). (In Russian).

Direct measurements of the energy of fission fragments on the basis of the length of the tracks in a detector is difficult, even when the mean energies of the fragments are markedly different. In order to solve this problem, the energy (free path) resolution of the fission fragments was determined in the external medium, using a specially designed chamber placed in the neutron beam and containing two ^{235}U targets prepared by the vacuum evaporation of UF_4 . The fragments were recorded by 2 mica films; they entered the layer under an angle of less than 30° with respect to the normal. The chamber contained dry air at a pressure of 360 mm of Hg. After an exposure of four hours, the mica was etched with concentrated hydrofluoric acid at 75°C . The tracks thus obtained consisted of rhombic depressions, the surface of which was independent of the energy. From the longitudinal distribution of the tracks, the integral distribution curve could be obtained. Examination of the curve indicated that there were two groups of free paths recorded. The graphic differentiation yielded a "double-humped" spectrum. Use of an empirical correlation between energy and free path allowed one to determine the mean energy of the light and heavy fragments. More reliable data were obtained from relative measurements by comparing the curves of the paths of fragments resulting from nuclear reactions. Reference measurements were made by radiochemical methods.

D26 IDENTIFICATION OF ETCHING PATTERNS OF FISSION-FRAGMENT TRACKS AND THEIR USE FOR DETERMINING CLARKE CONCENTRATIONS OF URANIUM IN IONIC CRYSTALS. Berzina, I. G.; Berman, I. B. (USSR). *Tr., Vses. Nauch.-Issled. Inst. Yad. Geofiz. Geokhim.* No. 7, 204-15. (1969). (In Russian).

D27 IDENTIFICATION OF FISSION FRAGMENT TRACKS IN LEXAN AFTER PREIRRADIATION TO HIGH DOSES OF ALPHA PARTICLES.

Stone, D. R. (Oak Ridge National Lab., Tenn.). *Health Phys.*, 16: 772-3. (June 1969).

It was shown that charged particles other than fission fragments produce visible tracks in chemically etched Lexan, these tracks being caused by recoiling carbon atoms. This may give rise to the making of fission fragment tracks in dosimetric applications. It was found that when Lexan previously exposed to an alpha particle fluence as high as $10^{12}/\text{cm}^2$, was exposed to fission fragments the latter were registered with an efficiency of within 1% of that with no previous alpha exposure. There was therefore no decrease in the critical angle of detection. The irradiation increases the etchability of the Lexan surface. For this reason the material should be etched for short periods and inspected between etchings when determining the number of fission fragment tracks in foils which have been pre-irradiated with charged particles or photons, in order to prevent overetching. The optimum etch time for Lexan with previous alpha exposure is less than 30 min., the time decreasing with increased alpha exposure. The fission fragment tracks are distinguishable by their cigar-like shape; alpha particles cause smaller circular pits.

D28 USE OF PLASTIC VISUAL DETECTORS FOR THE STUDY OF FISSION INDUCED BY HEAVY IONS. Debeaurain, Monique; Stein, Roland; Remy, Gerard; Tripler, Jean. (CRN, Strasbourg). *Compt. Rend., Ser. B*, 269: 593-6. (Sept. 1969). (In French).

After a brief account of the technique and a description of the equipment used, several results are given concerning the fission cross sections of uranium, thorium, bismuth, and gold induced by neon-22, at 170 MeV at Dubna (USSR). The values found are of the order of 1.3 barns. Two cases of ternary fission were analyzed; the approximate fragment masses are given in the hypothesis of invariant charge distribution.

D29 APPLICATION OF TOPAZ FOR RECORDING NUCLEAR FISSION. Pereygin, V. P.; Shadieva, N. Kh. (Joint Inst. for Nuclear Research, Dubna, USSR). *Prib. Tekh. Eksp.*, No. 4, 53-5. (July-Aug. 1969). (In Russian).

The method for using topaz for the recording of nuclear fission fragments was worked out. It was determined that the efficiency for detecting fission fragments is $70 \pm 10\%$ and that this detector has a threshold of recording charged particles with $Z > 18$.

D30 INVESTIGATIONS ON TERNARY PHOTOFISSION BY MEANS OF PLASTIC AND MICA TRACK DETECTORS. Medveczky, L. (Inst. of Nuclear Research, Debrecen, Hungary); Somogyi, G.; Goetz, G. *Acta Phys. Acad. Sci. Hung.*; 28: 169-84. (1970).

The aim of the present investigations was to obtain data for the ternary photo-fission of ^{232}Th , ^{238}U , and ^{239}Pu induced by 27.5 MeV bremsstrahlung. Sandwiches, made of solid-state track detectors, were used for the detection of the binary and ternary fissions. For the purposes of distinguishing between symmetrical and asymmetrical ternary fission events, our investigations were carried out simultaneously with two track detectors (mica and plastics) with different registration thresholds. The experimental methodology, i.e., the preparation of the sandwiches, the method of angle and range measurement and track evaluation are described. About 1.5 million binary fission events were scanned. Data are given for the frequency of occurrence of three-prong and two-prong events with a spatial angle of less than 165° . Data are also presented for the angular and range distributions measured for these events. The possible disturbing scattering phenomena and the methods of eliminating them are discussed. It has been established that the ratio of symmetrical ternary-fission events (the mass of each fragment being >30) to binary fission events, in the case of ^{232}Th , ^{238}U , and ^{239}Pu are $\sim 8 \cdot 10^{-6}$, $\sim 11 \cdot 10^{-6}$, and $\sim 3 \cdot 10^{-6}$, respectively. The relative frequency of occurrence of asymmetrical ternary fissions (the mass of one of the fragments being between 10 and 30) seems to be several times more.

D31 INVESTIGATIONS ON TERNARY PHOTOFISSION WITH TRACK RECORDERS OF DIFFERENT SENSITIVITY. Medveczky, L.; Somogyi, G. (Inst. of Nuclear Research, Debrecen, Hungary). *Radiat. Eff.*; 5: 51-9 (Aug. 1970).

The existence of the ternary photofission of ^{232}Th , ^{238}U , and ^{239}Pu induced with the bremsstrahlung of a 27.5-MeV electron beam has been looked for simultaneously with track detectors of different thresholds. In sandwiches prepared from both muscovite mica and plastic (Mellinex O), altogether about 1.5 million binary fission events have been scanned. Data are given for the frequency of (1) three-prong events, (2) two-prong events with a space angle smaller than 180° , and (3) recoil events produced by the fission fragment scattered on ^{39}K and ^{16}O occurring in the material of the mica and plastic detectors, respectively. In the

case of (1) and (2) range and angular distributions are also presented. Results obtained in mica and plastic are compared. A background consisting of short tracks has been discovered in plastic sandwiches containing ^{239}Pu . The track density shows a correlation with the concentration of target nuclei and the storage time before etching. A possible origin of this track is discussed.

D32 DETECTION OF ^{235}U FISSION FRAGMENTS BY THE SOLID STATE TRACK RECORDER USING CELLULOSE NITRATE. Song, Kwang Suk; Lee, Sang Soo. (Atomic Energy Research Inst., Seoul). *J. Korean Nucl. Soc.*; 2:223-8. (Dec. 1970).

A special design of the solid state track recorder or SSTR using cellulose nitrate was developed for detection of fission fragments of U-235. The cellulose nitrate film of the detector is 2mm apart from the fission source which is a thin layer of uranyl nitrate (87% enrichment of U-235) suspended in cellulose nitrate. The detector is then exposed to thermal neutron flux for induced nuclear fission, and then the film was etched in 5-N NaOH solution. The diameter of a track increased as the etching time and temperature and concentration of the etchant are increased since etching is a usual chemical reaction, however, in the present experiment the optimum conditions were found for a given room temperature. The histogram of track diameter as measured under a microscope shows the distribution is of the typical saddle shape, which is familiar in fission physics, yet correct correlation among these saddle shapes are not derived. Also a detailed technique for preparing cellulose nitrate detector films on a mercury pool and thin films of uranyl nitrate fission source are described.

D33 EVALUATION OF THE SPATIAL PARAMETERS K AND α IN EQUATIONS FOR FISSION-TRACK URANIUM ANALYSIS. Kleeman, J.D.; Lovering, J. F. (Australian National Univ., Canberra). *Radiat. Eff.*; 5: 233-7. (Oct. 1970).

The equations describing fission track densities registered in solid-state detectors contain some spatial parameters whose values are not well known. The product of K , a geometric factor approximately equal to the range of fission fragments in a solid, and α , the etching efficiency, is determined by simultaneously producing fission tracks from a glass of known uranium content and monitoring the thermal neutron dose using gold foil. For tracks recorded in Lexan plastic and produced by uranium in aluminosilicate glass, the value of this product is $8.1 \times 10^{-4} \text{ cm}$ (± 7 per cent),

and for tracks etched in the glass matrix itself it is 3.7×10^{-4} cm (± 8 per cent). These values are consistent with analogous values calculated from other published data, and by assuming a value of $\alpha = 1$ for Lexan plastic, K is found to be 8.1×10^{-4} cm (± 7 per cent).

D34 THE DIAMETER OF ETCHED FISSION-FRAGMENT TRACKS IN SOLID-STATE NUCLEAR TRACK DETECTORS AS A FUNCTION OF THE PARTICLE ENERGY. Fiedler, G.; Hoepfner, U. (Univ., Giessen, Ger.). *Radiat. Eff.*; 3: 271-3. (June, 1970).

Fission fragments with known mass and energy were separated and used to bombard glass. After etching in 48% HF at room temperature, the resulting mean etch pit diameter was plotted as a function of energy for various etching times. For long etching times (50 to 100 sec), the diameter increases with energy about 40 MeV with constant slope: an energy resolution of 3 to 5 MeV is possible between 15 and 80 MeV. The effect of heavy and light fragments is relatively small. This method was tested by measuring the energy distribution of ^{252}Cf -spontaneous fission fragments.

D35 TRACK DIAMETER DISTRIBUTION OF SPONTANEOUS FISSION FRAGMENTS OF ^{244}Cm ON SILICEOUS GLASS SURFACE. Gorshkov, V. K.; L'vov, L. N.; Khrudeva, G. A. *At. Energ. (USSR)*; 28: 73-5. (Jan. 1970). (In Russian).

Studies were made of the distribution of fission fragments from the spontaneous fission of ^{244}Cm . An isotope in oxide form with the thickness not exceeding $1 \mu\text{g}/\text{cm}^2$ was coated on an aluminum layer and the craters were studied with an MBI-3 microscope. The distribution of ^{244}Cm fission fragments along the crater diameter on a silicate glass was studied as a function of the thickness of the absorber using the air, at normal pressure and temperature, as a fission fragment moderator. The scheme of the experiment and the curves obtained are included.

D36 (AAEC/TM-541) MEASUREMENT OF THE FISSION TRACK RECORDING EFFICIENCY OF MICA. Wall, T. (Australian Atomic Energy Commission Research Establishment, Lucas Heights). 18 p. (Apr. 1970). Dep. NTIS (U. S. Sales Only).

A value for the fission track recording efficiency of mica, of 0.919 ± 0.019 relative to ^{197}Au reaction rate, was obtained. This was considered to agree with values obtained elsewhere, and was verified by a comparison of fission rates measured with a fission counter and with a solid state track recorder.

D37 MICA TARGETS WITH A NEARLY 4π GEOMETRY FOR FISSION STUDIES. Boos, A. H.; Brandt, R.; Starke, K. (Philipps-Univ., Marburg, Ger.). *Radiat. Eff.*; 3: 235-8. (June, 1970).

Mica was bombarded with fission products from ^{252}Cf . After etching the holes were filled with uranium, the mica now serving as a detector with a nearly 4π geometry. Qualitative results of irradiations with 0.6- and 20-GeV protons are given to demonstrate the usefulness of this technique.

D38 ELECTRON MICROSCOPY STUDY OF THE TRACKS OF Cf FISSION PRODUCTS IN A THIN PLASTIC LAYER. Chambaudet, Alain; Roulet, Henri. (Univ., Paris). *Compt. Rend., Ser. B*; 274: No. 2, 145-8. (10 Jan. 1972). (In French).

Various replica techniques were used in studying the nature of the tracks and the channel diameters as a function of the chemical development time.

D39 ABSOLUTE FISSION RATE MEASUREMENTS WITH SOLID-STATE TRACK RECORDERS. Gold, R., Armani, R. J., and Roberts, J. H. *Nuclear Science and Engineering*; 34, 13, (1968).

D40 SPONTANEOUS-FISSION DECAY CONSTANT OF ^{238}U . Roberts, J. H. and Gold, Raymond and Armani, Roland J., *The Physical Review*, Vol. 174, No. 4, 1968.

D41 ^{241}Am SPONTANEOUS FISSION DECAY CONSTANT MEASURED WITH SOLID STATE TRACK RECORDERS. Roberts, J. H. (Northwestern Univ., Evanston, Ill.); Gold, R.; Armani, R. J. *Ref. J18*. pp VIII. 15-19. (1969).

The spontaneous fission decay constant of ^{241}Am has been determined by fission track counting in mica to be $(6.53 \pm 0.26) \times 10^{-15}/\text{year}$. Several samples of ^{241}Am electroplated on platinum to various thicknesses were used in the measurement. Efficiency calibrations of the various samples were carried out by irradiations in a uniform flux of slow neutrons and subsequent fission track counting in mica. Good internal consistency of the results over a wide range of track densities was obtained. The mass of the ^{241}Am samples was determined by alpha counting.

D42 SPONTANEOUS-FISSION DECAY CONSTANT OF ^{241}Am . Gold, Raymond, Armani, R. J. and Roberts, J. H., *The Physical Review C*, Vol. 1, No. 2, 1970.

D43 REDETERMINATION OF THE ^{238}U (sp.f.) DECAY CONSTANT BY FISSION TRACKS IN A U-STAINED BOHEMIAN GLASS OF KNOWN AGE. Thiel, K. and Herr, W. (Univ. of Köln-Germany). *Transactions of the American Nuclear Society* 1970, Vol. 13.

D44 EVIDENCE FOR A DIRECT REACTION MECHANISM IN THE PRODUCTION OF FISSION ISOMERS. Repnow, R., Meta, V., Fox, J. D., and Von Brentano, P., *Nuclear Physics A147*. (1970).

D45 ANGEWANDTE CHEMIE, TERNARY FISSION. Brandt, Reinhard, *Angew. Chem. Intern'l. Edit.* Vol. 10 (1971).

D46 DETERMINATION OF FISSION RATE, DECAY CONSTANT, PROFILES, AND DISTRIBUTIONS OF ^{252}Cf , ^{239}Pu , AND ^{235}U FISSION SOURCES BY SOLID STATE TRACK DETECTORS. Khan, Hameed Ahmed. (Univ. of Birmingham, Eng.). *Nucleus* (Karachi); 8: No. 1-2, 63-75. (Jan. -June, 1971).

The use of a new type of detector, called the solid state track detector (SSTD), is made in the determination of the spontaneous fission rate and the fission decay constant of a ^{252}Cf spontaneous fission source. Also, they are used in finding profiles and distributions of fission sources like ^{235}U , ^{239}Pu , and ^{252}Cf .

D47 CALIBRATION OF THE DECAY CONSTANT OF ^{238}U SPONTANEOUS FISSION. Gentner, W., Storzer, D. (Max Planck Inst. - Germany), Gijbels, R., and Van der Linden, R., (State U. - Belgium); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

D48 MEASUREMENT OF FISSION AND CAPTURE RATES BY MEANS OF FISSION TRACK DETECTORS AND Ge(Li) DETECTORS. Korthaus, E.; Goel, B.; Guenther, G.; Scholtyssek, W. (Kernforschungszentrum, Karlsruhe, Ger.). pp 50-3 of *Reaktortagung, Bonn, 1971. Bonn; Deutsches Atomforum E. V.* (1971). (In German).

The work consists of two parts: (1) ^{238}U capture rate measurement with Ge(Li) detectors in the SNEAK-7A. The method is based on the determination of the ^{239}Np activity in irradiated U foils. (2) Automatic counting of fission track detectors. The track counter "Classimat" (Leitz) and the computer evaluation (FORTRAN IV) are described.

D49 APPLICATION OF SOLID STATE TRACK RECORDERS IN ABSOLUTE FISSION PRODUCT

YIELD MEASUREMENTS. Armani, R. J. (Argonne National Lab., IL.); Gold, R.; Larsen, R. P.; Roberts, J. H. *Ref. J47*. pp 495-501. (1970).

With the development of the solid state track recorder (SSTR) method for precision fission rate measurements, a simple direct method for measuring fast fission yields is now available. Measurements can be carried out at relatively low neutron fluences. Fission product yields is now available. Measurements can be carried out at relatively low neutron fluences. Fission product yields of ^{99}Mo and ^{140}Ba from $^{239}\text{Pu}(n,f)$ have been measured in the fast neutron spectrum of a low power reactor. Radiochemical techniques and radioactivity measurements were used to determine the amounts of ^{99}Mo and of ^{140}Ba produced through the irradiation of plutonium foils. The value found for the fast fission yields of ^{99}Mo and of ^{140}Ba are (0.0580 ± 0.0005) and (0.0500 ± 0.0006) , respectively.

D50 JUL-670-ST. DIRECTIONAL DEPENDENCE OF FISSION FRAGMENT AND RECOIL TRACK DOSIMETERS IN PLASTIC. Geisler, H. and Helzelmann, M. *At. Res. Etab. Julich, West Germany*. (1970). Abstract not available.

D51 HIGH SPATIAL RESOLUTION FISSION DETECTOR. Besant, C. B. (Imperial Coll. of Science and Tech., London). *Ref. J47*. pp. 737-744. (1970).

A technique for fission rate measurements in zero power fast reactors based on electron microscope measurements of unetched particle tracks in dielectric track detectors is described. It is possible to detect track densities of up to 10^8 tracks/mm² without serious track overlap interfering with counting.

D52 SPALLATION AND FISSION FRAGMENTS OF HEAVY NUCLEI INDUCED BY 18 GEV PROTONS REGISTERED BY MEANS OF SOLID PLASTIC DETECTORS. Debeauvais, M., Stein, R., Ralarosy, J., and Cuet, P. *Nucl. Phys. A90*, p186. (1967).

Abstract not available.

D53 DETECTION OF FISSION FRAGMENT TRACKS IN CRYSTALLINE QUARTZ: UTILIZATION IN NUCLEAR PHYSICS. Sowinski, M. (Institut de Physique Nucleaire, Orsay, France); Stephan, C.; Czyzewski, T.; Tyz, J. *Ref. J46*. pp. 117-119. (1970). (In French).

The crystal is polished in a potassium hydroxide bath at 200°C and then track etching is accomplished in a sodium carbonate solution (75 g Na_2CO_3 / 100 cc H_2O) at 120°C for 2 hours. Track parameters

including size and effects of angle of incidence are discussed. It is stated that synthetic crystalline quartz is best adapted for use as a detector containing the least possible amount of uranium in the search for superheavy elements by neutron-induced fission fragment detection.

D54 YIELD OF TERNARY FISSION OF ^{236}U INDUCED BY THERMAL NEUTRONS.

Juric, M.; Antanasijevic, R.; Vukovic, J. (Inst. of Physics, Belgrade). Ref. J47. pp. 481-487. (1970).

A comparison is made of data on ternary fission of ^{236}U induced by thermal neutrons obtained by the use of photonuclear emulsions with those obtained by the use of solid-state track detectors. The frequency of ternary fission of ^{236}U is determined as compared to the binary fission.

D55 DETERMINATION OF THE MASSES AND THE ENERGIES OF FISSION FRAGMENTS FROM ^{232}Th WITH A MICA DETECTOR. Casanova, J.; Nalda, J.; Valle, J. (Univ., Valladolid, Spain). Ref. J47. (1970). (In French).

Mica solid-state track detectors for determination of mass and energy distribution in the reaction ^{232}Th (n,f) at $E_n = 14.1$ and 4.5 MeV is studied, as well as the total cross section of this reaction.

D56 COINCIDENCE SPECTROSCOPY OF FISSION FRAGMENTS VIA MICA TRACK DETECTORS.

Kiely, F. M.; Pate, B. D. (Simon Fraser Univ., Burnaby, B.C.). Nucl. Instrum. Methods, 109: No. 2, 355-363. (1973).

The utility of mica track detectors in a sandwich configuration has been investigated in measurements of mass and angular distributions of fission fragments from ^{235}U + thermal neutrons, ^{238}U + 14-MeV neutrons, and ^{197}Au + 80-MeV alpha particles. It is concluded that, while angular distributions are poorly reproduced (due to problems with tracks at small angles to the mica surface and to the observation direction), fragment mass distributions may be inferred with useful accuracy.

D57 FISSION FRAGMENT ENERGY SPECTRUM DETERMINATION WITH SOLID STATE NUCLEAR TRACK DETECTORS. Khan, H. A.; Durrani, S. A. (Univ. of Birmingham, Eng.). Nucl. Instrum. Methods, 109: No. 2, 341-347. (1973).

Attempts are described to optimize the spectro-metric response of a number of solid state nuclear track detectors (SSNTD), including fused silica, soda-

lime glass, and phosphate glass. Diameters of the etch pits resulting from normally incident beams of fission fragments from a ^{252}Cf source in vacuum have been measured, by both optical and scanning-electron microscopy, as functions of the period of etching and of the thickness of Al absorber introduced in the path of the beam. The best resolution of the heavy and light fission fragment groups, as inferred from the diameter distributions, is obtained with phosphate glass SSNTD covered with $\approx 5 \mu\text{m}$ Al foil during irradiation.

D58 (AAEC/LIB/Bib-368) DETECTION OF FISSION FRAGMENTS BY TRACK-ETCH TECHNIQUE. A Bibliography. Newland, E. A. (comp.) (Australian Atomic Energy Commission Research Establishment, Lucas Heights). 57 p. (Sept. 1972).

Two hundred and forty-four references are given chronologically by year covering the period from 1961 to 72. Each year is arranged alphabetically by author. Reference is made to abstracts for citations in NSA.

D59 ANGULAR CHARACTERISTICS OF GLASS FISSION-FRAGMENT TRACK DETECTORS. Koroleva, T. V.; Kraitov, S. N. Instrum. Exp. Tech. (USSR) (Engl. Transl.); 15: No. 6, 1665-1668. (1972).

Translated from Prib. Tekh. Eksp.; 15: No. 6, 45-47. (1972).

The efficiency with which the fragments are recorded by a track detector made of silicate glass with targets made of ^{237}Np , ^{235}U , and ^{238}U was calculated with allowance for fission anisotropy. It was shown that the angular anisotropy of the fragments increases the efficiency when the detectors are irradiated along a normal to the surface and reduces it for irradiation along the surface. The variation of efficiency, depending on the neutron energy, may amount to 10 to 30%. The angular dependence of the efficiency with which the fragments are recorded was measured experimentally by neutron irradiation of detectors made of silicate glass with ^{237}Np and ^{238}U targets in the pulsed fast reactor of the Joint Institute of Nuclear Research (JINR). The results obtained are in agreement with the calculated data.

D60 ELECTROFISSION OF MAGNESIUM. Litherland, A. E. (Univ. of Toronto). Rev. Brasil. Fis.; 2: No. 1, 101-118. (Mar. 1972).

A method to study electrofission of magnesium and other light elements is presented. Accelerators and etch

pit technique are used. The technique is specifically described, and a polycarbonate Damage Track (PDT) detector is used. Special attention is given to symmetrical fission of ^{24}Mg . ^{24}Mg might be expected to show a larger cross section for electrofission than ^{27}Al .

D61 ANGULAR DISTRIBUTIONS OF FRAGMENTS IN THE FISSION OF URANIUM AND THORIUM NEAR THE $(n, 2n'f)$ THRESHOLD. Barutçugil, E.; Juhasz, S., Varnagy, M., Nagy, S. and Csikai, J. Nuclear Physics, A173, 571-576. (1971).

Abstract not available.

D62 FISSION-TRACK REGISTRATION IN SOLID-STATE TRACK DETECTORS IMMERSSED IN FISSILE-MATERIAL SOLUTIONS. Iyer, R. H., Sampathkumar, R., and Chaudhuri, N. K. Nuc. Inst. Meth. 115, 23-27. (1974).

Abstract not available.

D63 DEVICE FOR STUDY OF HIGH ENERGY FISSIONS IN Au NUCLEI. Tamsi, E. (Nihon Univ., Narashino); Roberts, J. H. Nihon Daigaku Seisan Kokoku Hokoku; 5: No. 1, 193-199. (Mar. 1972). (In Japanese).

A study of high-energy fission phenomena induced by N^{14} ion beams with energies of 250 MeV/nucleon and 1.0 and 2.05 BeV/nucleon in gold targets was undertaken. Stacks consisting of gold foils, Diacel films, and Lexan films in which etchable tracks are produced by fission fragments from Au nuclei are described.

D64 (BARC-690, pp 146-157). FISSION AND RELATED STUDIES USING SOLID STATE TRACK DETECTORS. (1973).

The fission track registration efficiency of Lexan track detectors immersed in solutions of fissile materials is reported. Also, results of neutron flux mapping at the Apsara reactor using dielectric track detectors are presented and discussed.

E. ALPHA PARTICLE DETECTION

E1 USE OF NONPHOTOGRAPHIC NUCLEAR TRACK TECHNIQUES FOR DETERMINATION OF ALPHA ACTIVITIES. Burger, Georg (Gesellschaft fuer Strahlenforschung m.b.H., Neuherberg bei Munich (West Germany). Institut fuer Strahlenschutz). pp510-16. (In German).

For the measurement of α particles, plastic foils were used and etched under standard conditions for one hour in 30% KOH at 60°C. The technique has been used for radiography of fuel elements and barium-containing materials following neutron exposure; as a leakage test and general contamination test for α -emitters; and for determination of radon, thoron, and their decay products in mining personnel. Problems encountered in the experimental series are discussed and possible solutions proposed.

E2 (CERN-65-4(Vol. II), ENREGISTREMENTS DE TRACES INDIVIDUELLES DANS DIVERS MATERIAUX SOLIDES. (Recording of Individual Tracks in Various Solid Materials). Debeauvais, Monique. pp 11-8.

The recording of α tracks in different types of nitrocelluloses and, in particular, in the commercial product celluloid (nitrocellulose plastified with camphor) was studied. Po α sources were used, and the

experimental apparatus is described. The effects of the reagent selective etching and the temperature on the registration sensitivity were determined. The results show that all of the nitrocelluloses could be used to detect low-energy α particles. The conditions for the registration of the particles were defined.

E3 (ORNL-4306), RADIATION CHEMISTRY. (Oak Ridge National Lab., Tenn.). pp 58-65.

Developments are reported for studies on: yield of ozone in the pulse radiolysis of gaseous oxygen at very high dose rate for use as a dosimeter; a high-intensity square-wave analytical flash lamp; radio-induced oxidation of Ce(III) in deaerated sulfuric acid solutions; reduction of Ce(IV) by hydrogen peroxide; alpha-particle recoil tracks in mica; energy transfer in the radiolysis of organic compounds; and radiation and hot-atom chemistry of inorganic crystalline solids.

E4 NEUTRON TIME-OF-FLIGHT STUDIES, PHOTONUCLEAR REACTIONS (CHARGED PARTICLE EMISSION), ELECTRON SCATTERING, AND THEORETICAL DEVELOPMENTS. Yale Univ., New Haven, Conn. In Los Alamos Sci. Lab. Rept. to the AEC Nucl. Cross Sect. Advisory Comm. 1968 p 212-227.

E5 ALPHA PARTICLE RECORDING WITH THE USE OF CELLULOSE ACETATE. Cervasek, J. (*Inst. of Nuclear Research, Rez, Czech.*). *Jad. Energ.*; 15: 413-15. (Dec. 1969). (In Czech).

Experiments carried out in the reactor indicated the ORWO cellulose acetate foils to be a convenient detector for registering 1.5 MeV alpha particles in the environment of gamma radiation and thermal neutrons, and at the temperatures of about 100°C. The 60 minutes of etching in the concentrated (20) solution of KOH at the temperature of 50 to 60°C proved to be satisfactory for the visibility of particle traces. This method has been used for the identification of boron phase in steel on the base of the $^{10}\text{B}(n,\alpha)^7\text{Li}$ nuclear reaction. The relative short exposure intervals and the temperature of 100°C showed no substantial recovery of the traces.

E6 STATISTICAL STUDY OF α PARTICLE TRACK COUNTING IN CELLULOSE NITRATE.

Anno, Jacques, (Univ., Toulouse); Blanc, Daniel; Teyssier, J.-L. *Ref. J17 pp III. 56-65. (1969).* (In French).

Cellulose nitrate was irradiated with 2.7 MeV alpha particles in air at normal temperature. The detector total registration efficiency lies between 90 and 100%. The maximum registration angle in relation to the perpendicular to the detector surface is 65°.

E7 USE OF CELLULOSE NITRATE FOR ALPHA-PARTICLE DETECTION. Anno, Jacques (Toulouse Univ. (France). Faculte des Sciences). 148 p. (1970). (In French).

A summary dealing with ionizing-particle detection in plastics and with the different mechanisms proposed to explain the track formation in those detectors is given. The most salient features of the most sensitive detecting material (cellulose nitrate) are given. After describing the apparatus and technical methods, the results of many counting experiments of alpha particle tracks recorded by the detector are discussed. An easy statistical method is proposed. Finally, this new kind of alpha particle detection is applied to calculate the activity of radon by counting the tracks due to alpha particles emitted by RaC^1 . (85 references.)

E8 REGISTRATION AND COUNTING OF ALPHA PARTICLE TRACKS IN CELLULOSE NITRATE.

Anno, J. (Toulouse Univ., France); Commanay, L.; Teyssier, J. *L. Radioprotection*; 5: 147-65 (1970). (In French).

The problem of alpha particle detection by track registration in cellulose nitrate was studied. From the

analysis of the statistical errors due to track counting with an optical microscope, the number of fields to be observed is deduced in order to know the density of tracks with a given accuracy. This method was applied to the detection of alpha particles in air.

E9 RECORDING AND USES OF α -PARTICLE TRACKS IN CELLULOSE NITRATE. Nicolae, M. *Rev. Roum. Phys.*; 15: 881-9 (1970). (In French).

A systematic study on the possibility and conditions of using cellulose nitrate, obtained from commercial collodium, for α -track recording is presented. The optimal conditions of chemical etching, when the effectiveness of the α -particle recording reaches 100%, were established. The influence of the preliminary heating of the detector was also studied in detail. For purposes of quantitative determination the rate of energy loss and the range-energy curve in cellulose nitrate were established for α particles with energies between 3 and 10 MeV. When the efficiency of the α -particle track registration is 100%, the critical energy for α -particle recording in the cellulose nitrate of the type mentioned above was calculated as 4.1 MeV, which is in good agreement with other results for commercial sheets of cellulose nitrate.

E10 RECORDING OF IONIZING PARTICLE TRACKS IN CELLULOSE FILMS IN VARIOUS GASEOUS MEDIA.

Kartuzhanskii, A. L.; Privalova, V. E.; Sorokin, E. S.; Fedyukin, V. Ya. (Leningrad Inst. of Soviet Commerce). *Zh. Nauch. Prikl. Fotogr. Kinematogr.*; 15: 59-61 (Jan-Feb. 1970). (In Russian).

Particle track recording on cellulose films was studied using α -particles of ^{210}Po (at 5.3 MeV energy) and nitrocellulose and acetyl cellulose films. The exposure was carried out in a vacuum (as 2×10^{-4} mm Hg) or with oxygen, carbon dioxide, or water vapor at various pressures. Histograms of the distribution of ^{210}Po particle tracks by their length in nitrocellulose film exposed in various gaseous media are included.

E11 DIELECTRIC TRACK DETECTORS. ALPHA PARTICLE DETECTION USING CELLULOSE NITRATE.

Anno, J.; Commanay, L. (Univ., Toulouse). *Ann. Phys. Biol. Med.*; 5: No. 2, 65-78 (1971). (In French).

The formation of alpha particle tracks in cellulose nitrate films, the developing technics and the counting of the tracks were studied. It was found that to form a track, particles must have an incident angle smaller than 65 deg. The recording efficiency of the detector

was 90 percent. It was also found that the statistical counting error decreases with the density of the tracks and was equal to 5 percent for a total of 2000 tracks.

E12 RECORDING OF ALPHA PARTICLES BY SOLID TRACK DETECTORS BASED ON CELLULOSE. Bondarev, V.N.; Korzin, E.G.; Parfanovich, D.M. *Instrum. Exp. Tech. (USSR) (Engl. Transl.)*; 14: No. 6, 1648-50 (1971). Transl. from *Prib. Tekh. Eksp.*; 14: No. 6, 59-9 (1971).

A study was made of solid track detectors based on cellulose. For films made of nitro- and acetyl-cellulose the energy ranges of α particles which can be recorded with 100% efficiency are established, and the dependences of the track dimensions of α -particle energy are obtained. The results of measurements of the space distribution of the density of thermal-neutron capture in a boron absorptive rod having a small diameter measured by means of a nitro-cellulose detector are presented.

E13 DETECTION OF ALPHA PARTICLES BY THIN TRIAFOL TN FOIL. Spurny, Frantisek (Lab. for Radiological Dosimetry, Prague). *Jad. Energ.*; 18: No. 9, 315 (Sep 1972).

The detection efficiency of Triafol TN (cellulose triacetate) track detectors for alpha particles was studied. A standard ^{241}Am source was used at various source-to-detector distances. Foils were etched by 10 N NaOH at 60°C. Results are tabulated.

E14 RECENT TECHNIQUE OF LOW-LEVEL ACTIVITY COUNTING. 1. ALPHA RADIO-ACTIVITY. Kikuchi, Jun (Waseda Univ., Tokyo). *Oyo Butsuri*; 41: No. 3, 281-3 (Mar 1972). (In Japanese).

In parallel plate type ionization chambers, a detector of 900 cm² has been produced, while in the cylindrical type an area of 15,000 cm² has been attained. In a chamber with cylindrical grid, resolution of 45 keV for ^{210}Po α ray and background of 0.17 cph full width at half maximum have been obtained. Useable scintillators include gas scintillation, ZnS, CsI, organic crystals, and plastic scintillators. Kraner and others fabricated a 450 cc cylindrical Lucite chamber, the inside of which is coated with ZnS and which is equipped with two 5" photomultipliers, and realized the low background of 0.8 cpm. It has been found that α activity can be detected with cellulose nitrate or cellulose acetate film. Si(Li) detectors of ~20 cm² are being produced.

E15 ALPHA PARTICLE TRACK DETECTION WITH CELLULOID FILMS. Hasegawa, H., Matsuo, M., Yamakoshi, K., and Yamawaki, K. *Radioisotopes*, 17, p419 (1968).

Abstract not available.

E16 INVESTIGATIONS ON ALPHA-RAY PATTERNS IN DIELECTRIC FOILS. Somogyi, G.; Srivastava, D. S. (Inst. of Nuclear Research, Debrecen, Hungary). *Ref. J47 pp 711-718. (1970).*

Americium-241 alpha particles were registered in cellulose nitrate, cellulose acetate, and polycarbonate foils. The track etching conditions and the resulting optical density characteristics are presented.

E17 RECORDING OF α PARTICLE TRACKS IN CELLULOSE NITRATE AND POSSIBLE UTILIZATION. Nicolae, M. (Inst. for Atomic Physics, Bucharest). *Ref. J46 pp 267-275. (1970). (In French).*

A study of the preparation, treatment, and characteristics of registration of alpha particle tracks in cellulose nitrate is given. The detector was etched in sodium hydroxide. The efficiency for detection of americium-241 alpha particles is given for different etching temperatures and times. The specific ionization loss and critical energy for alpha particles is given. The use of cellulose nitrate track detectors for radon dosimetry and for neutron dosimetry based on recoil or reaction product detection is suggested.

E18 RAPID SEPARATION OF NATURAL RADIONUCLIDES BY ELECTROMIGRATION AND DETECTION OF THE ALPHA EMITTERS BASED ON ALPHA PARTICLE TRACK. Iwata, S., Hashimoto, T., and Nishiwaki, Y. *Proc. IAEA Symp. Rapid Methods Meas. Radioactiv. Environ. Neuherberg (1971).*

Abstract not available.

E19 DETECTION OF α PARTICLES IN POLYMERS. Dutrannois, J. (CERN, Geneva). *Ref. J46 pp 277-285. (1970). (In French).*

The enhancement of α particle tracks in Makrofol track detectors based on an ozone treatment prior to etching is described. The detector is treated in a water-saturated mixture of ozone (20%) and oxygen.

E20 EFFECT OF IRRADIATION IN VACUUM ON THE OPTICAL DENSITY CURVES FOR α -PARTICLES IN PLASTICS. Somogyi, G.; Srivastava, D.S. (Inst. of Nuclear Research, Debrecen, Hungary). *Ref. J47 pp 719-722. (1970).*

To show the effect of environmental conditions on

the track registration features of plastic track detectors, the variation of optical density in various plastic track detectors when they were irradiated in vacuum were studied.

E21 EFFECT OF GAMMA IRRADIATION ON CELLULOID FILM AND RELATED INFLUENCE ON THE REGISTRATION OF ALPHA TRACKS.

Takemi, H.; Kinaga, Y.; Shinagawa, M. (Osaka Univ.). J. Nucl. Sci. Technol. (Tokyo); 10: No. 4, 214-218. (Apr. 1973).

Celluloid film, used for α -track detection was irradiated up to 3.5×10^7 rad by ^{60}Co γ -rays. The radiation damage was examined by weighing a piece of the film before and after etching with sodium hydroxide solution under various conditions. Six molar sodium hydroxide solution at 50°C was found to be the most suitable etching solution for this irradiated celluloid film. On measuring the optical density, it was seen that the absorption curve for UV light shifted to the longer wavelength side accompanying an increase of absorption dose of γ -ray energy on the film. Both the

gravimetric and the optical methods of determining radiation damage indicated its dependence on the γ -ray absorption dose. The sensitivity of α -track registration was also estimated by examining the appearance of α -tracks under the optical microscope according to etching time. The critical energy of the celluloid film for the registration of α -tracks decreased with the absorption dose of γ -rays.

E22 ALPHA DETECTION BY SOLID-STATE TRACK DETECTORS IN ELECTRON MICROSCOPE.

Paul, D. (Institut fuer Polymerchemie, Teltow, Ger.). Isotopenpraxis; 9: No. 5, 176 (May 1973). (In German).

The radiation source was an ultra-thin ($0.15\mu\text{m}$) section of a resin containing radium-226. After being covered by a detector foil of cellulose acetate with $0.12\mu\text{m}$ thickness, the section was exposed for 12 weeks, etched with sodium hydroxide, and contrasted with potassium permanganate which accumulated in the tracks, appearing as dark dots under the electron microscope. Depending on the energy of the alpha particles, the spots had diameters from 0.06 to $0.12\mu\text{m}$.

F. PROTON DETECTION

F1 ETCHING OF PROTON-BOMBARDED NaF CRYSTAL.

Kubo, Kazuko (Japan Atomic Energy Research Inst., Tokyo). J. Phys. Soc. Jap., 21: 2411 (Nov. 1966).

F2 PROTON TRACKS IN PLASTIC DETECTORS.

Beaujean, R. (Univ., Kiel). Ref. J17 pp II. 114-18. (1969).

An important characteristic of plastic detectors is the fact that they register higher charged particles even in the presence of high electron and proton fluxes. Measurements were performed with 0.5 to 1.7 MeV protons to study which proton densities influence the registration of higher charged particles. The measurements showed that the damaging effects of single protons in the plastic sheet can be added. Under certain conditions accumulated protons which cannot be registered at the same energy as single particles, produce etchable tracks. A disturbing track background is produced by 1.5 MeV protons at densities above 10^{11} protons per cm^2 . The effect of track forming by accumulated single protons allows to study the track forming mechanism and the critical energy loss

in different plastic materials. The number of etchable tracks depends on the flux and energy of the protons, the critical energy loss of the material, and the radius of the etchable damaged region.

F3 OBSERVATION OF PROTON TRACKS BY A PLASTIC DETECTOR.

Varnagy, M.; Csikai, J.; Szegedi, S.; Nagy, S. (Kossuth Univ., Debrecen, Hungary). Nucl. Instrum. Methods; 89: 27-8 (1970).
Cellulose acetate (Cellit) has been found to be suitable for detecting protons with a threshold of about 300 keV and an efficiency of $\approx 100\%$ within the error limits of the measurements.

F4 OBSERVING PROTON TRACKS IN CELLULOSE NITRATE.

Carpenter, B. S.; Lafleur, P. D. (National Bureau of Standards, Washington, D. C.). Int. J. Appl. Radiat. Isotop.; 23: No. 4, 157-9 (Apr. 1972).
Cellulose nitrate was used as a detector to observe monoenergetic proton tracks. These monoenergetic protons are produced from a ^{14}N source placed in contact with the detector and irradiated in a thermal-neutron flux. After irradiation the detectors were chemically etched to produce optically visible tracks.

G. PARTICLE IDENTIFICATION THROUGH TRACK REGISTRATION

G1 IDENTIFICATION OF ISOTOPES OF ENERGETIC PARTICLES WITH DIELECTRIC TRACK DETECTORS. Price, P.B. (General Electric Research and Development Center, Schenectady, N.Y.); Fleischer, R.L.; Peterson, D.D.; O'Ceallaigh, C.; O'Sullivan, D.; Thompson, A. *Phys. Rev.*, 164: 1618-20. (Dec. 1967).

A new principle of charged-particle identification by plastic track detectors is described. It was found that the rate of chemical etching (by a suitable reagent) along the track of a heavy ion in a plastic depends only on the primary ionization rate, which, as the particle slows down, increases at a rate that depends uniquely on atomic number Z and mass A . To identify the Z , A , and energy of a particle the etching rate at a known residual range [by analogy with a $(dE/dx) - E$ detector] or the etching rate at two known points along the trajectory in a stack of plastics can be measured. Experimental data are presented for ^{10}B , ^{11}B , ^{12}C , ^{14}N , and ^{16}O ions from the Yale accelerator, showing that masses differing by 9% can be resolved. Unique features of this method are its discrimination against intense background radiation and its combination of high resolution with large collecting area, which make it feasible to do certain cosmic-ray experiments, such as the detection of ^{10}Be nuclei.

G2 IDENTIFICATION OF NUCLEAR PARTICLES BY MEASUREMENTS OF ETCHING RATES ALONG THEIR TRACKS IN DIELECTRIC SOLIDS. Price, P.B., Fleischer, R. L., and Peterson, D.D. *Reactiv. Solids*, Schenectady 1968, S. 735-741. (Schenectady, N.Y., Gen. Elect. Res. & Devel. Cent.; Troy, N.Y., Rensselaer Polytech. Inst.

G3 NUCLEAR-PARTICLE-TRACK IDENTIFICATION IN INORGANIC SOLIDS. Fleischer, R.L.; Price, P.B.; Woods, R.T. (General Electric Research and Development Center, Schenectady, N.Y.). *Phys. Rev.*; 188: 563-7 (Dec. 1969).

The unique feature of track-recording plastics which allows them to be used to identify particles is that the chemical rate of attack V_T along a track is an increasing function of ionization rate. This same characteristic is shown to extend to inorganic dielectric solids. The relation between V_T and ionization rate has been measured for five different glasses, using fission fragments of different energies. The variation of V_T is least for ordinary lime glass and much the

greatest for a phosphate glass, suggesting that the latter should be useful in resolving atomic numbers and energies of fission fragments and other very heavy, energetic nuclei. Equations are derived that allow the shapes of etched tracks to be calculated as a function of etching time and particle ionization rate. The calculations agree well with recent experimental results.

G4 PARTICLE IDENTIFICATION BY DIELECTRIC TRACK DETECTORS. Price, P.B.; Fleischer, R. L. (General Electric Co., Schenectady, N.Y.). Ref. J17 pp IV. 2-34 (1969).

Chemical reactivity along the trajectory of a charged particle in a dielectric solid depends on the density of radiation damaged species. In inorganic crystals such as are found in meteorites, cosmic rays can be identified by etching for a long time and measuring the entire etchable ranges of the slowing particles, which are related to their atomic numbers. In plastics and glasses the etching rate is an increasing function of radiation damage density. Measurements of etched cone lengths at different points along the trajectory of a particle that passes through several sheets provide a very sensitive measure of atomic number. In favorable cases it is possible even to resolve isotopes with the same atomic number. Some unpublished experimental details that are useful in achieving high resolution and some new, unpublished measurements are given.

G5 PARTICLE IDENTIFICATION BY DIELECTRIC TRACK DETECTORS. Price, P.B.; Fleischer, R. L. (General Electric Research and Development Center, Schenectady, N.Y.). *Radiat. Eff.*; 2: 291-8 (Mar. 1970).

Chemical reactivity along the trajectory of a charged particle in a dielectric solid depends on the density of radiation-damaged species. In inorganic crystals such as are found in meteorites, cosmic rays can be identified by etching for a long time and measuring the entire etchable ranges of the slowing particles, which are related to their atomic numbers. In plastics, the etching rate is an increasing function of radiation damage density. Measurements of etched "cone" lengths at different points along the trajectory of a particle that passes through several sheets provide a very sensitive measure of atomic number. In favorable cases it is possible even to resolve isotopes with the same atomic number. In addition to serving as a general review of work on particle identification using these two schemes, this report provides some unpublished experimental

details that are useful in achieving high resolution and reports some new, unpublished measurements.

G6 RECENT DEVELOPMENT IN THE IDENTIFICATION OF HEAVY NUCLEI WITH SOLID-STATE TRACK DETECTORS. Maurette, M. (Inst. Phys. Nucl.-France); Transactions 1972 Annual Meeting of The American Nuclear Society, Vol. 15.

G7 (AFCRL-72-321; AFCRL-PSRP-493). USE OF PLASTIC DETECTORS TO CONFIRM THE ACCELERATION OF ARGON NUCLEI TO RELATIVISTIC VELOCITIES AT THE PRINCETON PARTICLE ACCELERATOR. Fitz, R.C.; McNulty, P.J.; Davis, A.F. (Air Force Cambridge Research Labs., L. G. Hanscom Field, Mass.). 13 p. (May 1972).

Argon ions were recently accelerated to 11.7 GeV at the Princeton Particle Accelerator. This represents a two-fold increase in the mass over particles previously accelerated to relativistic energies. The report describes how a stack of cellulose nitrate track detectors was used to confirm the successful acceleration with the unambiguous identification of 79 argon tracks within a clearly defined 1/4-inch-beam spot.

G8 CHARGE AND ENERGY INFORMATION FROM HEAVY ION TRACKS IN LEXAN. Stern, R.A.; Price, P.B. (Univ. of California, Berkeley). *Nature (London) Phys. Sci.*; 240: No. 100, 82-3. (Nov 1972).

A new technique is described that permits heavy ions of very low energy to be identified and extends the scope of plastic particle detectors for use in nuclear chemistry, as well as making possible the study of low-energy interplanetary particles. In multilayer plastic stacks used to detect heavy high-energy cosmic rays or solar particles, the trajectory of a typical particle is marked by a series of etched cones at the top and bottom surfaces of the sheets through which it passes, and the cone lengths increase as the particle slows down and causes heavier ionization until, finally, in the sheet where the particle stops, the etch pit resembles the shape of a test tube. The new method can be used if the energy of the particle is so low that it fails to penetrate even a single sheet. The initial etching time is optimized so that etch cones of the particles of interest are visible but is not so long that they have reached the end of their range. The Lexan detectors are processed with 6.25M NaOH at 40°C. The etched sheet is then irradiated with intense uv light for one to two days so that the chemical reactivity of the remaining unetched portions of the trajectories is greatly increased. This is followed by a second etch, in which

in order to achieve the maximum contrast between the initially etched portion and the final portion the etch time should be short, so that the final portion is a tube of $\sim 0.3\mu\text{m}$ diameter. Each track then contains a record of the charge and energy of the particle that produced it. The technique is proving very valuable for identifying solar particle with $6 \leq Z \leq 26$ and $1 \leq E \leq 10$ MeV/amu.

G9 COMPARISON OF THE IDENTIFICATION METHODS FOR MEASURING HEAVILY CHARGED PARTICLES. Miyajima, Mitsuhiro (Inst. of Physical and Chemical Research, Wako, Japan). Oyo Butsuri; 41: No. 3, 290-9 (Mar 1972). (In Japanese).

The technique of heavy-ion-nuclide discrimination with radiation detectors has become important with the progress of heavy ion accelerators and the studies of heavily charged particles in cosmic ray research. A brief discussion of their principles and an intercomparison of accuracy are given. Telescopes of the penetrating type and the dE/dz -E type using semiconductor detectors, scintillation detectors, and Cherenkov detectors; nuclear emulsions; and solid-state track detectors are discussed. The accuracies for particle discrimination are shown in tables, indicating that semiconductor detectors are best. However, long term measurement is required for them because it is difficult to manufacture large area detectors. Nuclear emulsions have the advantage that they may be observed at any time once they are developed, though they show fading of latent images and contraction before the developing. They are also expensive. The solid-state track detectors are not influenced by background, but often show the fading of latent images and sometimes the material is not homogeneous.

G10 CALIBRATION OF PLASTIC NUCLEAR TRACK DETECTORS FOR IDENTIFICATION OF HEAVY CHARGED NUCLEI USING FISSION FRAGMENTS. Endo, K. (National Lab. for High Energy Physics, Ibaraki, Japan); Doke, T. *Nucl. Instrum. Methods*; 111: No. 1, 29-37 (1973).

A method for measuring the variation of the etching rate as a function of the ionization rate for the plastic nuclear track detector using fission fragments is described. In the method, the ^{235}U fission fragments are used as energetic heavy ions for the track formation. The relation between the etching rate and the ionization rate for the polycarbonate film is obtained using the fission fragments kinematically identified and the most probable fission fragments, respectively. Both results are in good agreement. Also, the relation

for the cellulose triacetate film obtained using the most probable fission fragments is in good agreement with that obtained using nitrogen ions from a cyclotron. The energy loss region where this method is applicable is $(0.5-7) \times 10^4$ MeV cm²/g. Some applications of the calibration curves to particle identification are also shown.

G11 NEW METHOD FOR PARTICLE IDENTIFICATION ON LIGHT NUCLEAR CHARGED PARTICLES BY MEANS OF A SOLID-STATE TRACK DETECTOR.

Murakami, A. (Saga Univ., Japan). Nucl. Instrum. Methods; 111: No. 3, 567-571 (1973).

A new method is presented for particle identification and energy measurement on light nuclear charged particles by means of a solid-state track detector. The principle and the concrete method of particle identification are given with theoretical calculations. This method is applicable in the energy region from about 0.5 MeV per nucleon up to about critical energy for the particles with the atomic number $z \lesssim 20$.

H. GAMMA AND X-RAY DETECTION WITH DIELECTRIC PLASTICS

H1 (AERE-M-2481) INVESTIGATION INTO THE POTENTIAL OF POLYCARBONATE AND OTHER FILMS AS MEGARAD DOSEMETERS. Douglas, J.A.; Gibson, J.A.B.; Marshall, M.; Taylor, W.M. (Atomic Energy Research Establishment, Harwell (England)). 7 p. (Feb 1972).

A dosimeter was required to cover the range 10 to 100 Mrad. The effect of ⁶⁰Co γ -rays on the U.V. absorbance of various thicknesses of polycarbonate, Melinex and polypropylene film was examined. Melinex and polypropylene film were rejected because of fading and dose rate dependence. 210 μ m thick polycarbonate can measure doses in the range 3 to 50 Mrad with a precision of $\pm 1\%$ and can detect doses down to 0.1 Mrad. The reading is stable after 10 hours' storage and shows only a small (10%) dose rate dependence from 50 to 510 krad h⁻¹. The dose range can be extended to at least 160 Mrad by using a thin (1.7 μ m) polycarbonate sheet.

H2 DIELECTRIC PLASTICS AS HIGH EXPOSURE GAMMA-RAY DETECTORS. Frank, A.L.; Benton, E.V. (Naval Radiological Defense Lab., San Francisco). Ref. J18 pp V.84-92. (1969).

Dielectric plastics are being developed as high exposure dosimeters. The principle of operation is based on the relation between the absorbed dose and the increased chemical reactivity of these dielectric solids. Polycarbonate plastics can be utilized in measuring absorbed dose in the range of about 10^7 to 10^9 rads. The advantages of the technique lie in the low cost of the detectors, ease of data readout, and high degree of reproducibility achievable. It is hoped

that the method can be extended to include the dosimetry of massive doses of soft, low penetrating power x or gamma radiations.

H3 DIELECTRIC PLASTICS AS HIGH EXPOSURE GAMMA-RAY DETECTORS. Frank, A.L.; Benton, E.V. (Univ. of San Francisco). Radiat. Eff.; 2: 269-72 (Mar 1970).

Dielectric plastics are being developed as high exposure dosimeters. The principle of operation is based on the relationship between the absorbed dose and the increased chemical reactivity of these dielectric solids. Polycarbonate plastics can be utilized in measuring absorbed dose in the range of about 10^7 - 10^9 rads. The advantages of the technique lie in the low cost of the detectors, ease of data readout, and high degree of reproducibility achievable. It is hoped that the method can be extended to include the dosimetry of massive doses of soft, low penetrating power x- or γ -radiations.

H4 PRELIMINARY EXPERIMENT ON DOSIMETRY OF HIGH ENERGY X-RAYS WITH THE SOLID STATE TRACK DETECTOR. Matsuda, Yatsuka; Mamuro, Tetsuo. Annu. Rep. Radiat. Center Osaka Prefect., 9: 18-21 (1968).

A preliminary experiment has been made in order to confirm the possibility to make dosimetry of high energy x-rays with the solid-state track detector. It was found that the intensity of high energy x-rays produced by a linear accelerator can be measured even near the target with a mica plate placed in contact with an electroplated uranium film.

H5 MEGARAD PLASTIC FILM DOSEMETER.

Richold, P.H.C.V.; Douglas, J.A.; Marshall, M.; Gibson, J.A.B. (United Kingdom Atomic Energy Authority, Harwell, Eng.). *Phys. Med. Biol.*; 18: No. 5, 665-672 (Sep. 1973).

A simple dosimeter has been designed for the measurement of doses from 0.1 to 100 Mrad. The dosimeter is a thin film of polycarbonate (thickness 200 μm) and the response to radiation is recorded by an increase in absorbance at wavelengths of 290, 300, or 325 nm. The effect of ^{60}Co γ -radiation on the film has been measured. After an initial storage period of 10 h, the reading fades at the rate of 0.4% per week and is unaffected by extremes of temperature and humidity during storage. The precision is $\pm 2\%$ from 1 to 50 Mrad but doses of 0.1 Mrad and up to at least 100 Mrad can be measured. Above 37°C the dosimeter is sensitive to temperature during radiation and at dose rates below 50 krad h^{-1} there is a reduction in response by about 20%.

H6 GAMMA-RAY DOSIMETRY WITH THIN PLASTIC FILM. Yoo, Y.S.; Ro, S.G. (Atomic Energy Research Inst., Seoul). *J. Korean Nucl. Soc.*; 5: No. 3, 223-233 (Sep. 1973).

Thirty-two different kinds of domestic plastic films for use in measuring high gamma-ray doses have been collected and their dosimetric characteristics investigated with the help of a ^{60}Co -gamma radiation source. Among them is a rigid polyvinyl chloride (PVC) film of 0.06mm in thickness which seems to be the most suitable one for this purpose. The relation between optical density at 3100 $\text{\AA}$ and radiation exposure in this PVC film was linear in the range of $0.6 \times 10^6 \text{ R}$ to $1.3 \times 10^7 \text{ R}$, and also the film showed a good reproducibility within 9% under the standard experimental condition. The effect of absorbed dose, oxygen content of surrounding atmosphere and irradiation temperature have also been studied for this film. It appeared to have a good property in the dosimetric point of view.

I. PARTICLE RADIATOR PREPARATION

II PREPARATION OF THIN LAYERS OF ^{237}Np FOR ABSOLUTE COUNTING AND FISSION DETECTORS. Parker, W.; Colonosmos, M. (Instituto Venezolano de Investigaciones Cientificas, Caracas). *Nucl. Instrum. Methods*, 66: 137-40 (Dec. 1968).

A review of electrodeposition procedures for the preparation of ^{237}Np is given and two new procedures reported making use of molecular plating. High voltage - low current yield determinations were carried-out in the region 500 - 1700 V dc with a deposition current constant at 1.0 mA. The suitability of aluminium, titanium, copper and stainless steel as cathode material was also investigated. It was found that using stainless steel as a cathode and a voltage of 1700 V for a 10 min period resulted in a yield of 100% ^{237}Np , providing that the total solids in solution were within the limits of $20 \mu\text{g}/\text{cm}^2$ to $500 \mu\text{g}/\text{cm}^2$. The quality of the layers produced by the described method make them very suitable for alphaspectrometry and for the fabrication of fission detectors.

I2 (RT/FI-(70)23) PREPARATION OF THIN DEPOSITS OF FISSION MATERIALS. Balducci, G.; Bianciffiori, M.A.; Martini, M. (Comitato Nazionale per l'Energia Nucleare, Rome (Italy)). 38 p. (Apr. 1970).

Techniques of thin film deposition are widely employed to prepare detectors for neutron flux measurements. Methods adopted for the preparation of thin films of fission materials are described. They are based on the vacuum or controlled atmosphere evaporation and on the electrochemical deposition process. Methods to calibrate layer thicknesses are also described.

I3 ELECTRODEPOSITION OF AMERICIUM AND OBSERVATION OF THE SURFACE BY MEANS OF ALPHA PARTICLE TRACKS ON A CELLULOSE NITRATE FILM. Hashimoto, T., *Journal of Radio-analytical Chemistry*, 9, 251. (1971).

J. GENERAL TRACK REGISTRATION APPLICATIONS

J1 SOLID-STATE TRACK DETECTORS:

APPLICATIONS TO NUCLEAR SCIENCE AND GEOPHYSICS. Fleischer, R.L.; Price, P.B.; Walker, R.M. (General Electric Co., Schenectady, N.Y.). *Ann. Rev. Nucl. Sci.*, 15: 1-28(1965).

Experimental techniques for using solid-state track detectors are presented, followed by a description of those applications to nuclear science that have already been demonstrated or appear promising. The techniques for revealing tracks are described, and the various characteristics of solid-state track detectors are summarized, such as their sensitivities and the effects of temperature, pressure, and ionizing radiations or track stability. The theory of track formation is treated, and applications of solid-state track detectors to nuclear physics, radiation dosimetry, and activation analysis are dealt with. A discussion of fossil tracks in terrestrial and extraterrestrial minerals is included.

J2 TRACKS OF CHARGED PARTICLES IN SOLIDS. Fleischer, R.L.; Price, P.B.; Walker, R.M. (General Electric Research Lab., Schenectady, N.Y.). *Science*, 149: 383-93 (July 1965).

Heavy charged particles create narrow damage trails in many solids. The display of such tracks by preferential chemical etching has provided useful tools in many areas of endeavor: solid-state track detectors for nuclear physics, neutron dosimeters for nuclear engineering, a new means of performing chemical microanalysis of certain elements, filters capable of separating different biological cells, a method of dating geological and anthropological materials, and a means of examining the history and space environment of extraterrestrial objects.

J3 (AFCRL-65-305) RESEARCH INTO RADIATION DAMAGE EFFECTS IN SOLIDS. Final Report, April 1, 1962-March 31, 1965. Fleischer, R.L.; Price, P.B.; Walker, R.M. (Research Lab., General Electric Co., Schenectady, N.Y.). 32 p. (June 1965).

The work has shown that almost all insulating solids, including natural minerals, glasses, and plastics record tracks of nuclear charged particles. After a description of the nature of tracks in solids and ways of seeing them, their uses in such diverse problems as measuring the age of geological and archeological specimens, studying the early history of the solar system recorded in meteorites, observing nuclear inter-

actions, determining neutron fluxes, and separating biological cells of different sizes are discussed.

J4 TRACKS OF CHARGED PARTICLES IN SOLIDS AND THEIR APPLICATIONS IN METROLOGY OF RADIONUCLIDES. Price, P.B. (General Electric Research Lab., Schenectady, N.Y.). pp 1-14 of *Proceedings of the All India Symposium on Radioactivity and Metrology of Radionuclides, Bombay, March 14-18, 1966.* Bombay, Atomic Energy Establishment Trombay, 1966.

The production of tracks in materials when bombarded with massive energetic charged particles is discussed. Correlation of the track characteristics of materials is made with the electric conductivity of the materials. Age calculations of natural materials from studies of the tracks is also discussed.

J5 CHARGED-PARTICLE TRACKS IN SOLIDS. Goland, Allen N. (Brookhaven National Lab., Upton, N.Y.). pp 159-335 of *Studies in Radiation Effects*. Vol. 1. Dienes, G.J. (ed.). New York, Gordon and Breach Sciences Publishers, Inc., 1966.

Investigations of charged-particle tracks in solids are reviewed. Theoretical aspects are discussed. It was concluded that the behavior of "hot" electrons within individual crystallites comprising thin films is the controlling factor in the production of evaporation tracks. Nuclear fission, stopping power of solids, radiation-damage models related to track formation, electron microscopy, experimental results, mineral dating by determination of fission-track ages, and solid-state detectors are discussed.

J6 TRACK ETCHING: SOME NOVEL APPLICATIONS AND USES. Furman, S.C.; Darmitzel, R.W.; Porter, C.R.; Wilson, D.W. *Trans. Amer. Nucl. Soc.*, 9: 598-9 (Oct.-Nov. 1966).

J7 AN ATTEMPT TO APPLY MICA DETECTORS FOR BIOLOGICAL RESEARCH. (Próba zastosowania detektorów mikowych do badań biologicznych). M. Decowski, P. Decowski. (Institute for Veterinary Research, Pulawy; Department of Physics of Atomic Nucleus, University of Warsaw). *PTJ*, 11, 1041-1042 (1967). (In Polish).

J8 SOLID-STATE TRACK DETECTORS. Monnin, Michel (Faculte des Sciences, Clermont-

Ferrand, France). *Radioprotection*, 2: 105-17 (1967). (In French).

A general survey of characteristics of solid-state nuclear track detectors is presented. Organic detectors (polymeric systems) are emphasized. The development of ionizing particles tracks by chemical etching is described. The chemical etching reagents to be used with new detectors such as polyethylene, polypropylene and ionomeric polyethylene and, also, new methods to reveal some already known detectors are given. Then, the most important characteristic of detectors, i.e., its very sharp detection cut-off is explained and a suggestion to give a different definition of the detection threshold is given. Finally, possible mechanics for track formation are briefly discussed.

J9 SOLID DIELECTRICS AS DETECTORS FOR CHARGED PARTICLES. Iodogne, J.C. (Univ., Louvain, Belg.). *Rev. Quest. Sci.*, 139: 191-206 (Apr. 1968). (In French).

Bombardment of charged heavy particles results, for many insulators, in a sufficient number of ionizations to permit preferential chemical attack along the length of the trajectory. These tracks are stable and observable with a microscope. Such detectors are insensitive to neutrons, electrons, protons, and γ rays. The use of the electron microscope provides a method for the study of tracks of particles with extremely short lifetimes. Samples of the lunar surface may be studied by this technique to give information not only about the history of the moon, but also about the nature of primary heavy cosmic rays. Development of a technique for atomic number determination of the particles is described. Photographs illustrate the development of tracks.

J10 DETECTION OF THE TRACKS OF CHARGE PARTICLES IN SOLID MATERIALS. Tuyn, J.W.N. (Reactor Centrum Nederland, Petten, Netherlands). *Atoomenergie Haar Toepass.*, 10: 13-20 (Jan. 1968). (In Dutch).

Etching methods enable the enlarging of tracks of heavy, charged, fast particles, particularly fission products, in insulators until these tracks are visible in the optical microscope. This technique is explained and its application in nuclear fission, archeology, and the production of biological filters is discussed. Activation analysis and neutron dosimetry can be performed by combining an insulator foil with a foil of fissionable material. 28 references.

J11 NUCLEAR TRACK REGISTRATION IN SOLIDS BY ETCHING. Becker, K. (Oak Ridge National Lab., Tenn.). *Biophysik*, 5: 207-22 (1968).

A review is given on recent developments in the field of charged particle track registration in insulating solids by preferential etching. The basic mechanism of latent track formation in minerals and inorganic glasses seems to be a spike formation process. In the more sensitive organic polymers, radiation induced chemical changes along the track probably predominate. The sensitivity, etching kinetics, and stability of tracks in plastics and some of the factors which affect them are discussed on the basis of experimental data. Several microscopic and macroscopic methods for simplified or automatic track counting are described briefly. Among the many applications of the etching method, neutron dosimetry via (n,f) , (n,α) , and recoil reactions are discussed in some detail. Other applications in nuclear physics, chemistry, biology, space research, and for age determinations in geological and archeological samples are listed.

J12 (CEA-Bib-122) STUDY OF IONOGRAPHIC TRACKS IN INSULATORS. LITERATURE SURVEY. Thomas, Jean-Jacques; Teyssier, Jean-Louis (Toulouse Univ. (France). Centre de Physique Atomique et Nucleaire); Chapuis, Anne-Marie; Francois, Henri (Commissariat a l'Energie Atomique, Fontenay-aux-Roses (France). Centre D'Etudes Nucleaires). 98 p. (July 1968). (In French).

A literature survey of results published before 1967 on the detection of ionizing particles in solids is presented. The different modes of observation and of chemical development of these tracks and the criteria proposed for classifying the detector materials as a function of their sensitivity are described. A brief review of the hypotheses which make it possible to explain partially the mechanism of formation of tracks is included. The description of these detectors is limited to those liable to find applications in nuclear physics (spallation and fission reactions, cross-section measurements, neutron dosimetry) and in geophysics (study of fossil tracks in natural ores of terrestrial or extra-terrestrial origin).

J13 APPLICATION OF PLASTIC TRACK DETECTORS FOR DETECTION OF LIGHT NUCLEI. Somogyi, G.; Varnagy, M.; Peto, G. (Inst. for Experimental Physics, Debrecen, Hungary). *Nucl. Instrum. Methods*, 59: 299-304 (Feb. 1968).

The possibilities of registering and discriminating the products of the reactions $D + D$ and $D + T$ in cellulose nitrate and in cellulose acetate track detectors were studied. It has been shown, that the sensitivity of the solid state track detectors can be varied by using different etching reagents, and so it is possible to detect even proton tracks in these plastics. Using a given mixture as developing reagent, at cellulose acetate we evaluated the critical rate of energy loss for alphas, tritons and protons. The investigated plastics are applicable for studying such nuclear reactions where the outgoing particles are 3H , 3He , and 4He . By means of this method we could monitor neutrons from $D + D$ and $D + T$ reactions, and determine the tritium contamination of a deuterium target.

J14 Bib. 232. FISSION TRACK SOLID STATE DETECTOR. Burjan, V. (Ceskoslovenska Akademie Ved, Prague. Ustav Jaderneho Vyzkumu). 9p. (Oct. 1968). (In Czech).

A list of 46 reports and publications, compiled from NSA volumes 17-22 is presented.

J15 CHARGED PARTICLE TRACKS IN INSULATING SOLIDS. Mory, J. (CEN, Fontenay-aux-Roses, France). pp 393-443 of *Solid State Dosimetry*. (Amelinckx, S. (ed.). New York; Gordon and Breach, Science Publishers, Inc. (1969).

The development of particle tracks in insulating materials by etching, track counting, and characteristics of insulating particle track detectors including environmental factors, particle track formation mechanism, and sensitivity are discussed. The development of insulating particle track detectors for neutron detection and dosimetry is reviewed. Boron glasses (n,α) are used for low-flux thermal neutron detection and fission foils (n,f) are used for high-flux thermal and fast neutron detection. The characteristics of various fission foils and insulating detectors are briefly reviewed. Other studies which utilize particle tracks in insulating materials are discussed including the study of fission and spallation, measurement of half-life of unstable elements, measurement of age of terrestrial and extra-terrestrial minerals, and metallurgical microanalysis. Also, the use of particle track detectors in solid state physics for studying the channeling effect including the effect of orientation and grain boundaries, stacking faults, dislocations, and the deformation band is described. (65 references).

J16 NUCLEAR TRACKS IN SOLIDS. Fleischer, R.L.; Price, P.B.; Walker, R.M. *Sci. Amer.*, 220: No. 6, 30-9 (June 1969).

The mechanism of charged particle track formation in dielectric materials is described, and the chemical etching process for making the particle tracks more readily visible is discussed. Also, some of the scientific and technological applications of the phenomenon are discussed including fission track dating, cosmic ray studies, search for magnetic monopoles, search for ternary fission, use for identification of element number 104, and use for the manufacture of Nuclepore filters.

J17 PROCEEDINGS OF THE INTERNATIONAL TOPICAL CONFERENCE ON NUCLEAR TRACK REGISTRATION IN INSULATING SOLIDS AND APPLICATIONS, HELD AT CLERMONT-FERRAND, FRANCE, MAY 6-9, 1969. VOLUME 1. Isabelle, D.; Monnin, M. (eds.). Clermont-Ferrand, France: Universite de Clermont-Ferrand (1969). 418 p. (In French and English).

J18 PROCEEDINGS OF THE INTERNATIONAL TOPICAL CONFERENCE ON NUCLEAR TRACK REGISTRATION IN INSULATING SOLIDS AND APPLICATIONS, HELD AT CLERMONT-FERRAND, FRANCE, MAY 6-9, 1969. VOLUME 2. Isabelle, D.; Monnin, M. (eds.). Clermont-Ferrand, France: Universite de Clermont-Ferrand (1969). 424 p. (In French and English).

J19 VARIOUS APPLICATIONS OF DIELECTRIC TRACK DETECTORS. Monnin, M. (Univ., Clermont-Ferrand, France). Ref. J18 pp IX. 2-5 (1969). (In French).

A brief review is given of dielectric track detector applications in biology, metallurgy, and reactor physics. They can also be used for studying liquid or gas motion, for polymer electrolytic metalization and catalytic wall fabrication.

J20 SOLID STATE TRACK DETECTORS. Blanc, Daniel (Univ., Toulouse). pp 96-125 of *Radiation Dosimetry*. Vol. 2. Miric, I. (ed.). Belgrade; Boris Kidric Inst. of Nuclear Sciences (1971).

The subject of dielectric track detectors is reviewed. After a brief historical background, latent track properties are discussed. The properties of the developed track are next considered — development technique, con-

ditions under which a track is developable, and etch rate along the trajectory. Counting of developed tracks and particle spectrometry are discussed. Track formation mechanisms are described. Applications of these detectors in the measurement of time intervals, fundamental physics studies concerning nuclear reactions, cosmic rays, microanalysis, geochronology, astrophysics, space radiation protection, neutron detection and dosimetry, and biology are briefly reviewed. (9 figures, 7 tables).

J21 SOLID TRACK DETECTORS: PRACTICAL APPLICATIONS. Blanc, D. (Toulouse Univ., France). *Radioprotection*; 5: 201-28 (1970). (In French).

Because of their high sensitivity to fission fragments, solid track detectors can measure time interval measurements such as the spontaneous fission half-lives of ^{238}U and the isotope 260 of element 104. Their very high resolution power means that very short time intervals are measurable. These detectors can be used to study nuclear reactions of fission and spallation: neutron induced fission; fission and spallation induced by protons (3 and 18 GeV); fission induced by heavier nuclei; and photofission. Solid track detectors are used for measurements in balloon flights, recoverable-load rocket shots or space flights. In microanalysis, Rn and Tn and also U and Th were determined in natural crystals and the ^{235}U enrichment of metallic U measured. These detectors are employed in health physics for long-term space flights. Several types of dosimeters were designed for neutron detection and personnel protection (in mica, in plastic, threshold detectors and dosimeter glasses). A method of dating inorganic compounds based on the study of fossil tracks of spontaneous fission is being studied, together with a method to investigate minerals of extraterrestrial origin. The few existing applications in crystallography and aerosol physics are described.

J22 CHARGED-PARTICLE TRACKS IN SOLIDS. Morgan, D. Vernon (Atomic Energy Research Establishment, Harwell, Eng.); Van Vliet, Dirck. *Contemp. Phys.*; 11: 173-93 (Mar 1970).

When energetic heavy ions such as fission fragments pass through some solids, linear trails of damage (tracks) mark their trajectories. A review is presented of the large number of experimental observations of track structure in solids, and the track-storing ability of a solid in relation to the electronic excitation of the

bombarding ion and to a number of physical properties, of the solid is shown. Two models, "The Electron Thermal Spike" and "The Ion Explosion Spike," proposed to account for track formation are considered in the light of these results. A number of practical applications of the track-forming process are reviewed.

J23 NUCLEAR TRACK METHODS IN SOLIDS AND ITS DEVELOPMENT. PART I. FUNDAMENTALS, AND THE TRACKS IN MINERAL AND IN GLASS. Sakanoue, Masanobu (Kanazawa Univ., Japan). *Kagaku No Ryoiki*; 24: 124-37 (Feb. 1970). (In Japanese).

The fundamentals of the method for observing charged particle tracks formed in various dielectric solids by etching with a chemical reagent are explained. They involve the formation mechanism of tracks and sensitivity (1), the etching process (2), the influence of external conditions (3), and the observation method (4). The tracks in various minerals and their application are described and include the following subjects: 1. the distribution and concentration measurement of fissile nuclides such as uranium; 2. neutron flux distribution and dose measurement; 3. nuclear-chemical investigation such as the measurement of cross section for nuclear fission reaction; 4. age determination; and 5. α recoil tracks and other tracks. The tracks in glassy substances and their application are described with mention of uranium concentration and age determination and neutron dose measurement.

J24 NUCLEAR TRACK METHODS IN SOLIDS AND ITS DEVELOPMENT, PART 2. DISCRIMINATION OF INCIDENT PARTICLES AND OF THEIR ENERGY, NAD APPLICATION OF PLASTICS. Sakanoue, Masanobu (Kanazawa Univ., Japan). *Kagaku No Ryoiki*; 24: 207-21 (Mar 1970). (In Japanese).

In Part 1, the fundamentals of the nuclear track method in dielectric solids and its applications were described concerning the quantitative aspect of the track, that is, track density. In this article the fundamentals are explained in detail with regard to the qualitative aspects of the track such as track size and track length. The discrimination of incident particles and their energy can be made by the use of these qualitative characteristics of the tracks. Cellulose film and its application are described, and the applications of polycarbonate and other plastics are discussed.

J25 SOLID TRACK DETECTORS AND THEIR APPLICATIONS TO BIOLOGY. Monnin, Michel; Isabelle, Didier B. (Clermont-Ferrand Univ., France). *Ann. Phys. Biol. Med.*; 4: No. 2, 95-113 (Apr.-May-Jun. 1970). (In French).

The mechanisms of track formation by ionizing particles in insulating materials are briefly described. Suitable materials and the corresponding etching reagents are listed. The use of this technique in the field of biology for dosimetry, autoradiography, and micro-analysis is discussed, and special equipment is described.

J26 SOLID TRACK DETECTORS. Blanc, D. (Toulouse Univ.). *Radioprotection*; 5: 37-78 (1970). (In French.)

The text is the beginning of a course which will be continued in the next numbers of the journal. It includes a study of the latent track and development and properties of the particle track.

J27 TRACK-ETCH RESEARCH AND DEVELOPMENT AT GE VALLECITOS NUCLEAR CENTER. Weidenbaum, B.; Lovett, D.B.; Caputi, R. W. (General Electric Co., Pleasanton, Calif.). *Trans. Amer. Nucl. Soc.*; 13: 528-30 (Nov. 1970).

J28 SOME APPLICATIONS OF NUCLEAR TRACK ETCHING IN POLYMERS. Becker, Klaus (Oak Ridge National Lab., Tenn.). *Trans. Amer. Nucl. Soc.*; 13: 530-1 (Nov. 1970).

J29 FORMATION OF CHARGED PARTICLE TRACKS IN INSULATING MATERIALS. Khan, H.A. (Univ. of Birmingham, Eng.). *Nucleus (Karachi)*; 8: No. 3, 29-36. (Jul. - Sep. 1971).

During the last decade, a considerable amount of work has been done in understanding the basic mechanism of track formation in insulators. Various existing theories of track formation are reviewed and discussed in the light of experimental data.

J30 A TRACK ETCH TECHNIQUE FOR URANIUM EXPLORATION. Gingrich, J.E., and Lovett, D.B. (GE-Pleasanton); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

J31 TRACK ETCH ANALYSIS OF URANIUM PARTICLES AS A TRACER SYSTEM. Lovett, D.B. (GE-Pleasanton). *Transactions 1972 Annual Meeting of the American Nuclear Society*, Vol. 15.

J32 SCIENTIFIC APPLICATIONS OF PARTICLES IN SOLIDS. Fleischer, Robert L. (GE-Schenectady). *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

J33 NUCLEAR PHYSICS USING SOLID-STATE NUCLEAR TRACK DETECTORS. Perelygin, V.P. (JINR-Moscow). *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

J34 PARTICLE TRACK ETCHING. Fleischer, R.L. (General Electric Research and Development Center, Schenectady, N.Y.); Alter, H.W.; Furman, S.C.; Price, P.B.; Walker, R.M. *Science*; 178: No. 4058, 255-63 (Oct. 1972).

A survey is presented of the diverse technological applications of etched particle tracks. Applications are divided into four categories: porous membranes (filters and particulate counters), imaging and mapping, radiation dosimetry, and miscellaneous. Methods for enhancing the etched particle tracks are considered. 71 references. (D.L.C.).

J35 SOLID NUCLEAR PARTICLE DETECTORS: TRACK TECHNIQUE. Dejeht, F. (Univ., Louvain, Belg.). *Rev. Quest. Sci.*; 143: No. 4, 545-62 (1972). (In French).

When a heavy charged particle penetrates into a dielectric solid, it creates, by ionization, a permanent zone of damage susceptible to preferential chemical attack which can be observed microscopically. The counting and the examination of the morphology of the tracks make it possible to deduce a large number of data on the ionizing particle. Thus solid detectors find numerous applications in very diverse areas such as nuclear physics, chemical analysis, dosimetry of radiations, geochronology, and astrophysics. Also, tracks in extraterrestrial rocks and minerals offer interesting possibilities for the improvement of our knowledge of the universe.

J36 (UCRL-50007-72-1) HAZARDS CONTROL PROGRESS REPORT NO. 42, JANUARY-APRIL 1972. (California Univ., Livermore. Lawrence Livermore Lab.). 16 p. (July 1972).

RAD. DET., DIELECTRIC TRACK -track counting methods for.

J37 A SIEVE FOR THE ISOLATION OF CANCER CELLS AND OTHER LARGE CELLS FROM THE BLOOD. Seal, S. *Cancer*, 17, p637 (1964).

Abstract not available.

J38 FLOW CHARACTERISTICS OF HUMAN ERYTHROCYTES THROUGH POLYCARBONATE SIEVES. Gregersen, M.I., Bryant, C.A., Hammerle, W.E., Usami, S., and Chien, S. *Science*, 157, p825 (1967).

Abstract not available.

J39 A MODIFIED MEMBRANE FILTER TECNIC FOR CYTODIAGNOSIS. McAlpine, L.I., and Ellsworth, B. *Amer. J. Clin. Pathol.*, 52, p242 (1969).

Abstract not available.

J40 AEROSOL FILTRATION BY MEANS OF NUCLEOPORE FILTERS. Spurny, K. R., Lodge, J.P., Frank, E.R., and Sheesley, D.C. *Environ. Sci. Technol.*, 3, p464 (1969).

Abstract not available.

J41 COUNTING AND SIZING OF SUBMICRON PARTICLES BY THE RESISTIVE PULSE TECHNIQUE. DeBlois, R.W., and Bean, C.P. *Rev. Sci. Instrum.*, 41, p 909 (1970).

Abstract not available.

J42 OBSERVATION OF INDIVIDUAL VIRUS PARTICLES BY THE RESISTIVE PULSE TECHNIQUE. DeBlois, R.W., and Bean, C.P. *Biophysical Journal*, 11, p268a, (1971).

Abstract not available.

J43 Fleischer, R.L., Alter, H.W., Furman, S.C., Price, P.B., and Walker, R.M. Gen. Electr. REP. 72-CRD-107 (1972).

Title and abstract not available.

J44 Gen. Electr. REP. 0-5538 (1972).

Title and abstract not available.

J45 (UCRL-51362) RESULTS OF THE 1972 SURVEY ON TRACK REGISTRATION. Griffith, R.V. (California Univ., Livermore. Lawrence Livermore Lab.) 105p. (Mar. 1973).

The results of a survey of 118 laboratory groups in 20 countries on the registration of particles in dielectric materials is presented. The survey includes data on track registration applications, as well as materials used, particles studied, analyses performed, and methods of data acquisition and track image enhancement. A section is also included which presents detailed replies by 39 laboratories on techniques of spark counting.

J46 (CONF-700705-(Vol. 1)) 7TH INTERNATIONAL CONFERENCE ON CORPUSCULAR

PHOTOGRAPHY AND SOLID VISUAL DETECTORS. Volume 1. Conference held in Barcelona, Spain, July 7-11, 1970. Cuer, P.; Schmitt, R. (eds.) (Centre National de la Recherche Scientifique, Strasbourg (France). Laboratoire de Physique Corpusculaire). 432 p. (1970). (In French and English).

J47 (CONF-700705-(Vol. 2)) 7TH INTERNATIONAL CONFERENCE ON CORPUSCULAR PHOTOGRAPHY AND VISUAL SOLID DETECTORS, BARCELONA, SPAIN, JULY 7-11, 1970. Cuer, P.; Schmitt, R. (eds.) (Centre National de la Recherche Scientifique, Strasbourg (France). Laboratoire de Physique Corpusculaire). 444 p. (1970). (In French).

J48 NON-PHOTOGRAPHIC REGISTRATION OF NUCLEAR TRACKS IN SOLIDS AND THEIR APPLICATIONS. Piesch, E. (Kernforschungszentrum, Karlsruhe, Ger.). *G-I-T (Glas-Instrum.-Tech.) Fachz. Lab.*, 16: No. 7, 810-816 (1972). (In German).

A survey is given of the mode of detection, the method, and the following applications: neutron dosimetry, autoradiography, microanalysis, geologic age determination, cosmic radiation measurement, and determination of uranium enrichment.

J49 IONOGRAPHY: EMULSIONS AND SOLID STATE DETECTORS. Avan, L.; Avan, M.; Blanc, D.; Teyssier, J. L. Paris; Doin 347 p. (1973). (In French).

The chapter headings are as follows: ionization induced by charged particles; utilization of ionographic emulsions in particle physics, latent images; nuclear emulsions; general scattering theory; application of nuclear emulsions; solid state track detectors (formation of the latent image); solid track detectors (chemical development of the latent track and the obtaining of data); mechanism by which the tracks are obtained; and practical applications of solid track detectors.

J50 (BNL-50336.) SOLID-STATE TRACK DETECTORS: ACHIEVEMENTS AND CURRENT PROBLEMS. Walker, R. M. (California Inst. of Tech., Pasadena). pp 305-330. (Feb. 1973).

In interaction of energetic charged particles with solids.

A review on dielectric track detectors is given. Topics include the basic phenomena, geochronology, energetic particles from the sun and the galaxy, element mapping, dosimetry, controlled production of small holes, and current problems and future perspectives. (73 references).

K. NEUTRON DOSIMETRY AND SPECTROMETRY

K1 A VERSITILE, DISPOSABLE DOSIMETER FOR SLOW AND FAST NEUTRONS. R.M. Walker, P.B. Price, and R.L. Fleischer (General Electric Research Lab., Schenectady, N.Y.). *Appl. Phys. Letters*, 3: 28-9 (July 15, 1963).

Crystals such as mica and quartz, glasses, and plastics that exhibit radiation-damage trails from fission fragments when selectively etched were used as dosimeters for fast and thermal neutrons. The dosimeter consists of a thin detector sheet of such a solid covered by a sheet of fissile material. Recoiling fragments from neutron-induced fission produce tracks in the detector sheet, which is then etched and examined either microscopically or by a readout device to obtain the number of etched-out holes. For monitoring very high doses, the fissile cover is omitted and uranium impurities in the solid itself are utilized. Most of these solids are completely insensitive to gamma rays, electrons, protons, and alpha particles.

K2 (GE-63-RL-(3253M)). USE OF MICA AS A CONVENIENT AND SIMPLE DOSIMETER FOR BOTH SLOW AND FAST NEUTRONS. Price, P.B.; Walker, R.M. (General Electric Co., Schenectady, N.Y. Research Lab.). Feb. 1963. 16p.

A new neutron dosimeter is described which consists simply of a slab of mica placed next to a layer of fissile material. Neutron-induced fission fragments leave tracks in the mica which can be etched out to form holes. The dose is determined either directly, by counting holes in an optical microscope, or indirectly, by measuring the flow rate of gas or solute ions through the holes. The characteristics, sensitivity, and potential uses of the dosimeter are discussed along with ways to read the dose of either thermal or fast neutrons.

K3 REGISTRATION OF FISSION-FRAGMENT TRACKS IN SEVERAL SUBSTANCES AND THEIR USE IN NEUTRON DETECTION. M. Debeauvais (Laboratoire de Physique Corpusculaire, Strasbourg), M. Maurette, J. Mory, and R. Walker. *Intern. J. Appl. Radiation Isotopes*, 15: 289-99 (May 1964).

In a number of substances energetic, heavy charged particles leave trails of radiation-damaged material that can be selectively attacked by chemical reagents to produce tracks visible in an optical microscope. A comparative study was made of the density and length distribution of such tracks produced by uranium

fission fragments in several micaceous minerals, Makrofol (a polycarbonate polymer) and glass. By comparing the track densities with those measured in nuclear emulsions it was concluded that fission fragments are registered with 100% efficiency in the micaceous minerals and in the Makrofol, but only with 40% efficiency in the variety of glass that was studied. The results are shown to be consistent with the hypothesis that the average rate of energy loss of the charged particle determines the ability to form etched tracks. It was previously pointed out that mica in combination with a fissile cover material has some signal advantages as a neutron detector. Several aspects of this application, including the measurement of track yields from thick uranium source, are discussed.

K4 THERMAL AND FAST NEUTRON DETECTION BY FISSION-TRACK PRODUCTION IN MICA. P.R. Prevo, R.E. Dahl, and H.H. Yoshikawa (General Electric Co., Richland, Wash.). *J. Appl. Phys.*, 35: 2636-8 (Sept. 1964).

The recently developed method of etching fission fragment tracks in mica appears to be applicable to the measurement of neutron exposures in irradiation tests. The sensitivity of the method depends on the concentration of fissile elements. The naturally occurring uranium which is present in trace quantity can be used to measure thermal neutron exposures of 10^{16} to 10^{11} neutrons/cm². Deposition of fissionable material on the mica would increase the sensitivity to permit measurement of 10^6 to 10^{11} neutrons/cm². Density counts are reproducible to approximately 5% by using simple laboratory techniques.

K5 BNWL-339: SOLID STATE PARTICLE DETECTORS AND DOSIMETERS. Baumgartner, W.V., Brackenbush, L.W. *Dosimetry Technology Studies* 1965 (1966).

K6 (USNRDL-TR-904). NUCLEAR TRACK REGISTRATION IN DOSIMETER GLASSES FOR NEUTRON DOSIMETRY IN MIXED RADIATION FIELDS. Becker, K. (Naval Radiological Defense Lab., San Francisco, Calif.). Aug. 5, 1965. 43p.

The properties of combinations of some dosimeter glasses with several fissionable materials for thermal and fast neutron dosimetry in mixed radiation fields, using Fleischer, Price and Walker's etching technique for the visualization of the fission fragment tracks, were investigated. The effect of the glass composition,

different etching chemicals (NaOH, EDTA and HF), their concentration and temperature on etching kinetics, and the fading and "over-etching" stability of the tracks were studied. The neutron sensitivity is given for natural U and Th, ^{235}U , ^{233}U , and ^{237}Np with and without additional thermal neutron absorbers for several neutron energies (thermal, TRIGA and HPRR fission, 2.7 Mev. Pu/Be and 14 Mev.) For thick foils of fissionable metals, the sensitivity is 1.3×10^{-5} track/neutron/barn $\pm 10\%$. For higher neutron energies ($2 - >20$ Mev), ^{238}U is of particular interest because of its rem-equivalent response. The detection limits are discussed. Different techniques for the automatic optical (microscopic and macroscopic) evaluation of the fission track density in glasses are described. The effects of the foil radioactivity and the neutron induced fission fragments on the radiophotoluminescence in the glass were studied. Most of the results given are also valid for ordinary glasses. The possible applications of the system in personnel dosimetry and for special applications were investigated.

K7 NEUTRON DOSIMETRY BY THE FISSION-FRAGMENT METHOD. Widell, C.O. *Neutron Monitoring*, Wien 1966, 417-422. (Studsvik, AB Atomenergie). Siehe Ref. Nr. 1-24. (1966).

K8 (BNWL-SA-516) NEUTRON DOSIMETRY USING THE FISSION FRAGMENT DAMAGE PRINCIPLE. Baumgartner, W.V.; Brackenbush, L.W. (Battelle-Northwest, Richland, Wash. Pacific Northwest Lab.). June 9, 1966. 17p.

Plastics, glasses, and minerals used in conjunction with fissionable foils provide the basis for a full energy spectrum neutron dosimeter. Theoretical and experimental studies indicate that fast neutron doses as low as 100 mrem and thermal neutron doses of 1 mrem can be measured. Solid state nuclear track detectors were fabricated with fission foils of metallic U-235 (93%) and 20-fold depleted U-238. Neptunium oxide foils were fabricated using slow-curing polyester resin as a support base. Uniform surfaces of neptunium oxide were obtained that contained approximately 35 mg/cm² of neptunium. Exposure studies of RaBe, PuBe and PuF₄ neutron sources and monoenergetic fast neutrons obtained from a 2 Mev positive ion accelerator characterized the energy and dose response of this device. Comparison studies using solid state nuclear track detectors and NTA emulsions were made in field exposure situations. The solid state nuclear track detectors permitted dose evaluation in several neutron energy groups in mixed gamma and neutron radiation

fields. This new dosimeter principle used with a single Np-237 foil will provide substantially improved neutron dosimetry in mixed radiation fields compared to the commonly-used NTA emulsion dosimeters.

K9 (ORNL-P-1850). APPLICATION OF SOLID-STATE NUCLEAR TRACK DETECTORS TO THE HURST THRESHOLD DETECTOR SYSTEM. Kerr, G.D.; Strickler, T.D. (Oak Ridge National Lab., Tenn.). *Health Phys.*, 12: 1141-2 (Aug. 1966).

The application of solid-state nuclear track detectors to the Hurst threshold detector system improved the performance of the detectors and extended the energy range.

K10 NUCLEAR TRACK REGISTRATION IN DOSIMETER GLASSES FOR NEUTRON DOSIMETRY IN MIXED RADIATION FIELDS. Becker, K. (Naval Radiological Defence Lab., San Francisco). *Health Phys.*, 12: 769-85 (June 1966).

The properties of combinations of some dosimeter glasses with several fissionable materials for thermal and fast neutron dosimetry in mixed radiation fields, using an etching technique for the visualization of the fission fragment tracks, were investigated. The registration efficiency, effect of the glass composition, different etching chemicals (NaOH, EDTA, and HF), their concentration and temperature on etching kinetics, and the fading and over-etching stability of the tracks were studied. The neutron sensitivity is given for natural U and Th, ^{235}U , ^{238}U , and ^{237}Np with and without additional thermal neutron absorbers for several neutron energies. For thick foils of fissionable metals, the sensitivity was 1.3×10^{-5} track/neutron/barn ± 10 per cent. For higher neutron energies (2 to >20 Mev), ^{238}U is of particular interest because of its rem-equivalent response. The detection limits are discussed. Different techniques for the automatic optical (microscopic and macroscopic) evaluation of the fission track density in glasses are described. The effects of the foil radioactivity and the neutron induced fission fragments on the glass radiophotoluminescence were studied. The system was superior to nuclear track emulsions (gamma insensitive, no fading or fogging, easier evaluation, extended dose and energy range, no directional dependence, etc.) as well as to activation foils (no radioactive decay, higher sensitivity) in personnel dosimetry and for several special applications. Most of the results given are also valid for ordinary glasses.

K11 USNTRDL-TR-1089, A STANDARDIZED METHOD FOR MAKING NEUTRON FLUENCE MEASUREMENTS BY FISSION FRAGMENT TRACKS IN PLASTICS. Eugene Tochilin, S. Pretre, and Norman Goldstein. Naval Radiological Defense Lab., San Francisco, Calif. 14 Dec 66, 32p.

K12 (BNWL-SA-619) A NEW NEUTRON AND HIGH ENERGY PARTICLE DOSIMETER FOR MEDICAL DOSIMETRY APPLICATIONS. Baumgartner, W.V.; Brackenbush, L.W.; Unruh, C.M. (Battelle-Northwest, Richland, Wash. Pacific Northwest Lab.). July 20, 1966. 15p.

Principles, design, and performance of solid state track dosimeters are discussed. For neutron detection, a strip of plastic is used with a fissionable foil attached to it. Neutrons induce fission in the foil, and the fission tracks in the plastic can be detected by using etchants which preferentially attack the damaged areas. For proton detection, proton-fissionable foils can be used. Alpha particles and higher nuclei leave their own tracks directly in appropriate plastic detectors. However, large fluxes and doses of particles on photons, which do not provide a minimum critical rate of energy loss in traversing a material, do not leave tracks. Cobalt-60 gamma radiation doses to 10^5 R have not produced observable damage. Flat, cylindrical, and spherical detector designs are described. Methods of determining dose from exposed devices are given.

K13 NEUTRON MEASUREMENT BY TRACK IMAGING IN INSULATING MATERIALS. W.W. Schultz. *USA Trans. Inst. elect. electron. Engrs* v NS-13 n 3 407-423 Jun 1966.

K14 (STI/PUB-136) NEUTRON DOSIMETRY BY THE FISSION-FRAGMENT METHOD. Widell, C.O. (Neutron Monitoring. Proc. of the Symp. on ... for Radiological Protection Held by the Internat. Atomic Energy Agency in Vienna, 29 August - 2 September 1966. Vienna: IAEA 1967. S. 417-24, (1967).

K15 DETECTION OF LOW DOSES OF FAST NEUTRONS WITH FISSION TRACK DETECTORS - Cross, W.G. and Tommasino, L. Chalk River Nucl. Labs, Chalk River, Can. - *HLTH PHYS.* 13/8 (932-933) 1967.

K16 NEUTRON DOSIMETRY BY THE FISSION-FRAGMENT METHOD. Widell, C.O. (Atkibolaget Atomenergi, Studsvik, Sweden). pp 417-24 of STI/PUB-136. (1967)

Fission fragments, which are heavy particles able to

damage a material physically along their paths, are studied. Fissionable material is placed in contact with a material where these damage paths are easily developed and thus used as a neutron dosimeter. A system with uranium in contact with a mica foil is studied. The irradiation procedure and characteristic track dependence on etching time, concentration, and temperature are discussed. The sensitivity of the dosimeter is also studied.

K17 NEUTRON PERSONNEL DOSIMETRY BY NONPHOTOGRAPHIC NUCLEAR TRACK REGISTRATION. Becker, K. (Juelich Nuclear Research Establishment, Ger.). pp 317-41 of *Radiation Dose Measurements. Their Purpose, Interpretation, and Required Accuracy in Radiological Protection*. Paris, European Nuclear Energy Agency, 1967.

The recently discovered method of nonphotographic nuclear track visualization by etching of the surface of insulators can be used for thermal and fast neutron dosimetry by: (n,f) reactions (fission fragment registration in glasses, mica, or plastics); (n, α) reactions (alpha particle registration in alpha sensitive plastics); and registration of recoil nuclei. Neutron energy distributions can be measured by using additional absorbers and/or threshold reactions. The method is superior to nuclear emulsion techniques in many respects, such as sensitivity; dose range; directional dependence; insensitivity against x, γ , and β radiation, and disturbing environmental influences; fading stability; and fast and simple evaluation. The etch pit counting in the optical microscope can be avoided by several optical or electrical methods. Some aspects of the practical application of this technique in personnel routine and emergency dosimetry and examples of special applications (biomedical research, dE/dx spectroscopy, urinalysis) are briefly discussed.

K18 (BNWL-481-2: PARTICLE DOSIMETRY USING THE FISSION FRAGMENT DAMAGE PRINCIPLE. Baumgartner, W.V. Pacific Northwest Laboratory Annual Report for 1966 to the USAEC Division of Biology and Medicine. Vol. 2: Physical Sciences. Part 2. Radiological Sciences. 185-9, (1967).

K19 PERSONAL DOSIMETER FOR NEUTRONS. Nicolae, Marieta; Pop, Rodica (Inst. of Atomic Physics, Bucharest). *Rev. Roum. Phys.*, 13: 773-82(1968).

A dosimeter which comprises three dosimetric systems is described whereby the thermal neutron, γ rays and fast neutron dosimetry may be carried out in a single badge. By choosing a suitable detecting

material (photographic or solid detector) a large range may be covered in the field of current or accidental exposure doses. The first dosimetric system is the main system of this dosimeter. Using a pair of Orwo 3 + 4 dosimetric films and the filter arrangement Cd-0.7/Pb-0.3 mm + Sn-0.7/Pb-0.3 mm, it is possible to measure thermal neutron doses between 20 mrem and 100 rem and γ rays exposures in the range 20 mrad to 100 rad. The second dosimetric system (for accidental exposure), comprises as detecting material a mica foil on which a determined amount of natural uranium was evaporated. This allows to measure thermal neutron flux between 10^9 and 10^{12} n/cm² (1 to 10^3 rem). This dosimetric system is less sensitive to thermal neutrons than the photographic one, but is easily handled and suitable for use in current dosimetry. The third dosimetric system, which comprises a nuclear emulsion sheet as photographic material, allows to measure fast neutron intensities in the range of current exposure in a field of γ rays up to 10 rad.

K20 A STANDARDIZED METHOD FOR MAKING NEUTRON FLUENCE MEASUREMENTS BY FISSION FRAGMENT TRACKS IN PLASTICS. A SUGGESTION FOR AN EMERGENCY NEUTRON DOSIMETER WITH RAD RESPONSE. Pretre, S.; Tochilin, E.; Goldstein, N. (Naval Radiological Defense Lab., San Francisco). pp 491-505 of *Radiation Protection. Part I.* Snyder, W.S.; Abee, H.H.; Burton, L.K.; Maushart, R.; Benco, A.; Duhamel, F.; Wheatley, B.M. (eds.). New York, Pergamon Press, Inc., 1968.

A neutron detector is described which consists of a fission foil (²³²Th, ²³⁵U, ²³⁸U, ²³⁷Np or ²³⁹Pu) in contact with a plastic track detector. These detectors were exposed to reactor neutrons and to mono-energetic neutrons with energies between 1.0-18 MeV. Fission fragment tracks registered in the plastic were selectively etched by a hydroxide and counted in an optical microscope. For thick foils of fissionable metals the sensitivity of the system was found to be $(1.16 \pm 3\%) \times 10^{-5}$ fission fragment tracks/neutron - barn which is in good agreement with theoretical calculations. This sensitivity is independent of the fissionable element used, independent of the neutron energy, fairly independent of the material chosen for tracks registration (plastics, glass, mica) and of etching conditions. Since the (n,f) cross sections are accurately known for most neutron energies, the above constant can be used for standardized measurements of neutron fluences. An application to emergency neutron dosimetry is suggested. The fissionable mate-

rial must be readily available and have low specific activity while the (n,f) reaction cross section should follow the Rad/n/cm² curve for tissue. As first compromise, natural thorium is suggested to measure the "proton-part" of the neutron dose (above 1 MeV). The second compromise is an alloy made of natural thorium and 0.5% (by weight) of natural uranium. Using the technique of track counting, these dosimeters have a practical range between 5 and 30,000 Rad. To avoid track counting, a direct readout method using thin Mylar film was investigated. This plastic is opaque in the deep ultraviolet (below 3000 Å), and the etching of fission fragment tracks in this plastic film produces holes. Neutron dose is determined by the amount of uv light passing through the etched film.

K21 ON THE DETECTION OF NEUTRONS WITH THE ETCH-PIT COUNTING METHOD. Nishiwaki, Y.; Tsuruta, T. (Tokyo Inst. of Tech.). Tokyo Kogyo Daigaku Gakuho, 17: 131-42 (Nov. 1968).

Fission fragments mark scars on such an insulator as glass or mica, when neutron induced fission of the fissionable material takes place on the surface of or inside the insulator material. Very small scars on the surface of the insulator material caused by the fission fragments can be etched by the suitable chemical treatment to form etch-pits visible under the ordinary microscope. Therefore the combination of the fissionable material and the insulator material can be used for neutron detection or neutron dosimetry. A thin film of uranium or thorium was electrodeposited on gold foil as the fissionable material and the glass or mica was used as the detector material of the fission fragments. The thin film of the fissionable material was kept in contact with the surface of the glass or mica. The effect of the different etching condition and the stability of the stars have been studied. It has been shown by the fission film-glass or mica combination that a good agreement exists between the expected number of fissions and the number of etch-pits. Because of the use of the thin film of the fissionable material much thinner than the average range of the fission fragments, the effects of the spontaneous fissions may be considered negligible and the upper limit of the neutron measurement may be greatly increased. A wide range of neutron exposure 10 mrem to 1000 rem may be measured with a single detector of this type with reasonable accuracy. The activation of the metal, on which the fissionable material is electrodeposited, permits another simultaneous measurement of neutron flux at the time of accidental exposure,

independently of the stored information of the neutron exposure recorded on the insulator material. Distribution of thermal neutron flux in the reactor (UTR-B) was estimated with this system. The results of the etch-pit counting were in good agreement with those estimated with the activation method.

K22 DETECTION OF NEUTRONS WITH THE ETCH-PIT COUNTING METHOD. Nischiwaki, Yasushi; Harima, Yoshiko; Tsuruta, Takao; Ono, Takashi; Yamazaki, Katsuhiko; Fukano, Yoshinobu; Kawai, Hiroshi; Morishima, Horoshige; Kimura, Yuichiro; Koga, Taeko (Res. Lab. Nucl. Reactor, Tokyo Inst. Technol., Tokyo, Japan). *Hoken Butsuri* 1968, 3(1), 201-7 (Japan).

K23 PERSONNEL NEUTRON DOSIMETRY BY NUCLEAR TRACK REGISTRATION IN SOLID MATERIALS - Neutronen-Personendosimetrie durch Kernspurregistrierung in Festkörpern - Becker, K. Zent. Abt. Strahlenschutz, Kernforsch. Anl., Jülich - *ATOMPRAXIS*, 14/8 (331-336) 1968.

K24 (USNRDL-TR-68-126). NEUTRON FLUENCE AND DOSE MEASUREMENTS WITH FISSION FOIL-LEXAN DETECTORS. Rago, Paul F.; Goldstein, Norman; Tochilin, Eugene (Naval Radiological Defense Lab., San Francisco, Calif.). Nov. 4, 1968. 30 p.

A fission foil-Lexan detector system has been developed to monitor reactor neutrons. It is similar to the system based on counting fission gamma rays but has some advantages; i.e., permanently recorded tracks that can be read any time after exposure; integrated recording; microgram amounts of fissionable material needed; independence of fission product distribution; and the elimination of specialized gamma-ray counting equipment. Fission product damage tracks in the Lexan (or mica) are counted under an optical microscope. Fluence is determined from the sensitivity factor of 0.0000116 tracks/neutron-barn. Experimental results are given.

K25 (ORNL-4168) RADIATION DOSIMETRY. Auxier, J.A. (Oak Ridge National Lab., Tenn.). pp 183-230.

Current investigations in the area of radiation dosimetry are presented. Ichiban studies are discussed which include shielding studies associated with the Japanese bombing survivors, depth-dose calculations, and dosimetry related to Operation HENRE. Also discussed are spectrometry and dosimetry research, dosimetry applications, and HPRR and DOSAR Low-Energy Accelerator operations.

K26 (TM-SU-101) NEUTRON DOSIMETRY BY THE METHOD OF ETCHED FISSION TRACKS IN PLASTIC FOILS. ROUTINE INSERTIONS FOR PERSONAL DOSIMETRY IN THE EIR. Radiation Protection Memorandum No. 4. Pretre, S. (Eidgenössisches Institut fuer Reaktorforschung, Wuerentlingen (Switzerland)). Aug. 8, 1968. 9p. (In German).

Described are neutron measurements by a personnel dosimeter recording fission tracks in plastic. The device is inexpensive, lightweight, easy to evaluate, and shows no fading. Neutrons are detected by a foil of natural thorium in contact with a plastic plate; for thermal neutrons, a foil of an alloy containing 1% uranium and 99% aluminum; the uranium is 90% enriched ^{235}U . In routine surveillance, the plastic is etched once a year in potassium hydroxide and the number of tracks is counted under a light microscope. Time of etching, sensitivity, and dose ranges are described. Special procedures, applicable in the case of a nuclear incident, are also briefly discussed.

K27 PERSONNEL DOSIMETRY OF SLOW NEUTRONS BASED ON TRACK REGISTRATION IN SOLID SUBSTANCES. Behounek, F.; Novotny, J.; Spurny, Z. (Inst. Nucl. Phys., Prague, Czech.). *Radioisotopy* 9(1), 149-61 (1968), (Czech).

K28 (ORNL-TM-2120) NEUTRON-ENERGY THRESHOLD DETECTOR SYSTEM EMPLOYING SOLID-STATE NUCLEAR TRACK DETECTOR AND FISSION RADIATOR UNITS. Kerr, G.D. (Oak Ridge National Lab., Tenn.). Mar. 1968. 21p.

Improvements have been made in threshold detector systems used for measurement of neutron fluence and dose by the application of solid-state nuclear track detector-fission radiator units. Fission fragment tracks in the detectors are exposed by chemical etch and viewed with an optical microscope. Detection efficiencies for these units, techniques for evaluation of Lexan nuclear track detectors, and data used in fluence and dose calculations are given. Absorbed doses in a small sample of tissue from a fast fission spectrum of neutrons can be measured over a range of 10 to 10^6 rads with ^{239}Pu , ^{237}Np , and ^{238}U fission radiators of 30, 50, and $30\text{ }\mu\text{g}/\text{cm}^2$, respectively. Comparisons with conventional threshold detector systems under a variety of exposure conditions have given agreement to within 10%.

K29 CONTRIBUTION TO THE DOSIMETRY OF THE FLUENCE OF THERMAL NEUTRONS. Maurette, M. (Faculte des Sciences, Paris); Mory, J. *Rev. Phys. Appl.*, 3: 209-15 (Sept. 1968). (In French).

The recording of fission fragment trajectories in glass and mica and of α particles in cellulose nitrate has been used for the measurement of thermal neutron fluxes. A series of very cheap dosimeters, calibrated at $\pm 10\%$ for the measurement of absolute flux values between 10^6 and 10^{21} n/cm² have been realized; in this range of fluxes, the dosimeters can provide relative flux values with great accuracy.

K30 PERSONNEL NEUTRON DOSIMETER FOR NUCLEAR ACCIDENT. Kang, Yung-Ho (Kyung Pook National Univ., Taegu, Korea); Tatsuta, Hatsumi. *J. Nucl. Sci. Technol. (Tokyo)*, 5: 74-8 (Feb. 1968).

Two types of personnel dosimeter are presented: an emulsion containing ¹⁰B and a Toshiba glass-covered model embodying natural uranium foil. If a Cd sheet is used to reduce thermal neutrons leaving the human body, measurements of the dose equivalent will be possible to cover a neutron energy range between thermal and 10 MeV. Experimental results show that the minimum detectable dose equivalent with the dosimeters are 0.15 rem and 10 rem for the emulsion type and the etched pit type, respectively.

K31 FISSION TRACK SOLID STATE DETECTOR. (Ceskoslovenska Akademie Ved. Rez. Ustav Jaderneho Vyzkumu). [1968]. 9p. (In Czech).

A brief introduction to the use of fission foils with dielectric track detectors for neutron dosimetry is presented, and a list of 46 references from NSA from 1961 to 1968 is given.

K32 REGISTRATION OF FISSION-FRAGMENT TRACKS IN Th- OR U-DOPED PHOSPHATE GLASSES AND ITS POSSIBLE APPLICATION TO NEUTRON DOSIMETRY. Yokota, R.; Nakajima, S.; Muto, Y. (Tokyo Shibaura Electric Co. Ltd.). *Nucl. Instrum. Methods*, 61: 119-20 (Apr. 15, 1968).

New Th- or U-doped phosphate glasses can register the fission-fragment tracks in a neutron field, and the etch pits can be visualized with an optical microscope.

K33 EMERGENCY PERSONAL DOSIMETERS FOR GAMMA-NEUTRON RADIATION. Bocharov, I.A.; Vasil'eva, A.A.; Gimadova, T.I.; Keirim-Markus, I.B.; Kraitov, S.N.; Kushnerev, A. Ya.; Sergeeva, N.A.; Uspenskii, L.N.; Chernova, O.N.; Yakubik, V.V. (Inst. of Biophysics, Moscow). pp 235-45 of *Handling of Radiation Accidents*. Vienna: International Atomic Energy Agency (1969). (In Russian).

Two dosimetric systems are considered—thermo-luminescent dosimeters made of aluminophosphate

glass for measuring gamma-radiation doses, and fissionable materials in combination with a track detector for measuring neutrons. The gamma dosimeters are made in the form of aluminum buttons 16 mm in diameter and 5 mm in thickness, inside of which is a glass plate (8 mm in diameter and 1 mm in thickness) with a packing of heat-resistant rubber. The dosimeter weighs 2 g. The dosimeters are placed on the wearer's special clothing at 8 points and can withstand repeated cleaning operations. The basic dosimetric characteristics of the device are discussed. ²³⁵U and ²³⁷Np behind a filter consisting of a layer of ¹⁰B are used for recording neutron kerma. GOST-683-52 glass with an area of 1 cm² is used for detection. The sub-threshold fission of ²³⁷Np and the effect of the possible presence of ²³⁵U and ²³⁹Pu impurities therein are taken into consideration. It is shown that the error in the determination of the kerma of neutrons for neutron spectra actually present behind the shield is about 12%. The maximum sensitivity of the dosimeter is about 2 mrad/track and the measurable range of kerma is 0.02-10⁵ rad.

K34 NEUTRON PERSONNEL MONITORING: CORRECTION FACTORS AND A SUGGESTED DEVICE FOR MEASURING INTERMEDIATE ENERGY NEUTRONS. Nagarajan, P.S.; Krishnan, D. (Bhabha Atomic Research Centre, Trombay, India). *Health Phys.*, 17: 323-9 (Aug. 1969).

Monte Carlo estimates of neutron backscatter from an infinite slab of standard man composition were arrived at, in the incident neutron energy range of 0.025 eV-10 MeV, for normal and isotropic incidence. The information obtained includes: (i) the total and thermal components; (ii) the spectrum; and (iii) the angular distribution of the backscatter component. As the thermal neutron component of the backscatter would be recorded by thermal neutron personnel monitoring devices, the thermal backscatter response of such devices for various incident energies was estimated, and appropriate correction factors recommended. This correction is negligible at higher incident neutron energies (of the order of 0.5% in the range 1-10 MeV), whereas it increases to 50-60% in cases where thermal and intermediate energy neutrons are incident. The secondary gamma dose resulting from (n, γ) capture in tissue was also considered. This dose was estimated at the surface of an infinite slab of standard man composition, and was found to agree with reported experimental values. This gamma dose would be recorded in gamma radiation personnel

monitoring devices as a superfluous dose. The relevant correction factor was therefore estimated. This correction is negligible in the neutron energy range 1–10 MeV and reaches a steady value of about 10% in the neutron energy range of 10 keV to thermal. A composite personnel monitoring device for both thermal and intermediate energy neutrons, is suggested.

K35 NEUTRON MEASUREMENTS WITH FISSION FOIL DETECTORS. Gruenauer, F.; Burger, G. (Gesellschaft fuer Strahlenforschung mbH, Neuherberg, Ger.). Ref. J18 pp V.58–70 (1969).

Mathematical procedures for evaluating both integral and differential neutron flux densities with fission foil–dielectric track detectors are discussed.

K36 ENVIRONMENTAL NEUTRON MEASUREMENTS WITH SOLID STATE TRACK RECORDERS. Roberts, J.H. (Northwestern Univ., Evanston, Ill.); Parker, R.A.; Congel, F.J.; Kastner, Jacob; Oltman, B.G. Ref. J18 pp IX. 52–5 (1969).

The suitability of using ^{10}B and ^6LiF in contact with cellulose acetate butyrate (CAB) for the measurement of slow neutron densities was investigated. The upper energy threshold of clear Diacel cellulose nitrate (CN) and of the CAB were also measured. The CAB in good contact with thick ^{10}B or ^6LiF sources offers good promise for the detection of slow neutrons. For the actual CAB samples used, the CAB– ^{10}B combination had an efficiency of $\sim 1.3 \times 10^{-2}$ tracks per thermal neutron incident in a 2π solid angle. The corresponding number for the CAB– ^6Li combination is $\sim 5.6 \times 10^{-3}$ tracks per thermal neutron.

K37 DOSE SENSITIVITY OF TRACK-TYPE NEUTRON DETECTORS. Obaturov, G.M. At. Energ. (USSR); 27: 470–4 (Nov 1969). (In Russian).

In view of the absence of data on the neutron dose sensitivity of the track-type detectors, tests were carried out to determine this factor for detectors provided with layers of ^{237}Np , ^{238}U (230 fold depleted), natural U and ^{235}U (90% enriched) toward $0.5 < E < 10$ MeV monoenergetic neutrons. Similar mean dose sensitivity measurements were made for 12 different neutron spectra, ranging from soft to very hard—the fission spectrum. It was found that the dose sensitivity is strongly dependent on the neutron energy; however, for ^{238}U , and natural U detectors and neutrons with energies higher than 1.5 MeV, and ^{237}Np detectors for neutrons with $E > 0.6$ MeV, the sensitivity changes only slightly and remains within the (1.38 to 1.93) and (3.34 to 5.93) $\times 10^2$ tracks/rad.

cm^2 , with a maximum deviation of ± 16 and $\pm 28\%$ from the mean value. A formula was derived to calculate the tissue and the equivalent kerma for a given energy range. The natural U and ^{235}U type detectors cannot be used for the estimation of the kerma in any neutron energy range.

K38 IMPROVED RADIOPHOTOLUMINESCENT DOSIMETER AND NEW NUCLEAR TRACK DETECTOR. Yokota, R. (Tokyo Shibaura Electric Co., Ltd., Kawasaki, Japan); Kinoshita, M.; Maruyama, M.; Nishiwaki, Y. pp 287–98 of Radiation Protection Monitoring. Vienna, International Atomic Energy Agency, 1969.

A new dosimeter glass has been developed with a sensitivity 1.45 times greater than that of currently used glass, a 70% predose as compared with the present low predose, and a low atomic number. A new spherical badge case makes this new glass energy independent to .30 keV and good directional independence is achieved. A convenient apparatus for washing the dosimeter glass has also been developed, which enables reproducible readings to be obtained to within ± 2 mR. A device to project an enlarged image of the identification number written with a diamond pen on the glass within the cell is available and can be attached to the fluorimeter. As a result of the trapezoidal shape of the dosimeter glass and the cell, β -rays from 0.03 to 1 MeV (average energy) can be measured with high sensitivity. The badge case together with the glass is so small that it can be attached to the inner side of the forefinger. A nuclear track detector employing the etch-pit method and incorporating Toshiba phosphate glass and a thin film of fissionable material deposited on a gold foil is also described. The phosphate glass used in this detector is doped with Th and/or U, and the instrument thus has higher sensitivity and assures better protection for the exposure and better contamination of the fissile material than the usual fissile foil and insulator system.

K39 CALIBRATED U-Th GLASSES FOR NEUTRON DOSIMETRY AND DETERMINATION OF URANIUM AND THORIUM CONCENTRATIONS BY THE FISSION TRACK METHOD. Schreurs, J.W.H. (Corning Glass Works, N.Y.); Friedman, A.M.; Rokop, D.J.; Hair, M.W.; Walker, R.M. Ref. J18 pp VI.34–40 (1969).

Horn and Von Oertzen have suggested using elastically scattered recoil nuclei to measure the registration characteristics of solid state track detectors. To support this suggestion they have shown pictures of

tracks, in mica, that they have attributed to elastically scattered K and Fe nuclei produced by irradiation with 32 MeV ^{16}O ions. Although this is an interesting observation, it is believed that their interpretation is incorrect. It is first shown that the measured characteristics of the tracks do not match the theoretically predicted features for elastic processes. Furthermore the experimental features are consistent with those predicted for inelastic (mostly compound nucleus) reactions. However, the possibility cannot be ruled out that they are produced by contaminant ions present in the incident beam.

K40 APPROXIMATE DOSIMETRY AND SPECTROMETRY OF FISSION AND THERMONUCLEAR NEUTRONS WITH VISUAL PLASTIC DETECTORS. Remy, G.; Ralarosy, J.; Tripier, J.; Debeauvais, M.; Stein, R. (Univ., Strasbourg). Ref. J18 pp V. 72-83 (1969). (In French).

The characteristics and operating principles of a personal neutron dosimeter using Makrofol and nitrocellulose as visual detectors, are given. The products produced by the (n,f) and (n, α) reactions are recorded. The energy spectrum analyzed extends from thermal energies to about 20 MeV. The (n,p) (recoil protons) reactions are currently being studied in order to increase the accuracy of neutron measurements in the energy range extending from resonance to one hundred keV.

K41 NEUTRON FLUX DOSIMETRY BASED ON URANIUM FISSION FRAGMENT TRACKS. Berzina, I.G.; Gurvich, M. Yu.; Khelbnikov, G.I.; Shimelevich, Yu. S. (USSR). Tr., Vses. Nauch.-Issled. Inst. Yad. Geofiz. Geokhim. 1969. No. 7, 215-21 (Russ).

K42 NEUTRON FLUX MEASUREMENT USING FISSIONABLE ELEMENTS AND SOLID TRACK DETECTORS. Talagrand; Serbat (Laboratoire Central de l'Arnement, Arcueil, France). Ref. J18 pp V. 103-13 (1969). (In French).

The number of fission tracks registered under neutron irradiation with a solid track detector associated with a thick fissionable coating is calculated. The experimental results are given. The possibility of using these detectors in physical dosimetry and in radiology is discussed. Their specific qualities are underlined.

K43 NEUTRON PERSONNEL DOSIMETRY BY RECORDING THE FISSION FRAGMENTS IN MICA FOILS. Stolz, W.; Doerschel, B. (Technische

Hochschule, Dresden). Kernenergie, 12: 244-50 (July 1969). (In German).

A technique of separately determining the dose equivalent of thermal, intermediate, and fast neutrons by nonphotographical record of the fission fragments in a solid is described. The detailed investigation of various detector materials (mica, microscope cover glass, Yokota glass, cellulose acetate, Makrofol E) shows the most favorable properties for personnel neutron dosimetry to be possessed by the mica foils. Both natural and enriched uranium foils have been used as the fissile materials. The etched tracks of fission fragments are recorded either by visual counting of the tracks under microscope or by means of a photoelectric technique utilizing a sensitive photoresistance cell. Limits of the measuring range and dependence on direction of the dosimeter are discussed. The assembly consisting of combined fissile material and mica foils is suited for application in routine and emergency dosimetry.

K44 CONTROL OF PERSONNEL NEUTRON DOSES BY FISSION FRAGMENT TRACK COUNTING IN PLASTICS. Pretre, S.B. (Institut Federal de Recherches en Matiere de Reacteurs, Wuerrenlingen, Switzerland). Ref. J18 pp V.41-57 (1969).

A description is given of a neutron dosimeter, currently carried by personnel working at the Wuerrenlingen nuclear center (Switzerland). This dosimeter is as equally well adapted for measuring routine doses as it is for those likely to be encountered in an accident. It contains two detectors, each consisting of a disc of fissionable metal placed next to a plastic (Lexan) disc. The metal is composed of ^{232}Th (for the detection of fast neutrons) and an Al- ^{235}U alloy (for the detection of thermal neutrons). Some of the fission fragments penetrate into the plastic disc and leave traces, which are revealed by a KOH solution and then counted using microscopic techniques. The track density is directly proportional to the neutron dose.

K45 PROPERTIES OF NEW FISSION TRACK DETECTOR GLASS. Yokota, Ryosuke (Central Research Lab., Tosiaba, Japan); Muto, Yehei; Tanzawa, Katsujiro; Tsuruta, Takao. Proc. Jap. Conf. Radioisotop., 9th, Tokyo, 1969; 229-30(1969). (In Japanese).

Properties of dielectric track detectors of phosphate glass doped with thorium, natural uranium, or depleted uranium are briefly discussed. The detectors can be used for crude energy spectrum measurements of neutrons.

K46 MONITORING OF INTERMEDIATE-ENERGY NEUTRONS. Dayashankar; Venkataraman, G. (Bhabha Atomic Research Center, Trombay, India). pp 47-51 of *Radiation Protection Monitoring*. Vienna, International Atomic Energy Agency, 1969.

A method of monitoring thermal and intermediate-energy neutrons up to 300 keV by means of a cadmium-covered boron-trifluoride counter is described. The intermediate-energy spectrum is assumed to be of $1/E$ type from 0.3 eV to 10 keV, $1/E^{0.8}$ type from 10 keV to 100 keV and $1/E^{0.5}$ type from 100 keV to 300 keV. This instrument is (a) more portable, and (b) reasonably accurate, since the calibration factor in the present case is derived from an exact fit of the dose-equivalent values at various energies. Also, preliminary results obtained with a personnel monitoring device for intermediate-energy neutrons which consists of a cadmium-boron filter and a track recording plastic are discussed. For this device, the contribution due to the back-scattered spectrum from the body has also been taken into account.

K47 (UCRL-50007-68-3) MEASUREMENT OF THE NEUTRON SPECTRUM FROM THE LPTR FAST NEUTRON IRRADIATION FACILITY. Griffith, R.V. (California Univ., Livermore, Lawrence Radiation Lab.). 21-5.

The measurement of the flux and integral spectrum of the fast neutron irradiation facility at the LPTR using a combination activation and fission foils is described.

K48 PERSONNEL GLASS NEUTRON TRACK DOSIMETER. Obaturov, G.M.; Chumbarov, Yu. K. (USSR). *Vop. Dozim. Zashch. Izluch.* 1969, No. 10, 155-63 (Russ.).

K49 APPROXIMATE NEUTRON SPECTROMETRY IN AIR WITH SOLID TRACK DETECTORS. Talagrand; Serbat (Laboratoire Central de l'Armement, Arcueil, France). *Ref. J18* pp V.114-31 (1969). (In French).

A neutron spectrometry system made of solid track detectors and fissionable elements is described. This system is used for determining the neutron spectrum in air from a fission source. The formation of an equilibrium spectrum is verified.

K50 NEUTRON SPECTROMETRY WITH THE AID OF VISUAL IONOGRAPHIC DETECTORS. Debeauvais, M.; Stein, R.; Remy, G.; Rálarosy, J.; Tripier, J. (Centre de Recherches Nucleaires, Stras-

bourg). *Rev. Phys. Appl.*, 4: 259-60 (June 1969). (In French).

A spectrometer for 0 to 20 MeV neutrons is made with the aid of visual solid detectors. The following reactions are used: fission reactions on natural and enriched uranium with and without cadmium, neptunium and thorium targets, for 0 to 10 MeV neutrons; and (n, α) reactions on beryllium, carbon and oxygen targets, for 3 to 20 MeV neutrons. Makrofol and nitrocellulose are respectively used as detectors for fission and (n, α) reactions.

K51 MEASUREMENTS OF REACTOR NEUTRON FLUX BY FISSION TRACK METHOD. Hashimoto, T. (Kyoto Univ.); Iwata, S.; Nishimura, S.; Nakanishi, T.; Sakanoue, M. *Proc. Jap. Conf. Radioisotop.*, 9th, Tokyo, 1969; 231-4 (1969). (In Japanese).

The procedure and results of reactor neutron flux measurements using fission foils of natural uranium and thorium with mica and polycarbonate track detectors are discussed.

K52 APPLICABILITY OF TRACK DETECTORS IN NEUTRON DOSIMETRY. Burger, G.; Gruenauer, F.; Paretzke, H. (Institut fuer Strahlenschutz, Neuherberg, Ger.). pp 349-58 of *Advances in Physical and Biological Radiation Detectors*. Vienna; International Atomic Energy Agency (1971).

In spite of evident advantages in comparison with nuclear track film, the non-photographic track detectors have not yet found a wide application in practical dosimetry. This was partially due to the complicated methods of track counting with microscopes, which can be avoided by using spark-counters of the "Cross" type. A suitable improved counter is discussed and experience gained in its practical use is reported. The data refer to the reliability of the counting system, to the detector foils used and their dependence on environmental conditions. For some fission foils, the effective dose responses for certain calibration spectra and various assumed leakage spectra have been calculated and, in part, measured. Some theoretical aspects of using different neutron conversion reactions, which affect the dosimetric information obtained, are discussed.

K53 DEVELOPMENT OF NEW NEUTRON DETECTORS FOR ACCIDENT DOSIMETRY. Piesch, E. (Kernforschungszentrum, Karlsruhe, Ger.). pp 399-424 of *Advances in Physical and Biological Radiation Detectors*. Vienna; International Atomic Energy Agency (1971).

New detectors and measuring techniques are proposed to improve the assessment of individual doses in a criticality accident. The aim was to reduce the number of detectors in the conventional detector combinations, to use sensitive activation reactions and to measure the dose of intermediate and fast neutrons directly. The proposed neutron detectors for the dosimeter combination are: (a) Arsenic, to detect slow and intermediate neutrons up to 1 MeV by the $^{75}\text{As}(n,\gamma)^{76}\text{As}$ reaction (half-life of ^{76}As is 26.4 h); (b) Phosphorus, to detect fast neutrons above a threshold of 2 MeV by the $^{31}\text{P}(n,p)^{31}\text{Si}$ reaction (half-life of ^{31}Si is 2.6 h), and slow neutrons by the $^{31}\text{P}(n,\gamma)^{32}\text{P}$ reaction (half-life of ^{32}P is 14 d); (d) A polycarbonate detector (Makrofol E) as a nuclear track detector to detect fast neutrons above a threshold of 0.5 MeV by elastic scattering and (n,α) reactions in carbon and oxygen. The β -activity of ^{76}As , ^{31}Si and ^{32}P can be measured directly in As_2S_3 glass and in phosphate glass by means of the β -induced Cherenkov effect. It uses a liquid scintillation counter set up for tritium measurements. The calibration of the detectors was performed by calculations of the detector sensitivity for different neutron spectra and by irradiation with different neutron sources at different criticality installations. After an accident a first estimation of the neutron dose is obtained by a β -counting of the arsenic phosphate glass, which indicates the surface adsorbed dose or the total neutron fluence directly. It is energy independent over the range of intermediate and fast neutrons.

K54 TENTATIVE METHOD FOR FAST-NEUTRON FLUX MEASUREMENTS BY TRACK-ETCH TECHNIQUE. ASTM E418-70T. Philadelphia: American Society for Testing and Materials (1970). 5p.

The measurement of neutron flux by the use of fissionable materials is discussed. Fission fragments emitted by the fissionable materials during neutron bombardment penetrate a suitable recording medium, such as plastic, glass, or mica, that is in contact with the fissionable material. Appropriate etching techniques render the path of the fragment in the recording medium visible under an optical microscope. Since measurement of the decay of radioisotopes is not involved in the method, irradiation times are limited only by the maximum number of fission-fragment tracks that can be clearly distinguished without pile-up—approximately $2 \times 10^5/\text{cm}^2$. The neutron-energy range over which the common fissionable

materials are useful is between 1 keV and 18 MeV. As with other methods used to determine neutron flux, the uncertainties in some cross-section data make it difficult to assign an over-all accuracy value to this method.

K55 $1/\nu$ DIELECTRIC TRACK DETECTORS FOR SLOW NEUTRONS. Schultz, W.W. (General Electric Co., Schenectady, N.Y.). J. Appl. Phys.; 41: 5260-9 (Dec 1970).

The fabrication of track detectors with boron atoms uniformly dispersed throughout the volume of the track detector material has been successfully accomplished. Because of their small size they have little effect on the neutron flux one is trying to measure. It is possible to make measurements of neutron flux densities over a range of six to seven decades. Track density is found to be a function of the thickness of detector surface etched away and the ranges of the alpha particle and lithium recoil particle resulting from the capture of a neutron by a ^{10}B atom. At etching proceeds, track density may increase or decrease depending on the etching rate of the bulk material relative to the maximum etching rate perpendicular to the particle path. A new method of studying diffusion through thin layers at the surface of a solid is suggested.

K56 APPLICATION OF SOLID-STATE TRACK RECORDERS FOR NEUTRON SPECTRA MEASUREMENTS IN A REACTOR IRRADIATION FACILITY. Koehler, W. (International Atomic Energy Agency, Vienna). Radiat. Eff.; 3: 231-3 (June 1970).

In connection with the IAEA-neutron seed irradiation programme, a standard neutron irradiation facility has been constructed. The application of solid state track recorders for fast neutron spectra measurements inside this facility is discussed. Fissionable targets of ^{235}U , ^{239}Pu , ^{237}Np , ^{238}U , and ^{232}Th will be used, and an approximative solution for the incident neutron spectrum will be obtained by a five-group method.

K57 MONITORING OF PERSONNEL NEUTRON DOSES BY COUNTING OF FISSION-FRAGMENT TRACKS IN CERTAIN PLASTICS. Pretre, S.B. (Institut Federal de Recherches en Matière de Reacteurs, Wuerenlingen, Switzerland). Radiat. Eff.; 5: 103-10 (Aug 1970). (In French).

A neutron dosimeter is described which is at present being worn by personnel of the Nuclear Research Center, Wuerenlingen (Switzerland). This dosimeter allows the measurement of routine as well as accidental doses. It contains two detectors, each

of which is composed of a fission metal disc in contact with a plastic foil ("Lexan"). For the fast neutron detector the metal used is ^{232}Th and for the thermal neutron detector it is an alloy of $\text{Al}-^{235}\text{U}$. Neutrons induce fission in the metals. Some of the fragments penetrate into the plastic foils, thereby producing tracks which can be developed in a KOH solution and then visualized under the optical microscope. Neutron doses are directly proportional to track densities.

K58 DEVELOPMENTS IN THRESHOLD DETECTORS FOR PERSONAL DOSIMETERS. Cross, W.G. (Chalk River Nuclear Labs., Ont.). pp 117-29 of Nuclear Accident Dosimetry Systems. Vienna; International Atomic Energy Agency (1970).

A technique is described which makes visible and automatically counts the damage-track holes made by fission fragments through a thin, plastic sheet. This method considerably reduces the time required to read damage-track neutron detectors and overcomes some of the restrictions of using ^{237}Np in a dosimeter to be worn regularly by people. The reaction $^{103}\text{Rh}(n,n')^{103m}\text{Rh}$ has a threshold close to that of ^{237}Np and gives roughly equivalent performance in combination with U and S threshold detectors. Addition of either Np or Rh to an In-S dosimeter significantly improves the accuracy of dose measurements on moderated fission spectra. For a criticality accident the remaining error in such measurements is expected to arise mainly from neutrons with energies between 0.1 and 0.6 MeV.

K59 NEUTRON DOSE ESTIMATION USING A NATURAL URANIUM FISSION FRAGMENT TRACK PERSONNEL DOSIMETER. Gomas, M.A. Hassib, G. (Atomic Energy Establishment, Cairo). pp 343-7 of Advances in Physical and Biological Radiation Detectors. Vienna; International Atomic Energy Agency (1971).

The idea of using a natural uranium fission fragment track dosimeter, in the neutron field of thermal, intermediate and fast neutrons in air, has recently been introduced. The system can be used for thermal neutron dose estimation as well as intermediate plus fast neutron dose estimation if the spectrum and the percentage contribution of each neutron group is known. Feasibility of the use of such dosimeters when they are worn by radiation workers is investigated. Detailed study of the system shows the possibility of differentiating between doses received from fast, intermediate and thermal neutrons if one takes into

account reflection from the body of thermal, intermediate and fast neutrons.

K60 EMERGENCY PERSONAL n - γ RADIATION DOSIMETERS. Keirim-Markus, I.B. (Inst. of Biophysics, Moscow); Knyazev, V.A.; Kozlov, B.F.; Obaturov, G.M.; Turkin, A.D. pp 103-15 of Nuclear Accident Dosimetry Systems. Vienna; International Atomic Energy Agency (1970). (In Russian).

Work on emergency personal n - γ radiation dosimeters, including activation (Cu, P) track dielectrics of glass or mica, placed in contact with layers of fissionable materials (^{235}U , ^{238}U , natural U and ^{237}Np), photographic dosimeters (M3-32-1 film type), and IKS-A thermoluminescent dosimeters, which have been investigated in the USSR and put to practical use, are reviewed. The track dosimeter containing ^{237}Np with a boron filter can be used to advantage in the measurement of neutron kerma as can the IKS-A thermoluminescent dosimeter in the measurement of γ -radiation dose.

K61 NEUTRON PERSONNEL DOSIMETRY ON TISSUE-EQUIVALENT PHANTOMS BY SOLID-STATE TRACK DETECTORS. Doerschel, B.; Stolz, W. (Technische Univ., Dresden). Kernenergie; 13: 290-5 (Sept. 1970). (In German).

Phantom studies by means of solid-state track detectors in the neutron field of a Pu - Be source and of a nuclear reactor are described. Detector material was mica, and fissile materials were ^{235}U and natural uranium. Indication of a neutron personnel dosimeter worn on the front side of the body was studied for routine and emergency dosimetry. Body burden is shown to be estimated for any depth within the body from depth distributions of dose equivalent measured. The body orientation effect in the neutron field may be corrected by determining direction factors. If conclusions for doses absorbed in the human body should be drawn from health physics measurements made in air, backscattering has to be taken into account for thermal and intermediate neutrons, and buildup factors must be considered for fast neutrons. A comparison of measured and calculated build-up factors is made.

K62 (KAPL-M-7121) $1/\nu$ DIELECTRIC TRACK DETECTORS FOR SLOW NEUTRONS. Schultz, W.W. (Knolls Atomic Power Lab., Schenectady, N.Y.). 43 p. (Mar. 1970).

The fabrication of track detectors with boron atoms uniformly dispersed throughout the volume

of the track detector material has been successfully accomplished. Because of their small size they have little effect on the neutron flux one is trying to measure. It is possible to make measurements of neutron flux densities over a range of six to seven decades. Track density is found to be a function of the thickness of detector surface etched away and the ranges of the alpha particle and lithium recoil particle resulting from the capture of a neutron by a ^{10}B atom. As etching proceeds, track density may increase or decrease depending on the etching rate of the bulk material relative to the maximum etching rate perpendicular to the particle path. A new method of studying diffusion through thin layers at the surface of a solid is suggested.

K63 (AECL-3430). HEALTH PHYSICS RESEARCH.

Cowper, G. (Atomic Energy of Canada Ltd., Chalk River (Ontario). Chalk River Nuclear Labs.). pp 33-44.

Abstracts are presented for 20 research projects conducted by the Health Physics Branch during the reporting period. Areas of investigation included: neutron dosimetry; tritium detectors; and a variety of counters, detectors, dosimeters, and health instruments in progress. The results of routine personnel dose monitoring during the reporting period are presented in tabular form. Lists of staff members and staff publications are also included.

K64 NEUTRON RADIATION PRODUCED BY THE 32-MeV X-RAY BEAM OF A MEDICAL BETA-TRON.

Lofgren, Kaj E.; Spring, Erik (Radiother. Clin., Univ. Cent. Hosp., Helsinki, Finland). *Acta Radiol., Ther., Phys., Biol.* 9 (3), 247-56. (1970).

K65 ENVIRONMENTAL NEUTRON MEASUREMENTS WITH SOLID-STATE TRACK RECORDERS.

Roberts, J.H. (Northwestern Univ., Evanston, Ill.); Parker, R.A.; Congel, F.J.; Kastner, J.; Oltman, B.G. *Radiat. Eff.*; 3: 283-5 (June 1970).

The suitability of using ^{10}B and ^6LiF in contact with cellulose acetate butyrate (CAB) for the measurement of slow neutron densities has been investigated. The upper energy threshold of clear Diacel cellulose nitrate (CN) and of the CAB have also been measured. The CAB in good contact with thick ^{10}B or ^6LiF sources offers good promise for the detection of slow neutrons. For the actual CAB samples used, the CAB- ^{10}B combination had an efficiency of $\sim 1.3 \times 10^{-2}$ tracks per thermal neutron incident in a 2π solid angle. The corresponding number for the

CAB- ^6Li combination is $\sim 5.6 \times 10^{-3}$ tracks per thermal neutron.

K66 DOSIMETRY AND SPECTROMETRY OF FISSION AND THERMONUCLEAR NEUTRONS BY MEANS OF VISUAL PLASTIC DETECTORS.

Remy, G.; Ralarosy, J.; Tripier, J.; Debeauvais, M.; Stein, R. (Laboratoire de Physique Corpusculaire, Strasbourg-Cronenbourg, France). *Radiat. Eff.*; 5: 221-5. (Oct. 1970). (In French).

Characteristics and the scheme of an individual neutron dosimeter are presented. The principle of the dosimeter is based on (n, f) and (n, α) threshold reaction track visualization in solid-state detectors, especially makrofol and cellulose nitrate. The analysed energy spectra is between the thermal neutron energy and about 20 MeV.

K67 (ANL-7615). ENVIRONMENTAL NEUTRON MEASUREMENTS WITH SOLID STATE TRACK RECORDERS.

Roberts, J.H.; Parker, R.A.; Congel, F.J.; Kastner, Jacob; Oltman, B.G. (Argonne National Lab., Ill.). pp 198-201.

The suitability of using ^{10}B and ^6LiF in contact with cellulose acetate butyrate (CAB) for the measurement of slow neutron densities has been investigated. The upper energy threshold of clear Diacel cellulose nitrate (CN) and of the CAB have also been measured. The CAB in good contact with thick ^{10}B or ^6LiF sources offers good promise for the detection of slow neutrons. For the actual CAB samples used, the CAB- ^{10}B combination had an efficiency of 1.3×10^{-2} tracks per thermal neutron incident in a 2π solid angle. The corresponding number for the CAB- ^6Li combination is 5.6×10^{-3} tracks per thermal neutron.

K68 SOLID-STATE DOSIMETRY.

Becker, Klaus. (Oak Ridge National Lab., Tenn.). *CRC Crit. Rev. Radiol. Sci.*; 1: 363-433 (Aug. 1970).

A comprehensive review on solid-state dosimeters including dielectric track detectors, radiophotoluminescent dosimeters, thermoluminescent dosimeters, TSEE (thermally stimulated exoelectron) dosimeters, and miscellaneous solid-state dosimeters is presented. (200 references).

K69 (AECL-3430). NEUTRON DOSIMETRY AND DAMAGE TRACK DETECTORS.

Marko, A.M. (Atomic Energy of Canada Ltd., Chalk River (Ontario). Chalk River Nuclear Labs.). pp 1-3.

The application of particle track etching techniques to neutron dosimetry is discussed. Of particular

interest, is a rapid method for determining whether an individual has received a neutron dose of biological significance. Particle track etching techniques in combination with the spark replica technique (discussed in the paper) seem to be useful for these rapid determinations. Other applications of the combined techniques are also discussed.

K70 NEUTRON DOSIMETRY WITH NUCLEAR TRACK DETECTORS APPLIED TO IN-VIVO NEUTRON ACTIVATION ANALYSIS. Agard, E.T., Jervis, R.E., McNeill, K.G. (Univ. Toronto, Ontario, Canada). 15th annual meeting of the Health Physics Society (abstracts), Chicago, Ill., USA. p4-5. (1970).

K71 ENVIRONMENTAL NEUTRON MEASUREMENTS WITH SOLID-STATE TRACK RECORDERS. Roberts, J.H. (Macalester Coll., St. Paul, Minn.); Congel, F.J.; Armani, R.J.; Gold, R.; Kastner, J.; Olman, B.G. *Trans. Amer. Nucl. Soc.*; 13: 419-20. (Jun. Jul. 1970).

K72 SOME RECENT METHODS FOR NEUTRON PERSONNEL MONITORING. Nikodemova, Denisa (Inst. of Industrial Hygiene and Occupational Medicine, Bratislava). *Jad. Energ.*, 17: No. 9, 312-15. (Sept. 1971). (In Slovak.).

Although nuclear emulsions are still the most widely used personnel dosimeters for fast neutrons dose equivalent measurements, they do not completely meet all desired requirements. A review of some new dosimetric techniques for neutron personnel dosimetry is presented. The method of nuclear track registration with a combination of fissionable materials and plastics, LiF thermoluminescent dosimeters with and without moderators, and the activation technique are discussed. (52 references).

K73 SETTING-UP OF A NEUTRON DOSIMETER USING IONOGRAPHIC TRACKS IN AN INSULATING SOLID. Carli, N.; Dugnani Lonati, R.; Mangialajo, M. (Centro Informazioni Studi Esperienze, Milan). pp 359-63 of *Advances in Physical and Biological Radiation Detectors*. Vienna; International Atomic Energy Agency (1971).

The use of dielectrics such as mica, glasses and plastic materials for charged particle track recording has been developed in the past years; track recording of fission fragments produced in fissile materials under neutron irradiation is particularly interesting. The method has not as yet been applied to neutron dosimetry owing to the difficulties of track observation and counting using optical microscopes. A method

has recently been proposed which results in markedly reduced counting times by electronic counting of the electric discharges between two electrodes through the dielectric which was perforated by the fission fragments. The reasons for adopting this new technique to set-up a neutron dosimeter are: (a) economic advantages, since a rather simple electronic instrumentation will give a reading of the dosimeter, preparation of which can be carried out immediately and at a modest cost; (b) fast reading, since the response can be obtained in less than two hours from irradiation; and (c) dosimetric advantages owing to the lack of fading and insensitivity to β or γ radiations. The method adopted and the equipment used to set up the dosimeter are described. Results are reported and briefly discussed.

K74 CALIBRATED U-TH GLASSES FOR NEUTRON DOSIMETRY AND DETERMINATION OF URANIUM AND THORIUM CONCENTRATION BY THE FISSION TRACK METHOD. Schreurs, J.W.H. (Corning Glass Works, N.Y.); Friedman, A.M.; Rokop, D.J.; Hair, M.W.; Walker, R.M. *Radiat. Eff.*; 7: 231-3 (Feb. 1971).

A series of standard uranium glasses was prepared. A primary standard containing 41 ppm of added U had its concentration and isotope ratio verified by mass spectrometry and by fission track techniques. Secondary standards were compared to the primary standard using the fission track technique. These glasses are useful for measuring both Th and U in solids. The U concentration in an unknown is determined by comparing the fission track density induced by thermal neutron irradiation with the corresponding density in the standard. Th is measured by a cyclotron irradiation using the same U standards. The glasses are also useful for neutron dosimetry. Investigators may obtain small samples of most of these standards from R.H. Brill of the Corning Museum of Glass. Although most of the glasses were fabricated from depleted uranium, one standard containing natural uranium is available. A standard Th glass with concentration of 41 ppm was also made.

K75 NEUTRON EMERGENCY DOSIMETRY USING SOLID-STATE TRACK DETECTORS. Doerschel, B. (Technische Univ., Dresden). *Kernenergie*; 14: No. 10, 333-7 (Oct. 1971). (In German).

Utilization of solid-state track detectors in emergency dosimetry is possible if fissile material layers of appropriate thickness are available. Very thin films of enriched uranium may be manufactured by spraying uranyl nitrate on to aluminum backing

under the action of a strong electric field. For manufacturing comparatively thick layers of natural uranium the electroplating technique is utilized. In a dosimeter badge, mica detectors, fissile layers, and cadmium filters are arranged in such a manner that the fluences of thermal, intermediate, and fast neutrons may separately be determined. Track density is determined by measuring the α -permeability of the etched mica detectors. The neutron fluences from which the neutron doses can be derived by using well-known conversion factors can be calculated from the track densities by means of mathematical relations. Testing of dosimeters was made in various neutron fields, whereby the derived relations between neutron fluence and track density have been verified. A discussion of measuring ranges and accuracy shows that the doses to be measured are in the required range of 1 to 1000 rad and that the maximum permissible deviations of -20 and +30 percent are not exceeded.

K76 CALCULATED RESPONSE OF FILM BADGE AND FISSION FRAGMENT TRACK DOSIMETERS WITH INDIUM AND CADMIUM FILTERS TO INTERMEDIATE NEUTRONS. Gomaa, M.A. (Atomic Energy Establishment, Cairo). *Atomkernenergie*; 18: No. 4, 321-2 (1971).

Neutron interaction with cadmium covered indium filters produces beta induced activity mainly due to intermediate neutrons. This activity may cause film blackening under the filter as well as track density loss when a cadmium fission fragment track dosimeter is used. The intermediate neutron dose may be estimated from the film blackening and track density loss, where the calculated response is found to be 1.22 net density/rem for the film badge and 190 track/cm²/rem for fission fragment track dosimeter.

K77 NEUTRON FLUENCE MEASUREMENT WITH URANIUM- OR THORIUM-DOPED FISSION TRACK DETECTOR. Yoo, Young Soo (Atomic Energy Research Inst., Seoul). *New Phys. (S. Korea)*; 11: No. 1, 1-6 (Mar. 1971).

A neutron detector which consists of a phosphate glass doped with a fissile material such as natural uranium (UO₂) or thorium (ThO₂) is described. Fission fragment tracks registered in the glass were etched by sodium hydroxide and counted under an optical microscope with a magnification of about 420. The detector was exposed to Pu-Be standard neutron sources and thermal neutrons in a graphite pile for calibration. The registration efficiency as a function of etching concentration, temperature

of etching solution, and etching time was also studied. For each parameter, an optimum time for etching in NaOH of 20 percent concentration by weight was found to be 20 minutes at 60°C for U-doped FTD and 10 minutes at the same condition for Th-doped FTD. The sensitivities of U-doped FTD for fast and thermal neutrons were found to be respectively, 0.48×10^{-6} ($\pm 1.9\%$) and 2.35×10^{-6} ($\pm 1.4\%$) fission fragment tracks/neutron, and that of Th-doped FTD for fast neutron was 0.32×10^{-6} ($\pm 3.2\%$) tracks/neutron.

K78 TRENDS IN DEVELOPMENT OF INDIVIDUAL DOSIMETRY OF OCCUPATIONALLY EXPOSED MEN. Kraus, W.; Will, W. (Staatliche Zentrale fuer Strahlenschutz, Berlin). *Kernenergie*; 14: No. 9: 277-83 (Sept. 1971). (In German).

A review of the recent state of individual dosimetry of occupationally exposed men is given. The properties of recent solid-state detectors (thermoluminescent, photoluminescent, exoelectron, and track detectors) and their applicability to routine and accidental dosimetry or in plant and central monitoring are discussed. In particular, advantages and drawbacks of the recent detectors are presented as compared with film dosimeters and the state attained in substituting or complementing the film dosimeter is shown. Trends of future development are estimated.

K79 (KFK-1461) WORK ON SOLID-STATE TRACK DETECTORS. Guenther, Gudrun (Kernforschungszentrum, Karlsruhe (West Germany). Institut fuer Angewandte Reaktorphysik). 30 p. (Aug. 1971). (In German).

Investigations in preparation for routine application of solid state track recorders for measurements in SNEAK are described. A polycarbonate foil (Lexan) was chosen as a detector material satisfying all requirements. In this type of material fission products leave tracks which can be enlarged by etching until they are visible in a light microscope. A simple model of the etching process was compared to experimental results. In order to increase the contrast of the tracks against the background they were finally colored using a felt pen. The evaluation is performed with the image analyzer CLASSIMAT, an apparatus designed to count single particles. The operation of the CLASSIMAT was tested and calibration curves were taken. Using some experimental results the principle of operation was demonstrated. A modification of the CLASSIMAT is planned in preparation of a completely automated image analysis using a computer.

K80 SOLID STATE TRACK RECORDER AS A THERMAL NEUTRON DOSIMETER. Carfi, N.; Dugnani Lonati, R.; Mangialajo, M. (CISE, Milan). *Energ. Nucl. (Milan)*; 18: No. 6, 360-2 (June 1971).

A thermal neutron dosimeter using a fission foil-polycarbonate track detector and a rapid discharge readout system is described. The fission foils used are described, and the calibration procedure is discussed.

K81 (RT/FI-71)5 SOLID-STATE TRACK RECORDERS. Bozzi, L.; D'Angelo, P.; Martini, M. (Comitato Nazionale per l'Energia Nucleare, Rome (Italy)). [nd]. 148 p. (In Italian).

The present state of the art in solid-state track recorders is reviewed, and relative and absolute fission rate measurements with solid-state track recorders are discussed. SSTR of polycarbonate resin (Makrofol 10 and 50 thick) have been used, coupled with fission sources prepared in different ways. A jumping-spark counter, developed by Cross and Tommasino, has been employed for detection of fission product tracks and the results have been compared with visual counting techniques. The efficiency and sensitivity of the counting method have been examined by the use of absolute fission chambers. Also, a series of applications, based on fission rate measurements are described.

K82 RECORDING AND MONITORING OF NEUTRON FLUXES BY MEANS OF FISSION-FRAGMENT GLASS DETECTORS. Kashlukev, N.; Rilarov, S.; Neova, I.; Taneva, T.; Todorov, N. *Izv. Fiz. Inst. Aneb. Bulg. Akad. Nauk.*; 20: 247-58 (1971). (In Bulgarian).

The effects of the time of development, density of tracks, and the developer concentration and temperature on the variation of the optical density of fission-fragment glass detectors, irradiated by neutrons, are investigated. On the basis of these investigations the optimal conditions for obtaining visual images of neutron fluxes on glass and the conditions under which these images may be used for the purposes of the neutron dosimetry are determined.

K83 (ANL-7760(Pt.1)). ABSOLUTE SLOW NEUTRON MEASUREMENTS WITH SOLID STATE TRACK RECORDERS. Congel, F.J.; Roberts, J.H.; Armani, R.J.; (and others) (Argonne National Lab., Ill.).

It is shown that measurements with mica as a recorder of slow-neutron induced fission events from thick (0.125 mm) natural uranium or thin (<100 μ g/

cm²) enriched uranium (93.2% ²³⁵U) provide comparable accuracy to gold-foil activation. It is also shown that background-free mica can be obtained. The electronic track counting method of Cross and Tommasino looks promising for the measurement of extremely small neutron fluxes.

K84 (INR-1332) FISSION TRACK DETECTORS IN NEUTRON FLUENCE MEASUREMENTS. Jozefowicz, Krystyna (Institute of Nuclear Research, Warsaw (Poland)). 13 p. (1971).

Fission track detectors consisting of Makrofol polycarbonate foil and thick fissionable foils of thorium and natural and depleted uranium (bare or cadmium covered) were allowed to determine the fluence of fast, intermediate, and thermal neutrons. Several experiments are described concerning application of fission track detectors to reactor and Po-Be source neutron fluence measurements and to neutron accident dosimetry.

K85 NEUTRON ROUTINE DOSIMETRY USING SOLID-STATE TRACK DETECTORS. Doerschel, B. (Technische Univ., Dresden). *Kernenergie*; 14: No. 11, 360-3 (Nov. 1971). (In German).

Fissile layers of high sensitivity are necessary for the use of solid-state track detectors in routine monitoring. The conditions for manufacturing sprayed ²³⁵U layers and pressed ²³²Th tablets are described. Track density is determined by visual counting of etch pits on a television screen. The neutron fluences and dose equivalents for thermal, intermediate, and fast neutrons can be calculated using mathematical relations and well-known conversion factors. The calculations have been verified by experiments in various neutron fields. The required measuring range of 0.1 to 50 rem is realized for thermal, intermediate, and fast neutrons without the maximum permissible error limits of ± 30 percent being exceeded. Testing of the routine dosimeter was performed with the (d,d) generator (TU Dresden, AuBenstelle Pirna-Copitz) and the WWR-S reactor (ZfK Rossendorf).

K86 SIMPLE TECHNIQUE FOR MAKING NEUTRON MEASUREMENTS. Kehrer, M.L.; Robinson, J.E. (Univ. of Maryland, Baltimore). *Int. J. Appl. Radiat. Isotop.*; 23: No. 3, 141-2 (Mar. 1972).

Track detectors composed of polycarbonate (Lexan, 0.15 mm thick, 1.7 cm dia.) sandwiched between depleted uranium fission foils (0.03 mm thick and 1.25

cm dia.), were used to measure the neutron flux density in and outside the beam of the Brown-Boveri medical betatron at the University of Maryland School of Medicine in Baltimore. Preliminary fast neutron measurements indicated that the neutron beam dropped off very slowly compared with the x-ray beam, where photofission of ^{238}U contributed to the difference between in-beam and out of beam measurements.

K87 ROUTINE AND ACCIDENT PERSONNEL DOSIMETRY WITH SOLID STATE FISSION TRACK DETECTORS FOR THERMAL AND FAST NEUTRONS, WITH AUTOMATIC EVALUATION. Pretre, S. and Heusi, K. Eidg. Institut für Reaktorforschung Würenlingen, Switzerland. TM-SU-149. (June 1972).

K88 APPLICATIONS OF TRACK ETCHING IN NEUTRON DOSIMETRY. Becker, Klaus (ORNL); Transactions 1972 Annual Meeting of The American Nuclear Society, Vol. 15.

K89 THORIUM FISSION FRAGMENT DOSIMETERS IN NEUTRON DOSIMETRY. Heinzlmann, M. and Schuren, H. Nuclear Research Facility, Jülich. Central Department, Radiation Protection D-517 Jülich.

K90 INDIVIDUAL DOSIMETRY IN A CATASTROPHY (METHODOLOGY). Wachsmann, F. *Strahlenschutz Forsch. Prax.*; 11: 29-35 (1971). (In German).

The suitability of various dosimeters for individual persons during civil defense emergencies is analyzed. For γ ray determination, condenser chambers, glasses, thermoluminescent dosimeters, films, and self-developing films are considered. For neutron determination, nuclear track methods, foil etchings, and activation foils are discussed. (6 figures).

K91 (FEI-296) STUDY OF THE CHARACTERISTICS OF EMERGENCY TRACK DETECTORS. Obaturov, G.M.; Chumbarov, Yu. K. (Gosudarstvennyi Komitet po Ispol'zovaniyu Atomnoi Energii SSSR. Obninsk. Fiziko-Energeticheskii Institut). 30 p. (1971). (In Russian).

Mica track neutron detectors with layers of ^{237}Np , natural U, and ^{238}U were investigated; and on the basis of the results a track dosimeter was designed with two layers of natural U and a layer of ^{238}U and ^{237}Np , making it possible to determine neutron doses for both the whole energy spectrum and for various

energy intervals with acceptable accuracy. Results are given of comparative studies of track dosimeters, thermoluminescent dosimeters, and tissue-equivalent, low-efficiency Geiger counters for critical assemblies.

K92 COMPARISON OF NEUTRON AND GAMMA-RAY PERSONNEL DOSIMETERS AT CRITICAL ASSEMBLIES. Keirim-Markus, I.B.; Kraitir, S.N.; Kuz'min, V.V.; (and others). *At. Energ. (USSR)*; 33: No. 1, 563-5 (July 1972). (In Russian).

Comparative results of neutron and gamma-ray personnel dosimeters are presented. It is shown that data obtained by means of neutron-track dosimeters and thermoluminescent (CaS) dosimeters agree within 30% and, when measurements are conducted with sufficient statistical accuracy, 15%. There is agreement within the same limits for gamma-ray dosimeters: pocket film (IFK-2,3), glass (IKS), and LiF. The results obtained by means of neutron personnel dosimeters agree with LET spectra measured by a set of tissue-equivalent low-efficiency Geiger counters and neutron spectra measured by means of threshold detectors.

K93 (KURRI-TR-89). NEUTRON DOSIMETRY WITH THE SOLID STATE TRACK DETECTOR. Tsuruta, T. (Kyoto Univ). pp 64-70. (1971). (In Japanese).

The properties of several types of solid state nuclear track detectors for neutron dosimetry have been investigated. The detectors were irradiated with fast neutrons (2.5 MeV, 14 MeV) and a count was made of the number of etch-pits on the surfaces of irradiated detectors after etching with suitable chemical reagents. The first type of the detectors used in these experiments was phosphate glass or natural mica, on which the electrodeposition thin film of natural uranium or thorium on gold foil was contacted. The experiment proved that a good agreement exists between the expected number of fissions and the number of etch-pits. The second type was the glass or mica or plastics, on which the foil of the fissionable material much thicker than the range of the fission fragment was contacted. It has been shown that the sensitivity is explained by the range of the fission fragment in the fissionable material. The third type was the phosphate glass, in which natural uranium and/or thorium was doped. It was found that the number of etch-pits and sensitivity increase with the etching time. Broad energy range neutron dosimetry in mixed radiation fields with this solid state fission track detector was discussed. The fourth type was

plastics, such as polycarbonate, cellulose nitrate and cellulose acetate. It may be inferred that the etch-pits observed in polycarbonate might have developed at the site of radiation damage caused by the recoil carbon and oxygen due to fast neutron irradiation.

K94 (KFK-1635) NUCLEAR ACCIDENT DOSIMETRY MEASUREMENTS AT THE SECOND I.A.E.A. INTERCOMPARISON AT OAK RIDGE, USA, MAY 1971. Plesch, E. (Kernforschungszentrum, Karlsruhe (West Germany)). 21 p. (Dec. 1972).

Teams from several countries participated in an international intercomparison of nuclear accident dosimeter systems, organized by the I.A.E.A., in which criticality dosimeters were exposed to mixed pulses of neutron and gamma radiation from the Health Physics Research Reactor at Oak Ridge. The final results of the measurements made with the personnel dosimeter system of the Karlsruhe Nuclear Research Centre are given. The dose assessment both in free air and on phantoms is based on standard interpretation of the routine personnel dosimeter, the phosphate glass dosimeter, and threshold detectors. During the experiment the dosimetric properties of a belt of polycarbonate foil were studied using the neutron-induced recoils and (n,α) reaction in the plastic foil for a detection of neutrons >1 MeV. The effect of fission neutrons on the reading of gamma dosimeters was studied on different phosphate glass dosimeters and LiF dosimeters.

K95 (BNWL-1616) SECOND AEC WORKSHOP ON PERSONNEL NEUTRON DOSIMETRY, JULY 8-9, 1971, New York, New York. (Battelle Pacific Northwest Labs., Richland, Wash). 109 p. (1971).

Research and development activities are reported from ORNL, LLL Livermore, Chalk River Nuclear Labs, BNL Battelle-Northwest, Rocky Flats, Savannah River Plant, University of Wisconsin, and Stanford Linear Accelerator. Ten papers were presented. Topics include albedo neutron dosimeters, anthracene dosimeters, fission fragment dosimeters, thermoluminescent dosimeters, and thermally stimulated exoelectron emission dosimeters. Also, the results of a survey of procedures and equipment for spark counting of fission fragment dosimeters at several laboratories are tabulated.

K96 FLUENCE AND DOSE EQUIVALENT DETERMINATION IN A NEUTRON FIELD BY MEANS OF MODERATING SPHERES CONTAINING FISSION TRACK RECORDERS. Mijnheer, B.J.;

Pauw, H.; Van Herk, G. Jr.; Aten, A.H.W. Jr. (Instituut voor Kernfysisch Onderzoek, Amsterdam). *Health Phys.*; 24: No. 4, 423-427 (Apr. 1973).

A description is given of the determination of neutron fluence and dose equivalent by means of registration of tracks in plastic foils from thin layers of fissile material surrounded by moderator spheres.

K97 (UCRL-74247) USE OF ^{10}B -LOADED PLASTIC IN PERSONNEL NEUTRON DOSIMETRY. Griffith, R.V. (California Univ., Livermore, Lawrence Livermore Lab.). 21 p. (Oct. 9, 1972).

At the Lawrence Livermore Laboratory, various plastics loaded with enriched ^{10}B have been used as small shields for personnel dosimeters, in environmental neutron monitors, and for special dosimetry application. Unlike other forms of ^{10}B shielding, the borated plastic is inexpensive to fabricate, easy to handle, and can be shaped for fabricating special shields. Small discs of plastic filled with ^{10}B to a density of 1.40 g/cm^3 are now used as shields for copper and indium foils in nuclear-accident dosimeters worn by Laboratory personnel. The use of borated plastic in place of cadmium for low-energy neutron shielding increases the effective threshold for the $^{63}\text{Cu}(\gamma,\gamma)^{64}\text{Cu}$ reaction by nearly two orders of magnitude. Also, by suppressing the low-energy activation, the copper response is more representative of the neutron flux for 0.1 keV to 1 MeV, which enhances the usefulness of copper as an accident dosimeter. The indium foil is covered with borated plastic to suppress the $^{115}\text{In}(\eta,\gamma)^{116\text{m}}\text{In}$ reaction. Thus, the activation of the more useful $^{115}\text{In}(\eta,\eta')^{115\text{m}}\text{In}$ threshold reaction can be almost immediately determined, without the long delay usually required for decay of the short-lived $^{116\text{m}}\text{In}$ activity. Also, borated plastic is being used in the development of a TLD albedo dosimeter to reduce the low-energy neutron response of the $^6\text{Li}(\eta,\alpha)\text{T}$ reaction in TLD-600. In addition to these applications, the $^{10}\text{B}(\eta,\alpha)^7\text{Li}$ reaction in the plastic has been used to locate and define low-energy neutron beams from various neutron-generating facilities. For this application, the borated material is placed against a sheet of cellulose nitrate in a neutron beam. When the cellulose nitrate is chemically etched, the pattern made by the alpha tracks accurately defines the neutron field.

K98 PROGRESS IN SOLID-STATE FAST NEUTRON PERSONNEL DOSIMETRY. Becker, Klaus (Oak Ridge National Lab., Tenn.). 20 p. (1972).

The poor stability of latent recoil proton tracks in photographic emulsions has frequently been underestimated due to unrealistic testing conditions. Thin polycarbonate foils to be evaluated by automatic spark-counting exhibit no fading for at least three months at 32°C and 95% humidity. As one of several alternatives to the NTA film, optimized combinations containing ^{237}Np or ^{232}Th and 10 μm polycarbonate foils are described (^{237}Np covers a wide dose range of $\geq 10^{-3}$ to ≤ 10 rad, and neutron energies ≥ 0.6 MeV). The directional response is given for different neutron energies and detector-phantom distances. Another approach consists of the amplification of recoil nuclei etch pits to facilitate automatic counting. The inherently low fast neutron response of most solid-state detectors can be increased by intimate contact with a hydrogenous material. TSEE detectors based on BeO , for example, which are covered with a hydrogenous radiator, have been used successfully in recent tests of criticality monitoring systems at ORNL. The thin sensitive layer of exoelectron detectors makes this approach especially attractive for intermediate neutron energies.

K99 PRACTICAL METHOD FOR NEUTRON DETECTION BY FISSION TRACK REGISTRATION.

I. Koshijima, Tokusaburo (National Inst. of Radiological Sciences, Chiba, Japan). *Nippon Igaku Hoshasen Gakkai Zasshi*; 31: No. 8, 928-932 (Nov. 1971). (In Japanese).

An easy method for neutron detection based on fission tracks in solids is reported. A small amount of solution of fissionable material was evaporated on a solid. The fissionable layer had a thickness of 15 to 30 mg/cm^2 . Uranylacetate served as the fissionable material. For the track registering solid, the dosimeter glass (FD-P8-3, Toshiba) and a cellulose triacetate sheet were used. To investigate the effect of the thickness of the fissionable layer on the track density, detectors that had various thickness of the layer were studied. There was a linear relationship between track density and neutron flux. For thin fissionable layers of less than 5 mg/cm^2 , the track density depends on the thickness of layer. The combination of a dosimeter glass with uranylacetate had a sensitivity of 1.9×10^{-6} tracks/neutron for the $\text{Ra} - \text{Be}$ source.

K100 CHARACTERISTICS OF A PERSONAL NEUTRON TRACK DOSIMETER. Keirim-Markus, I.B.; Koroleva, T.V.; Kraitov, S.N.; Uspenskii, L.N. *At. Energ. (USSR)*; 34: No. 1, 11-15 (Jan. 1973). (In Russian).

The characteristics of a personal neutron dosimeter, consisting of track detectors of fission fragments from ^{237}Np beyond a 0.1 g/cm^2 ^{10}B filter and ^{235}U are investigated. The dose response was determined. The dependence of dosimeter readings on the distance from a human body surface and the radiation incidence angle were estimated. The measurement results for various neutron spectra are presented. It is shown that the dose response spread does not exceed 10 per cent. The experimental results agree with the calculated data.

K101 (EUR-4896(Vol.1)). IMPROVEMENTS IN THE USE OF NUCLEAR-TRACK DETECTORS IN NEUTRON DOSIMETRY. Faengewisch, G.L.; Scharmann, A. (Univ., Giessen, Ger.). pp 303-314. (Sept. 1972). (In German).

By utilizing (n,f) and (n,α) reactions nuclear track detectors can be used for neutron dosimetry. One main problem is to count very large numbers of tracks. A great deal of work has been done to apply image analyzing computers for automatic counting. Some plastics are suitable for detecting both fission and α -particles. The efficiency and the track density dependence on dose were investigated for Triafol TN. This was carried out for the fission-particles of a ^{252}Cf source and for the α -particles of a ^{210}Po -source. Detecting neutrons is possible via α -particles from an (n,α) reaction, which takes place in the plastic itself or in a converting material placed very close to the detecting foil. For a number of nuclides the (n,α) cross sections are very low respecting thermal neutrons and increase above a characteristic energy in the MeV-region. Thus a rough energy discrimination can be reached by using a combination of materials containing Be, F, and Al as converters. C-recoils and α -particles from (n,α) reactions in the detecting foils make a considerable contribution to the neutron detecting efficiency in the dosimeter combinations.

K102 (EUR-4896(Vol.1)). THORIUM FISSION FRAGMENT DOSIMETERS IN NEUTRON DOSIMETRY. Heinzelmann, M.; Schuren, H. (Kernforschungsanlage, Juelich, Ger.). pp 315-327. (Sept. 1972). (In German).

Personal dose monitoring by means of nuclear track films rarely reveals exposure to neutrons. Fission fragment dosimeters were therefore studied as devices independent of the nuclear track film. Large-surface fission fragment dosimeters with a thin thorium layer are fabricated electrolytically and tested in practical use. They are evaluated automatically, and their

sensitivity to fast neutrons is found to be comparable with nuclear track films. The fabrication of the fission fragment dosimeters, their properties (sensitivity, zero effect, direction-dependence and fading) and behavior in practical use are described. When used for personal dose monitoring, the fission fragment dosimeters frequently reveal slight fast-neutron dosage which is not detected by nuclear track films.

K103 NOVEL TRACK ETCH TECHNIQUE FOR NEUTRON MEASUREMENTS. Robinson, J.E.; Kehrer, M.L. (Univ. of Maryland, Baltimore). pp 497-503 of *Proceedings of the 5th International Betatron Symposium*. Bucharest; Inst. for Atomic Physics (1971).

The use of dielectric track detectors sandwiched between fission foils for measuring low levels of neutron flux in association with pulsed photon or electron beams from a medical betatron is discussed.

K104 Fleischer, R.L., Price, P.B., and Walker, R.M. Gen. Electr. REP. 64-RL-3834 (1964).

Title and abstract not available.

K105 AECL-2657, MEASUREMENT OF NEUTRON FLUENCE BY FISSION FRAGMENT DAMAGE TRACK DETECTION. Bhatt, R.C. Chalk River, Canada (1966).

Abstract not available.

K106 PERSONNEL NEUTRON DOSIMETER DEVELOPMENTS. Unruh, C.M., Baumgartner, W.V., Kocher, L.F., Brackenbush, L.W., and Endres, G.W.R. Proc. IAEA Symp. Neutron Monitoring p433 (1967).

Abstract not available.

K107 SPECTROMETRIE DE NEUTRONS A L'IDE DE DETECTEURS IONOGRAPHIQUES SOLIDES. Remy, G., and Tripiet, J. Proc. Int. Colloq. Nucl. Electron. Radioprot. Toulouse (1968).

Abstract not available.

K108 RICHTUNGSABHANGIGKEIT EINES DOSIMETERS MIT NICHTFOTOGRAFISCHER SPALTFRAGMENT-REGISTRIERUNG. Heinzelmänn, M. Atompraxis 14, Direct-Informat 1/68 (1968).

Abstract not available.

K109 LES DETECTEURS IONOGRAPHIQUES DANS LA DOSIMETRIE ET LA SPECTROMETRIE DES NEUTRONS. Debeaumont, M., and Cuet, P. Proc. Int. Colloq. Nucl. Electron. Radioprot. Toulouse (1968).

Abstract not available.

K110 PERSONAL DOSIMETER FOR NEUTRONS. Nicolae, M. Int. Congr. IRPA, 2nd, Brighton (1970).

Abstract not available.

K111 A FEASIBILITY STUDY OF THE USE OF TRACK REGISTRATION FROM FISSION FRAGMENTS FOR NEUTRON PERSONNEL DOSIMETRY AT THE 20 GEV SLAC. Svensson, G.K. Proc. Int. Congr. IRPA, 2nd, Brighton. (1970).

Abstract not available.

K112 USE OF MAKROFOL POLYCARBONATE FOILS FOR THE MEASUREMENT OF THE FAST NEUTRON DOSE DISTRIBUTION INSIDE A HUMAN PHANTOM. Tuyn, J.W.N.; Broerse, J.J. (Reactor Centrum Nederland, Petten, Netherlands). Ref. J47 pp 527-531. (1970).

The application of Makrofol foils for absorbed neutron dose measurements was tested by exposing foils inside a human phantom and comparing the experimental data with the results of tissue equivalent ionization chamber measurements. The optical density distribution of the exposed foils was found to be in agreement with the ionization chamber results. The ratio of optical density and darkfield light intensity is a function of the depth in the phantom. The absorbed dose distribution can also be derived from etch pit counting, but in this case the best fit is obtained when only the number of etch pits with a diameter above a certain threshold is counted.

K113 EVALUATION OF DOSE EQUIVALENT BY FISSION FRAGMENT DETECTORS. Tatsuta, H., and Bingo, K. Proc. Int. Congr. IRPA, 2nd, Brighton (1970).

Abstract not available.

K114 JUL-670-ST. SPALTFRAGMENTDOSIMETER FUR HOHE NEUTRONENENERGIEN. Heinzelmänn, M., and Schuren, H. At. Res. Estab. Jülich, West Germany, p 147 (1970).

Abstract not available.

K115 NEUTRON DOSIMETRY WITH NUCLEAR TRACK DETECTORS APPLIED TO IN VIVO NEUTRON ACTIVATION ANALYSIS. Agard, E.T., Jervis, R.E., and McNeill, K.G. Health Physics, 21, p625 (1971).

Abstract not available.

K116 A NEUTRON DOSIMETER BASED ON TRACK REGISTRATION IN INSULATORS. Carli, N., Lonati, R.D., and Mangialajo, M. *Proc. IAEA Symp. Advan. Radiat. Detectors*, p359 (1971).

Abstract not available.

K117 TENTATIVE METHOD FOR FAST-NEUTRON FLUX MEASUREMENTS BY TRACK-ETCH TECHNIQUE. ASTM. *Book ASTM Stand.* 1971 (71, 30), p1191 (1971).

Abstract not available.

K118 THE APPLICABILITY OF TRACK DETECTORS IN NEUTRON DOSIMETRY. Burger, G., Grunauer, F., and Paretzke, H. *Proc. IAEA Symp. Advan. Radiat. Detectors*, Paper SM-143, p340 (1972).

Abstract not available.

K119 ORNL-TM3605, TRACK ETCHING IN PERSONNEL FAST NEUTRON DOSIMETRY. Sohrabi, M., and Becker, K. *Oak Ridge Nat. Lab., Oak Ridge, Tennessee.* (1972).

Abstract not available.

K120 ABSOLUTE SLOW NEUTRON MEASUREMENTS WITH SOLID STATE RECORDERS. Congel, F.J. (Macalester Coll., St. Paul); Roberts, J.H.; Armani, R.J.; Gold, R.; Kastner, J.; Oltman, B.G. *Ref. 347* pp 469-479 (1970).

High accuracy (~1%) in the measurement of absolute slow neutron fluxes can be obtained by the well-established method of gold foil activation. It has been shown that measurements with mica as a recorder of slow-neutron induced fission events from thick (0.125 mm) natural uranium or thin (<100µg/cm²) enriched uranium (93.2% ²³⁵U) provide comparable accuracy. The technique is also applicable to much lower neutron fluxes. It is also shown that background-free mica can be obtained by annealing muscovite in a furnace at 580°C for about 24 hours and then etching it in 49% HF at room temperature for 24 hours. Studies of the electronic track counting method of Cross and Tommasino are also reported. This method looks promising for the measurement of extremely small neutron fluxes.

K121 (KFK-1638). FINGER DOSIMETER FOR THE MEASUREMENT OF NEUTRON RADIATION. Burghardt, B.; Piesch, E. (Kernforschungszentrum, Karlsruhe, Ger.); Buijs, K.; Vaane, J. (European Inst.

for Transuranium Elements, Karlsruhe, Ger.). pp 183-194. (May 1972). (In German).

The conditions governing the use of solid nuclear track detectors for ²⁵²Cf dosimetry have been simulated in a neutron-shielded facility. The neutron energy spectra of a ²⁵²Cf-source have been obtained for various distances from the source; more than 90% of the total neutron dose received during normal work at usual distances from the source are made up of neutron energies of more than 0.75 MeV and the dose is found to be inversely proportional to the square of the distance to the source. Quite an important problem to be solved was the design and realization of a stable holding device for the dosimeter. It has to protect the thin foil and to guarantee simple exchange of foils. The dosimeter itself consists of fission foils (²³⁷Np, ²³²Th) which are in contact with polycarbonate foils. In addition, a thick polycarbonate foil has been inserted into the dosimeter for measuring the neutron-induced recoil reactions. Counting is made automatically by a spark counter. The sensitivity of the dosimeter is 200 mrem.

K122 (LA-UR-73-1262) PROGRESS IN PERSONNEL NEUTRON DOSIMETRY. Hankins, D.E. (Los Alamos Scientific Lab., N. Mex.). 13p. (1973).

Recent progress in personnel neutron dosimetry is reviewed. A survey of the various albedo-neutron dosimetry systems that have been developed shows the advantages and disadvantages of each of the systems. The energy dependence of the albedo-neutron dosimeters is rather poor, and the effect of this on their accuracy and usefulness is discussed. Fission-fragment damage to polycarbonates has been studied extensively, with most investigators using the spark-counter technique for evaluation. A survey is made of the systems currently in use, and the problems associated with their use are discussed, including sensitivity, evaluation time, and exposure of the wearer to the fissionable material. Other systems under study but not yet in practical application are discussed briefly and include thermally stimulated exoelectron emission (TSEE), direct response of thermoluminescent-dosimeter (TLD) materials to fast neutrons, and the response of TLD materials to recoil protons.

K123 (UCRL-50007-72-3). DEVELOPMENTS IN LIGHT PARTICLE TRACK REGISTRATION FOR PERSONNEL NEUTRON DOSIMETRY. Griffith, R.V. pp 1-3. (Mar. 29, 1973).

Neutron dosimeters based on fission track registration contribute to the radiation dose of the wearer. Research work on development of neutron dosimeters based on light particle track registration using non-radioactive materials is reported. The systems investigated included $^6\text{Li}(n,\alpha)\text{H}^3$ and $^{14}\text{N}(n,p)^{14}\text{C}$ with cellulose nitrate used as the registrant.

K124 (ORNL-TM-4297) LONG-TERM STABILITY OF FILM, TLD, AND OTHER INTEGRATING DOSIMETERS IN WARM AND HUMID CLIMATES.

Becker, K. (Oak Ridge National Lab., Tenn.). (Aug. 1973).

With the increasing use of radiation source in hot and/or humid climates, the long-term stability of dosimeters selected for personnel, environmental, and postal intercomparison dosimetry is becoming a matter of world-wide concern. Laboratory tests with various film, TLD, RPL (glass), silicon diode, TSEE and track etching dosimeters at ORNL and other laboratories are reviewed and compared with the results of field tests, in particular a recent study involving the storage of different gamma monitoring films with or without additional protective sealing, LiF : Mg, Ti (TLD-100), and CaSO_4 : Dy at seven locations in four Latin American countries. The observed fading rates range from 0 to 100% for the Kodak Type 2 and 3 films, and from 0 to 23% for the TLD phosphors, depending on the climate of the location. In four of the seven locations, unsealed films should not be used in X- and gamma-radiation personnel dosimetry (in two of those places, even optimum sealing did not prevent 54 to 89% fading). Extremes in storage temperature are most critical for TLD, extremes in relative humidity for the film fading. The results and the consequences to be drawn are discussed. Apparently, even carefully sealed dosimeter films cannot be used in the climate prevailing at many locations. Some desirable follow-up studies are outlined.

K125 EMERGENCY NEUTRON TRACK DOSIMETER. Obaturov, G.M.; Rybanov, V.V.; Chumbarov, Yu. K.; Shalin, V.A. (Physical-Power Engineering Inst., Obninsk, USSR). pp 651-661 of *Dosimetry in Agriculture, Industry, Biology and Medicine*. Vienna; International Atomic Energy Agency (1973). (In Russian).

The characteristics of an emergency neutron track dosimeter consisting of four detectors (^{237}Np , ^{238}U and natural uranium with and without a cadmium filter) in contact with mica or glass

are described. The sensitivity of such detectors to flux and dose has been determined with a $\text{Po}-\text{Be}$ source. The mean dose sensitivity of the track detectors to neutron fluxes with 12 different spectra is calculated and the results are presented. It appears from the calculations that the dose sensitivity of the Np -detector is independent of the shape of the spectrum to within $\pm 10\%$ for neutrons with $E_n \geq 0.45$ MeV and to within $\pm 10\%$ for neutrons with $0.5 \text{ eV} < E_n \leq 10 \text{ MeV}$. With the other detectors the dose sensitivity is more dependent on the shape of the spectrum. Using this dosimeter one can measure the absorbed dose and dose equivalent of thermal neutrons in the ranges 2×10^{-4} to 70 rad and 2×10^{-3} to 700 rem, epithermal ($0.5 \text{ eV} \leq E_n \leq 10 \text{ MeV}$) neutrons in the ranges 0.3×10^{-2} to 10^4 rad and 0.3×10^{-1} to 10^5 rem, and the fast ($E_n \geq 1.5$ MeV) neutrons in the ranges 0.2×10^{-1} to 5×10^3 rad and 0.2 to 5.5×10^4 rem.

K126 THERMAL NEUTRON FLUENCE MEASUREMENTS BY THE FISSION TRACK METHOD USING THE STANDARD U GLASSES. Oncescu, M.; Danis, A. (Inst. of Atomic Physics, Bucharest). *Rev. Roum. Phys.*; 18: No. 6, 789-791 (1973).

Thermal neutron fluence measurements by the fission track method using uranium as the fissionable element in calibrated glasses are described. The constant K from the relation $\Phi = Kp$ for the reactor conditions was calibrated for U-2 and U-3 standard U glasses by the gold foil activation technique. Makrofol and Melinex plastic SST detectors and a mica muscovite mineral SST detector were used. Neutron fluences for a number of exposures into the thermal column 3 of the VVR-S reactor, Bucharest, were measured. U-235 induced fission fragment tracks were counted at 400 times magnification using an optical microscope.

K127 MIXED-FIELD DOSIMETRIC TECHNIQUES APPLIED TO MEDICINE AND BIOLOGY. Goma, M.A., El-Naggar, A.M. (Atomic Energy Establishment, Cairo). pp 165-168 of *Dosimetry in Agriculture, Industry, Biology and Medicine*. Vienna; International Atomic Energy Agency (1973).

The natural uranium fission fragment track dosimeter and the thermoluminescent dosimeter were tested for use in a mixed field of neutrons and gamma rays. Application of these dosimeters includes dosimetric response with human phantoms, and dose estimation in biological systems.

K128 DOSIMETRY BY MEANS OF THE NUCLEAR TRACK METHOD. Faengewisch, G.L.; Scharmann, A. (Univ., Giessen, Ger.). *Kern-technik*; 15: No. 5, 207-213 (1973). (In German and English.)

The nuclear track method is suitable for demonstrating on the surface of insulating detector materials the effects of impact of heavy particles with a sufficiently high linear energy transfer (LET). The zones of detector material damaged by the impinging particles are enlarged by etching after irradiation, and can then be counted, e.g., under a light microscope. Neutrons cause tracks indirectly, by secondary products such as alpha or fission particles. By appropriate choice of various reaction partners for the neutrons it is possible to arrive at a coarse energy discrimination. Neutron dosimetry by this method is not disturbed by the concurrent presence of gamma radiation because the LET values of this radiation are below the detection threshold. The importance of the nuclear track method is stressed by listing further application possibilities.

K129 (DASA-2573). NEUTRON AND GAMMA-RAY MEASUREMENTS WITH NUCLEAR TRACK DETECTORS. Final Report. Frank, A.L.; Benton, E.V. (San Francisco Univ., Calif. (USA). Dept. of Physics). 57 p. (Nov. 30, 1970).

The replacement of activation analyses and photographic plates as the means of passive dosimetry are discussed. Whereas activated foils have a short half-life, speed of analysis is imperative and presents a problem. Furthermore, the analysis is complex and the energy dependence of the few foils available is such that abstracting spectral information is very difficult. One of the more significant new developments in the field of neutron detection has been made possible by the discovery of a new class of charged particle detectors called nuclear track detectors. The detecting principle is based on the delineation of individual paths of heavily ionizing charged particles such as fission fragments, recoil nuclei, alpha particles, and low velocity protons. Delineation is accomplished through a selective chemical attack of the narrow, radiation damaged region along the particle's trajectory. The resulting narrow channels referred to as tracks, can be enlarged to a convenient size for direct viewing with an optical microscope. Unlike photographic emulsions, track etch materials are insensitive to beta and gamma radiation and also to light. They can, therefore, be in the high gamma fields of testing environments.

K130 (EUR-5041) PERFORMANCE OF FISSION TRACK DOSIMETER FOR MONITORING THE NEUTRON RADIATION FROM ^{252}Cf SOURCES ON HANDS INSIDE GLOVE BOXES. Mijnheer, B.J. (Commission of the European Communities, Geel (Belgium). Central Bureau for Nuclear Measurements). 49 p. (Oct. 1973).

A description is given of a personnel neutron dosimeter based on fission track registration in a $10\text{ }\mu\text{m}$ thick Makrofol foil in combination with two thorium discs, for use on the hands of operators during the handling of ^{252}Cf sources inside glove boxes or during implantation work for therapy purposes. The device also contains a TLD-100 chip for measuring the γ -dose equivalent on the hand. The angular dependence of the response of the dosimeter with thorium and other fissile materials was measured at different energies. The neutron sensitivity of the dosimeter was determined with a calibrated ^{252}Cf source and amounts to $14.9 \pm 0.7\text{ mrem/spark}^{-1}$. The neutron spectrum scattered inside the glove box was measured. The resulting dose equivalent, which will not be recorded by the dosimeter, amounts to about 50 mrem.hr^{-1} per $\mu\text{g } ^{252}\text{Cf}$, and is not very dependent on the distance to the source. Experience with the dosimeter over a period of about one year at CBNM shows that the ratios of the gamma dose on the finger tip to that on the hand and the gamma to neutron dose equivalent at the place of the dosimeter varies considerably.

K131 (ORNL-4903). HPRR AND ACCELERATOR OPERATIONS. Ward, D.R.; Haywood, F.F.; Dickson, H.W.; Fox, W.F.; Littleton, C.P.; Shoup, R.L.; Poston, J.W. pp 51-57. (Sept. 1973).

Health Physics Research Reactor operations are summarized; and research on high-density track counting in dielectric track detectors using an electron beam and the development of long-lived tritium targets for neutron generators are briefly discussed.

K132 NEUTRON DOSIMETRY WITH VARIOUS SOLID STATE FISSION TRACK DETECTORS. Tsuruta, T. (Kyoto Univ., Kumatori, Japan). *Nippon Genshiryoku Gakkaishi*; 67: No. 3, 462-472 (Sept. 1973).

The properties of three types of solid state fission track detectors for neutron dosimetry have been studied. The detectors were irradiated with monochromatic fast neutrons and a count was made of the number of etch-pits on the surfaces of the irradiated detectors after etching with suitable chemical reagents. The first type of detector examined was

glass or mica, which was in contact with a thin film of thorium or uranium. The experiment proved that the sensitivity is in proportion to the amount of fissionable material per unit area. The second type was glass, mica or plastics, which was in contact with a thick foil of the fissionable material. It was shown that the measured sensitivity could be explained in terms of the range of the fission fragment in the fissionable

material. The third type was metaphosphate glass, which was doped with thorium and/or uranium. It was found that the dependence of the sensitivity on etching time could be explained from the thickness of the layer removed from the glass surface by the etching. A discussion is given of neutron dosimetry having a wide range of energy in mixed radiation fields with these detectors.

L. FAST NEUTRON DOSIMETRY AND SPECTROMETRY

L1 MEASUREMENT OF 14 MEV NEUTRON FLUX DENSITY BY FISSION TRACK METHOD. Nakanishi, T. and Sakanoue, M. *Radiochemical Radioanalytical Letters*. XX 2, 313 (1969).

L2 HIGH ENERGY NEUTRON FLUX DETECTION WITH DIELECTRIC PLASTICS. Frank, A.L.; Benton, E. V. (Naval Radiological Defense Lab., San Francisco). *Ref. J18 pp V. 93-102.* (1969).

Dielectric plastics were irradiated with high energy neutrons to investigate their usefulness as flux detectors. Shields thick to heavy particles and of varying composition were placed in front of the plastics to test their effectiveness as radiators. Track producing particles resulted from $(n, {}^4\text{He})$ reactions and from recoils of light nuclei. Elements possessing high $(n, {}^4\text{He})$ cross sections were chosen as shields along with other heavy elements chosen to screen the surface of the plastic from all external track-producing particles. Carbon and aluminum satisfied the second. After etching, the track densities in cellulose nitrate were counted. The sensitivity under graphite varied from about 2.7×10^{-5} to 3.4×10^{-5} tracks/cm²-n₀/cm² for neutrons between 13.1 and 17.1 MeV. Useful track densities are produced by fluxes in the range of about 2×10^8 to 5×10^{10} n₀/cm². The ${}^{12}\text{C}(n, n' {}^3\text{He})$ reaction also took place in the carbon nuclei within the plastic itself. This allowed the triple- ${}^4\text{He}$ particle tracks to be counted. The sensitivity of this method varied from about 2.7×10^{-8} to 5.7×10^{-8} tracks/cm²-n₀/cm². The useful flux range in the best case (under gold) was from 5×10^{10} to 5×10^{11} n₀/cm².

L3 (UCRL-19364) ENERGY AND FLUX DETERMINATIONS OF HIGH-ENERGY NUCLEONS. Wollenberg, Harold A.; Smith, Alan R. (California

Univ., Berkeley. Lawrence Radiation Lab.). 12 p. (Aug. 1969).

The fission track method is used to determine the energy and flux of neutrons and protons in the energy range above 50 to 100 MeV. Foils of U, Bi, Au, and Ta together with muscovite mica track detectors are exposed to nucleons of unknown high energy and flux. The effective energy of these nucleons is determined by comparing ratios of fission track densities of various targets (the ratios U/Au, U/Ta, and Bi/Au, for example) with calibration curves of energy versus track-density ratio. Knowing the effective energy, one can then select the appropriate cross section from experimentally determined cross-section curves, and can then determine an effective nucleon flux for the exposure conditions. This technique was tested using data from an experiment at the CERN P.S.; results were in good agreement with those from measurements of ${}^{11}\text{C}$ activity in plastic scintillators exposed under the same conditions.

L4 MEASUREMENT OF 14 MeV NEUTRON FLUX DENSITY BY FISSION TRACK METHOD. Nakanishi, T.; Sakanoue, M. (Kanazawa Univ., Japan). *Radiochem. Radioanal. Lett.*; 2: 313-19. (Dec. 1969).

The fission track method for measuring neutron fluence was applied to a measurement of the neutron flux distribution in the neighborhood of a disk-shaped tritium target of a commercial 14 MeV neutron generator. By combining a uniform fission source of vacuum-evaporated natural uranium with muscovite track detector, the minute variation of neutron flux density over the area of the cooling cap was measured easily, and the decrease of flux density with distance from the cooling cap was also estimated.

L5 DETECTION OF ^4He PARTICLES AND RECOIL NUCLEI PRODUCED BY HIGH-ENERGY NEUTRONS IN DIELECTRIC PLASTICS. Frank, A.L.; Benton, E.V. (Univ. of San Francisco, Calif.). *Trans. Amer. Nucl. Soc.*; 13: 420 (Jun.-Jul. 1970).

L6 FAST-NEUTRON-INDUCED ETCH-PIT DISTRIBUTIONS IN MAKROFOL POLYCARBONATE FOIL. Tuyn, J.W.N. (Reactor Centrum Nederland, Petten, Netherlands). *Trans. Amer. Nucl. Soc.*; 13: 523-4 (Nov. 1970).

L7 IMAGE DETECTION METHODS FOR 14.5-MeV NEUTRONS: TECHNIQUES AND APPLICATIONS. Berger, H. (CEN, Grenoble, France). *Int. J. Appl. Radiat. Isotop.*; 21: 59-70 (Feb. 1970).

Three methods for detecting images with neutrons produced by the T(d,n) reaction are considered. These are (1) the direct method, in which x-ray film with or without intensifying screens is exposed to the neutron beam, (2) the transfer method in which an autoradiograph of a neutron-activated foil is obtained and (3) the track-etch method, in which radiation damage tracks in polycarbonate and cellulose nitrate plastics are made visible. The latter two methods offer the advantage that they are insensitive to gamma rays. Sensitivities and contrast capabilities of each method are discussed. The best methods in each group, with the total fast-neutron exposure needed for a good quality image enclosed in parentheses, are scintillator-film detectors ($5 \times 10^7 \text{ n/cm}^2$) for the direct method, double foil copper screens ($1.2 \times 10^{10} \text{ n/cm}^2$ for a 30-min, 3 half-life activation) for the transfer method, and a new cellulose nitrate plastic ($2 \times 10^{10} \text{ n/cm}^2$) for the track-etch method. Applications of these image-detection methods to the study of the uniformity of neutron beams, to the detection of interfering gamma or x-radiation, to the location of irradiation samples in the neutron beam, and to the performance of radiography with fast neutrons are discussed.

L8 HIGH ENERGY NEUTRON FLUX DETECTION WITH DIELECTRIC PLASTICS. Frank, A.L.; Benton, E.V. (Univ. of San Francisco). *Radiat. Eff.*; 3: 33-7 (May 1970).

Dielectric plastics were irradiated with high energy neutrons to investigate their usefulness as flux detectors. Shields thick to heavy particles and of varying composition were placed in front of the plastics to test their effectiveness as radiators. Track producing particles resulted from (n, ^4He) reactions and from recoils of light nuclei. Elements possessing high (n, ^4He) cross sections were chosen as shields along

with other heavy elements chosen to screen the surface of the plastic from all external track-producing particles. Carbon and aluminum satisfied the first condition while gold and lead satisfied the second. After etching, the track densities in cellulose nitrate were counted. The sensitivity under graphite varied from about 2.7×10^{-5} to 3.4×10^{-5} tracks/neutron for neutrons between 13.1 and 17.1 MeV. Useful track densities are produced by fluxes in the range of about 2×10^8 to $5 \times 10^{10} \text{ n}_0/\text{cm}^2$. The $^{12}\text{C}(n,n')^3\text{He}$ reaction also took place in the carbon nuclei within the plastic itself. This allowed the triple- ^4He particle tracks to be counted. The sensitivity of this method varied from about 2.7×10^{-8} to 5.7×10^{-8} tracks/neutron. The useful flux range in the best case (under gold) was from 5×10^{10} to $5 \times 10^{11} \text{ n}_0/\text{cm}^2$.

L9 ON THE DETECTION OF FAST NEUTRONS BY THE ETCH PIT METHOD OF NUCLEAR TRACK REGISTRATION IN PLASTICS. Nishiwaki, Y. and Tsuruta, T. (Tokyo Inst. Techn., Meguro ku, Tokyo). *Ilth Phys.* 19/1 (104). (1970).

L10 DETECTION OF FAST NEUTRONS BY ETCH-PIT METHOD OF NUCLEAR TRACK REGISTRATION IN PLASTICS. Nishiwaki, Yasushi (Tokyo Inst. of Tech.); Tsuruta, Takao; Yamazaki, Katsuhiko *J. Nucl. Sci. Technol. (Tokyo)*; 8: 162-6. (Mar. 1971).

Plastics, such as polycarbonate, cellulose nitrate, and cellulose acetate were irradiated with fast neutrons (2.5, 14 MeV) and a count was made of the number of etch-pits on the surfaces of the irradiated material after etching with suitable chemical reagents. The experiments proved that the number of etch-pits increases with the etching time, and that at least during the early period of etching, a close correlation seems to exist between ΔP the increment in the number of etch-pits per unit area and Δl the increment of thickness of layer removed for a common increment of etching time Δt . In other words, an approximate relation $\Delta P/\Delta l = \rho$ was observed to hold during this early period, ρ being a constant that seems to correspond to the number of etchable damages produced by fast neutron irradiation per unit volume. The value of ρ was found to correspond roughly to the estimated number of recoil carbon and oxygen atoms in a unit volume in the case of polycarbonate which consists of carbon, oxygen and hydrogen. This indicated that the etch-pits observed in polycarbonate might have developed at the sites of radiation damage caused by the recoil carbons and oxygens due to fast neutron irradiation.

L11 ENERGY THRESHOLD FOR NEUTRON DETECTION IN A MAKROFOL DIELECTRIC TRACK DETECTOR. Jozefowicz, K. (Inst. of Nuclear Research, Swierk, Poland). Nucl. Instrum. Methods; 93: No. 2, 369-70 (1971).

The energy threshold for neutron registration in a Makrofol E particle track detector due to carbon recoil atoms is estimated at about 1.2 MeV. Mono-energetic neutron irradiations confirm this prediction.

L12 (IFA-PN-24) APPLICATION OF CELLULOSE NITRATE IN FAST-NEUTRON DOSIMETRY.

Dragu, A.; Nicolae, M. (Institutul de Fizica Atomica, Bucharest (Romania)). 25 p. (1971). (In French).

A systematic study was made of the use of cellulose nitrate for the dosimetry of fast neutrons. The principle of solid detectors and the theoretical limit of their sensitivity are studied. The registration characteristics of the detector were determined. The experimental results led to the conclusion that the cellulose nitrate detector can be used for the dosimetry of fast neutrons by the utilization of elastic scattering on C, N, and O and also using (n,α) reactions. The recoil nucleus method is not suitable for dosimetry. In comparison with nuclear emulsions, the cellulose nitrate detector is more convenient and easier to use.

L13 NEUTRON IRRADIATION MONITOR FOR USE WITH Ge(Li) DETECTORS. Wilenzick, R.M. (Univ. of Texas, Houston). Nucl. Instrum. Methods; 103: No. 2, 429-30 (1972).

A fission-track dosimeter is suggested as a method of monitoring the integrated fast neutron flux incident on a Ge(Li) detector in order to prevent overexposure and subsequent radiation damage.

L14 FAST NEUTRON PERSONNEL MONITORING BY FISSION FRAGMENT REGISTRATION FROM ^{237}Np . Sohrabi, M.; Becker, K. (Oak Ridge National Lab., Tenn.). Nucl. Instrum. Methods; 104: No. 2, 409-11 (1972).

A combination of ^{237}Np ($\approx 3\text{ mg/cm}^2$) and a polycarbonate foil, to be spark-counted after etching, is used for fast neutron dosimetry between $\approx 10^{-3}$ and >10 rad.

L15 INTEGRAL METHODS OF FAST NEUTRON PERSONNEL DOSIMETRY. I. SURVEY OF APPLIED METHODS. Spurny, Frantisek (Czech. Academy of Sciences, Prague). J. Energy; 18: No. 10, 332-41 (Oct. 1972). (In Czech).

Integral methods suitable to fast neutron personnel dosimetry are reviewed. Presently applied methods

are treated in the first part of this paper. Nuclear track emulsions, sets of activation detectors, methods based on solid state track detectors, moderation of fast neutrons and gaseous ionization and semiconductor radiation detectors are discussed. Fundamental dosimetric characteristics, i.e., energy dependence, dose and dose rate range, gamma sensitivity, fading, and direction dependence are given for each of the methods.

L16 (BNL-17452) DEVELOPMENTAL STUDY OF PERSONNEL NEUTRON DOSIMETRY AT THE AGS. Distenfeld, C.H.; Klemish, J.R. Jr. (Brookhaven National Lab., Upton, N.Y.). 59 p. (Dec. 1972).

Neutron exposure at Brookhaven National Laboratory is primarily received by the occupants of the experimental facilities associated with the Alternating Gradient Synchrotron. The exposure field is composed mainly of neutrons and gamma rays of differing composition and energy spectra. Natural thorium fission track detectors and ^6LiF TLD materials are capable of responding to different parts of the neutron spectra. This provides a discrete response for each exposure spectrum. The personnel monitoring value of a fission track - TLD system depends on consistent dose equivalent response with field location. A multisphere Bonner neutron spectrometer was used to determine the maximum neutron dose equivalent. Concurrently, ^{232}Th fission track detectors and TLD (^6Li and ^7Li) were exposed. This procedure was repeated to establish the variation of calibration constants with field location. The constants weighted over field spectral variations are 3.5 mrem/spark for the Th fission track detector and 0.2 to 0.04 mrem/mR for the TLD difference detectors, depending on spectrum fitness defined as TL to track ratio. The most significant difficulty in employing thorium fission track detection involves the radioactivity of the detector and the prejudice against monitoring exposure with a radioactive dosimeter. In this regard the fission track efficiency was studied with different foil thicknesses down to about one micron. It was observed that the production of fission fragments is optimum for foils of about 5 microns and thicker. The personnel exposure from a minimally shielded foil of about 5 microns thickness (5 cm^2) is about 1.3 to 2.1 mR/40 hour week at 0.5 cm for foils about 2 to 15 years old.

L17 APPLICATION OF CELLULOSE NITRATE TO FAST NEUTRON DOSIMETRY. Dragu, A.; Nicolae, M. (Institutul de Fizica Atomica, Bucharest). Radioprotection; 7: No. 2, 87-102 (1972). (In French).

Solid state track detectors have some advantages over

nuclear emulsions in fast neutron dosimetry. The two main processes used to detect the neutrons are examined: the elastic scattering of neutrons by carbon, nitrogen and oxygen nuclei with the detection of the recoil nuclei (the theoretical yield of a Pu-Be source is 10^{-3} tracks per neutron); and interactions involving (n, α) reactions with these elements (with the same spectrum, the corresponding yields is $8 \cdot 10^{-6}$ tracks per neutron). The good agreement between the experimental results and the theoretical calculations concerning cellulose nitrate detectors indicates their suitability as fast neutron integrating devices for energies below 10 MeV with conventional neutron sources having known spectra.

L18 (ORNL-4811) APPLIED DOSIMETRY RESEARCH. Becker, Klaus; Cheka, J.S.; Craze, K.W.; Gammage, R.B.; Lee, M.H.; Nagpal, J.S.; Sohrabi, M. pp 62-73. (Sept. 1972).

Topics include the role and nature of activators in thermally-stimulated exoelectron emission (TSEE); TSEE reader development; reproducibility and stability of TSEE detectors; atmospheric, temperature, and other effects on TSEE; fading stability of solid-state (dielectric track, photoluminescent, and thermoluminescent) and film dosimeters; thermoluminescence dosimetry; and track etching of dielectric track detectors for fast neutron personnel dosimetry.

L19 Medveczky, L., and Somogyi, G. Proc. Int. Conf. Corpuscular Photogr., 6th, Florence (1966).

Title and abstract not available.

L20 ORNL-4446, DIRECT FAST NEUTRON INTERACTIONS WITH POLYMERS. Becker, K. Oak Ridge Nat. Lab. Oak Ridge, Tennessee p266 (1969).

Abstract not available.

L21 ON THE DETECTION OF FAST NEUTRONS BY THE ETCH-PIT METHOD OF NUCLEAR TRACK REGISTRATION IN PLASTICS. Nishiwaki, Y., and Tsuruta, T. Int. Congr. IRPA, 2nd, Brighton, Paper No. 101 (1970).

Abstract not available.

L22 MEASUREMENTS OF ^4He PARTICLES AND RECOIL NUCLEI PRODUCED BY HIGH ENERGY NEUTRONS IN PLASTICS. Frank, A.L.; Benton, E.V. (Univ. of San Francisco). Ref. J47 pp 441-446. (1970).

Plastic nuclear track detectors are being developed for the selective detection of high-energy neutrons (>10 MeV). Spectral information on high energy

neutrons is obtained from measurements of ^4He particles from (n, α) reactions, elastically scattered recoil nuclei, and the characteristic manner in which track densities change with absorber thickness.

L23 ANALYSIS OF THE ETCH PIT SIZE DISTRIBUTION IN MAKROFOL POLYCARBONATE FOIL AFTER FAST NEUTRON EXPOSURE. Tuyn, J.W.N.; Broerse, J.J. (Reactor Centrum Nederland, Petten, Netherlands). Ref. J47. pp 521-526. (1970).

The registration of relatively light charged particles like carbon and oxygen recoils, and α -particles in Makrofol E polycarbonate foil can be used for fast neutron dosimetry. Therefore, an analysis was made of the etch pit size distribution in Makrofol foils after exposure to mono-energetic neutrons produced by the $\text{D(d,n)}^3\text{He}$ and $\text{T(d,n)}^4\text{He}$ reactions. The dependence of the etch pit size distribution on the angle of neutron incidence and the neutron energy was studied. An empirical relation is given for the maximum diameter of the etch pits as a function of etching time and neutron energy which fits the experimental data within a wide energy range. The ratio of optical density and darkfield light intensity for exposed and etched foils was found to be strongly dependent on the etch pit size distribution.

L24 (DNA-2918-F) DEVELOPMENT OF A HIGH-ENERGY NEUTRON DETECTOR. Final Report. Benton, E.V.; Frank, A.L. (San Francisco Univ., Calif. (USA). Dept. of Physics). 47p. (15 June 1972).

A detector is being developed for the measurement of high-energy neutron fluences. A series of neutron energy thresholds are employed to yield spectral information. The method employed is to measure the fluences of elastically scattered recoil nuclei from low Z ($4 < Z < 8$) materials. Nuclear track recorders are used for this purpose. A cellulose nitrate track recorder which selectively registers recoil nuclei in the presence of ^4He particle backgrounds has been developed. Neutron energy thresholds are due to selected thicknesses of gold degrader films which separate the recoil particle radiator and the track recorder. A computer code (FLUENZ) has been written to supplement detector response measurements and to determine response over the full useful neutron energy range. Another computer code (HENDU) is being adapted to the unfolding of neutron spectra from the detector measurements.

L25 FAST-NEUTRON DOSIMETRY BY SOLID-STATE TRACK DETECTORS. Khan, H.A. (Univ. of Birmingham, Eng.). Nucl. Instrum. Methods; 113: No. 1, pp55-60. (1973).

Various plastic Solid-State Track Detectors (SSTDs) commonly used for the detection of light charged particles have been examined for their use in fast-neutron dosimetry. It is observed that more and more etched tracks are accumulated as the etching process is prolonged and that this increase in number of etchpits is quite sensitive to etching interruptions. The detection sensitivity of these detectors for various combinations of energy, etching time and angle of incidence of neutrons has been determined. Also, attempts have been made to explore the neutron spectrometric characteristics of these detectors.

L26 ORNL-TM-4460. AUTOMATIC SPARK COUNTING OF FAST NEUTRON INDUCED RECOIL PARTICLE TRACKS IN POLYMER FOILS. Becker, K. (1974).

Abstract not available.

L27 (ASTM-E-418-70-T). TENTATIVE METHOD FOR FAST-NEUTRON FLUX MEASUREMENTS BY TRACK-ETCH TECHNIQUE. 1973 Annual Book of ASTM Standards. Part 30. Philadelphia: American Society for Testing and Materials Sp. (1973).

This method covers the measurement of neutron flux by the use of fissionable materials. Fission fragments emitted by the fissionable materials during neutron bombardment penetrate a suitable recording medium, such as plastic, glass, or mica, that is in contact with the fissionable material. Appropriate etching techniques

render the path of the fragment in the recording medium visible under an optical microscope. Since measurement of the decay of radioisotopes is not involved in this method, irradiation times are limited only by the maximum number of fission fragment tracks that can be clearly distinguished without pile up: approximately $2 \times 10^5/\text{cm}^2$. The number of tracks produced can be varied by changing the amount of available target nuclei or the length of the irradiation period, or both.

L28 SENSITIVE FAST NEUTRON MONITOR USING FISSION-FOIL LEXAN DETECTORS. Rago, P.F.; Barrall, R.C.; Carter, T.G. (Stanford Univ., CA). Health Phys.; 26: No. 1, pp 102-104. (Jan 1974).

A method of monitoring neutron fluence is described using thick ^{235}U fission-track registers developed for use as a neutron area monitor. The method allows integration of neutron dose equivalent for times up to at least 1 yr. The moderated fission foil-Lexan detector has been found to be a useful method of monitoring the neutron fluence and dose equivalent around the Stanford High Energy Physics Laboratory and Ryan Laboratory Research Reactor. The present yearly dose equivalent limit for an uncontrolled area is 500 mrem and thus a very sensitive method for detecting the accumulated dose equivalent is necessary and the reported method has been found most satisfactory.

M. ALPHA EMITTER DOSIMETRY

M1 (MIT-952-5(Pt.1), URANIUM MINE DOSIMETRY AND RADIATION CONTROL. (Massachusetts Inst. of Tech., Cambridge. Dept. of Physics). pp 315-409.

A discussion of radiation dosimetry and control in uranium mines is presented. Topics include a personal alpha monitor for measuring exposure to inhaled radon daughter products, techniques for mine ventilation, tracer for marking flow in leaching holes, theoretical growth and decay of the short-lived daughter products of radon as deposited on filters, accuracy of the Kuznetz method for estimating working level values in mine atmospheres, instrumentation for in-mine, instant measuring of working level alpha radon concentrations, and basic concepts in uranium mine ventilation. An engineers' guide is also presented on the elementary behavior of radon daughters or some basic principles concerning radioactive transformations, radon

daughter product working levels, the accumulation of activity in filters, and the summation rules.

M2 PROCEDE ET DISPOSITIF POUR DECELER LA PRESENCE DE RADON ET DE SES DESCENDANTS EMETTEURS DE RAYONNEMENT ALPHA DANS UNE ATMOSPHERE. General Electric Company, Bulletin Officiel de la Propriété Industrielle, No. 33 (14/8/69, p. 11489, Br. fr. No. 1.578.275 du 19/7/68).

M3 ALPHA PARTICLE REGISTRATION IN PLASTICS AND ITS APPLICATIONS FOR RADON AND NEUTRON PERSONNEL DOSIMETRY. Becker, Klaus (Oak Ridge National Lab., Tenn.). Health Phys., 16: 113-23. (Feb. 1969).

The number and size of visible alpha particle tracks in different cellulose derivatives (nitrate, acetate,

acetobutyrate, and propionate) and other polymer foils depend mainly on the chemical structure and physical treatment of the foils, the presence or absence of oxygen during irradiation, the humidity and/or chemical pre- or post-treatment of the foils, and on the etching conditions. The stability of unetched tracks decreases close to the softening temperature of the plastics. Up to 100°C the fading in the investigated foils was small. Cellulose derivatives are most suitable for several applications, such as simple and inexpensive personnel dosimetry of radon and radon daughters in uranium mines; thermal neutron dosimetry using (n, α) reactions in B, Li, etc.; and fast neutron measurements via (n, α) reactions and recoil reactions in the foil. The sensitivity of this method is superior to the fission fragment registration method above 1 MeV, but there is a directional dependence up to -30%. Very high energy neutrons can also be measured via spallation in high-Z cover materials. Some depth-dose measurements for neutrons of different energies are reported.

M4 ALPHA PARTICLES OF NATURAL RADIO-ACTIVITY IN AIR MEASURED BY CELLULOSE NITRATE PLASTIC DETECTORS. Meyerbroeker, H. (Univ., Kiel). Ref. J18 pp VI 5-11. (1969).

A defined volume of air (related to 760 torr) has been filtered in a commercial dust collector. In front of the filter, pieces of emulsion (50 μ thick) and cellulose nitrate (50 μ thick) were placed at a distance of 1.3 cm from the filter surface. The daughter products of ^{222}Rn and ^{220}Tn have been collected on the filter. The alpha decay of the contamination was registered in emulsion and cellulose nitrate. A method first given by Somogyi, Debrecen, was used to get the energy spectrum of the alpha particles. It is possible to determine energies of normal incident alpha particles by measuring the diameters of their tracks as a function of the etching time. A peak of 7.7 MeV which is produced by alpha particles of ^{214}Po was measured. The contents of ^{222}Rn and ^{220}Th in air can be calculated using the counted number of all registered tracks. These measurements agreed with measurements performed in emulsion on the same subject. An electronic counter was used to check the measurements of the contents of ^{222}Rn and ^{220}Tn .

M5 INVESTIGATIONS ON THE PROPERTIES OF RADON DAUGHTER PRODUCTS USING CELLULOSE NITRATE AS AN ALPHA DETECTOR.

McLaughlin, J.P. (Univ. Coll., Dublin). Ref. J18 pp VI. 56-60. (1969).

Studies are being made of the attachment of radon daughter products to condensation nuclei. The mobility spectrum of the alpha emitting aerosols so formed is analyzed in a mobility spectrograph in which the plastic cellulose nitrate is used as an alpha detector. In controlled experiments, by varying the radon loading of the air, it is possible to obtain values of the attachment coefficients involved.

M6 APPLICATION OF SOLID-STATE TRACK DETECTOR FOR RADON DAUGHTER NUCLIDES AND THEIR ALPHA PARTICLES. Shinagawa, M.; Takemi, H.; Kinaga, Y.; Nishizawa, K.; Narisada, K. (Osaka Univ.). Proc. Jap. Conf. Radioisotop., 9th, Tokyo, 1969; 226-8 (1969). (In Japanese).

Dielectric track detectors were used to study the surface of electrodes of fractionally deposited thorium-228 decay products on nickel targets. The relation between the diameter of the alpha tracks of lead-212 and etching time and an alpha track spectrum of lead-212 are presented.

M7 RADON-DAUGHTER EXPOSURE MEASUREMENT WITH TRACK ETCH FILMS. Rock, R.L. (Bureau of Mines, Denver); Lovett, D.B.; Nelson, S.C. Health Phys., 16: 617-21 (May 1969).

The registration of alpha particles in cellulose nitrate dielectric films may be used as a basis for an exposure integrating device to measure the individual worker's exposure to alpha particle irradiations from radon and radon daughter products in mine atmospheres. These films are insensitive to beta, gamma and light radiations and to alpha activity plated-out on the surface. Tests in mine atmospheres indicated good correlation between film track densities and measurements of the mine atmospheres by standard filtered air samples.

M8 TRACK ETCH DETECTORS FOR ALPHA EXPOSURE ESTIMATION. Lovett, D.B. (General Electric Co., Pleasanton, Calif.). Health Phys., 16: 623-8 (May 1969).

Solid state dielectric detectors have been applied as integrating alpha particle monitoring devices to permit the estimation of alpha particle lung doses received by workers in radon-radon daughter contaminated atmospheres. The characteristics of these detectors are discussed and the results of laboratory and field testing are summarized.

M9 ALPHA DOSIMETRY AND SPECTROMETRY BY SOLID-STATE NUCLEAR TRACK DETECTOR.
Novotny, J. (*Katedra Dozimetrie a Aplikace Ionizujiciho Zareni FJFI, Prague*). *Radioisotopy*; 11: No. 5, 777-86 (1970). (In Czech).

A new method of alpha particle dosimetry and spectrometry by triacetate cellulose plastic is described on the basis of general tracks studies in the detector. The factors having influence on the registration efficiency and various dosimetric application of alpha particle detectors are discussed.

M10 (HASL-TM-71-17) EVALUATION OF MOD AND ORNL RADON DAUGHTER DOSIMETERS.
White, Otto Jr. (New York Operations Office (AEC), N.Y. Health and Safety Lab.). 41 p. (8 Oct. 1971).

Dielectric track and thermoluminescent (TL) air-flow dosimeters were evaluated for monitoring exposures of uranium miners to radon daughter products. The performance of the TL dosimeter was very good in laboratory tests but only fair in mine tests; the overall performance of the other dosimeter was unsatisfactory in both types of tests. (13 figures, 13 tables).

M11 NEW TECHNIQUES FOR DOSIMETRY. On the Application of Solid State Track Detector to Alpha Track Monitor in Uranium Mine. Kurosawa, R. (Waseda Univ., Tokyo). *Hoken Butsuri*; 7: No. 2, 105-111 (June 1972). (In Japanese).

Alpha track monitoring with solid state track detectors (SSTD) is described, which is one method of measuring average concentration of α -emitters in the environment of uranium mines. The majority of the α -emitters in uranium mine air consists of ^{222}Rn , ^{218}Po , and ^{214}Po . Since there are many α -emitters in the form of uranium ore in the mines, the detector holder itself is contaminated and influenced by them. There seems to be no better way to avoid the influence than to select an appropriate mounting position for the holder. It has been found that SSTD is practical enough for personal monitors in uranium mines if applied properly. It will require more time for the method to become established as a field monitor system because some problems must be solved, such as the manufacturing of the detectors, simple calibration methods, and track counting methods.

M12 THE RADIATION DOSE-RATES NEAR BONE SURFACES IN RABBITS AFTER INTRAVENOUS OR INTRAMUSCULAR INJECTION OF ^{239}Pu .
Bleaney, B. *Brit. J. Radiol.*, 42, p51 (1969).

Abstract not available.

M13 DIE VERWENDUNG DER NICHTPHOTOGRAPHISCHEN KERNSPURTECHNIK BEI DER BESTIMMUNG VON ALPHA-AKTIVITÄTEN.
Burger, G. *Proc. Annu. Meet. Fachverband Strahlenschutz*, 4th Berlin, p510 (1969).

Abstract not available.

M14 COLLECTION OF THE DAUGHTERS OF RADON ON A FILTER. Discrimination and Counting of the Alpha Particles Emitted by Means of the Tracks Registered in Cellulose Nitrate. Anno, J. (Centre de Physique Atomique et Nucleaire, Toulouse); Blanc, D.; Teyssier, J. L. *Ref. J47* pp 543-551 (1970). (In French).

It is known that air contains three natural radioactive gases: radon, thoron, and actinon. The first is the most abundant. In order to detect it, use is made of the fact that it has two solid daughters that decay by emitting an alpha particle: radium A and radium C'. The radium A and radium C' are collected on a filter and the number of tracks left in a solid visual detector by the alpha particles they emit is calculated. From this is deduced the activity of the radon at the moment the operation of filtration is stopped. The detector chosen is made of cellulose nitrate. It has the advantage of registering the number of tracks from alpha particles with energy less than 4 MeV. On the other hand, it is not very sensitive to light and humidity, and it is strong and not very expensive.

M15 HASL-70-3, EVALUATION OF MIT AND ORNL RADON DAUGHTER DOSIMETERS.
White, O., Jr. USAEC Health and Safety Lab., New York, N.Y. (1970).

Abstract not available.

M16 A NEW RADON PROGENY DOSIMETER.
Auxier, J.A., Becker, K., Robinson, E.M., Johnson, D.R., Boyett, R.H., and Abner, C.H. *Health Phys.*, 21, p126 (1971).

Abstract not available.

M17 STUDIES ON DETERMINATION OF RADON AND ITS DAUGHTER PRODUCTS IN THE AIR USING TRIACETATE CELLULOSE FOILS.
Domanski, T., Chrusciewski, W., and Liniecki, J. *Health Phys.*, (1972).

Abstract not available.

M18 Lovett, D.B. Gen. Electr. Nucl. Div. REP. APED-5391 (1967).

Title and abstract not available.

N. MISCELLANEOUS RADIATION DOSIMETRY APPLICATION

N1 (ORNL-4316). RADIATION DOSIMETRY RESEARCH. Auxier, J.A. (Oak Ridge National Lab., Tenn.). pp 231-69.

ACCIDENTS—gamma and neutron dosimetry intercomparison for nuclear.

HENRE OPERATION—gamma and neutron air dose distribution measurements during

IRRADIATION FACILITIES—radiation dosimetry at UT-AEC Agriculture Research Laboratory variable dose-rate

NEUTRONS—reactions with phantoms at 15.09 MeV, calculation of spectra of recoil heavy particles from

NUCLEAR WEAPONS—yields of, exploded over Hiroshima and Nagasaki

--blast and thermal effects of, at Hiroshima and Nagasaki

--human mortality and injury as result of, over Hiroshima and Nagasaki

ORNL FAST BREEDER REACTOR—operation of

PHANTOMS—neutron reactions at 15.09 MeV, calculation of spectra of recoil heavy particles from

PHOSPHORS—evaluation of organic, for gamma and neutron dosimetry

RADIATION DETECTORS—description of solid-state track alpha, for personnel monitoring of radon and radon daughters

--particle track overlapping in solid-state, probability of

--particle track formation in plastic, chemical processes involved in latent

RADIATION DETECTORS—sensitivity of organic solid-state track, effects of oxygen and humidity on

--use of organic polymer solid-state track, for fast neutron dosimetry

RADIATION DOSIMETERS—development based on thermally stimulated exoelectron emission

RADIATION DOSIMETERS, PHOTOLUMINESCENT—description of lithium borate glass

--linear energy transfer effects in

RADIATION DOSIMETRY—program of Atomic Bomb Casualty Commission in Japan for survivors of Hiroshima and Nagasaki

X RADIATION—hazards associated with vacuum electrical components.

N2 (ORNL-4446). APPLIED RESEARCH. Becker, Klaus; Boyett, R.H.; Chantaniakorn, Nongnook; Cheka, J.S.; Crase, K.W.; Johnson, D.R.; Oberhofer, M.; Robinson, E.M.; Wilson, J.F. (Oak Ridge National Lab., Tenn.). pp 251-70.

Research and developments in TSEE (thermally stimulated exoelectron emission) dosimetry are discussed including instrumentation, LET dependence of TSEE response, thermal stability (fading), pre-treatment, and relation between TSEE and thermoluminescence. Recent developments in radiophotoluminescence and thermoluminescence are outlined. Also, nuclear track registration in polymers is discussed including the damage mechanism, automatic track counting, special applications of spark counting, and miscellaneous track studies.

N3 APPLICATIONS OF THE TRACK ETCHING PROCESS IN RADIATION PROTECTION. Becker, K. (Oak Ridge National Lab., Tenn). Ref. J18 pp V.2-31. (1969).

A brief review of the more important developments in the application of track etching techniques in health physics, in particular neutron dosimetry, is given; and some previously unpublished recent results from the author's laboratory are summarized. Two methods for fast, automatic counting of alpha particle track densities in polymers are described. One is based on a flying-spot scanner, the other on a jumping-spark technique similar to the Cross method for fission fragment counting. They greatly simplify the practical application of the etching method in fast neutron dosimetry via recoil reactions (further data on dosimetric properties are given), and radon and radon daughter product personnel dosimetry for uranium miners (detector prototypes with and without forced air circulation are described). Examples of other applications of the jumping-spark counter in health physics include imaging and quantitative determination of fissile material distributions in organic samples (for instance by neutron-induced autoradiography of bone counting ^{239}Pu), and simplified measurement of fissile materials in urine, air, etc.

N4 RADIOPHOTOLUMINESCENT DETECTORS, PARTICLE TRACK DETECTORS, AND LIQUID-FILLED IONIZATION CHAMBERS. Francois, H. (CEA, Fontenay-aux-Roses, France). pp 343-60 of

Radiation Protection Monitoring. Vienna, International Atomic Energy Agency, 1969.

Some of the more recently developed methods that are now beginning to replace the use of photographic film for measuring the radiation doses received by person are reviewed. These methods are based on the use of radiophotoluminescent and radiothermoluminescent solids, ionographic tracks in insulating solids and ionization chambers filled with dielectric liquids. The characteristics of these devices and their responses to different types of radiation are reviewed, their applications to area and individual monitoring are summarized and their advantages and disadvantages are compared. It is emphasized that each device should be examined objectively while taking into account its distinctive features, its limitations and its ability to complement other devices in measuring the dose received in mixed radiation fields. (29 references).

N5 (ORNL-4584). APPLIED DOSIMETRY RESEARCH. Becker, Klaus; Boyett, R.H.; Cheka, J.S.; (and others). (Oak Ridge National Lab., Tenn.). pp 165-86. (July 31, 1970).

The emphasis on thermally stimulated exoelectron emission (TSEE) has continued, with major advances made in the sensitivity and stability of detectors, especially sintered BeO. Initial studies of neutron response characteristics have been completed, and the response per unit dose as a function of photon energy has been measured for several detector types. TSEE techniques were also applied to samples of lunar material with the objective of learning more about the thermal and radiation history of the moon. Also, registration of charged-particle tracks in insulating solids has proved to be of increasing practical value, with application in autoradiography with alpha particles and radon monitoring. More basic studies of track registration were made, with emphasis on alpha-particle registration in cellulose nitrate.

N6 NEW TRENDS IN PERSONNEL DOSIMETRY. Becker, Klaus (Oak Ridge National Lab., Tenn.). Oak Ridge Nat. Lab. Rev.; 3: No. 5, 1-5 (Fall 1970).

A general review of personnel dosimetry is presented. Etching of alpha tracks in thin plastic foils is discussed, as well as a spark technique for rendering these holes more easily visible with the use of aluminized Mylar foil. Recent results in exoelectron dosimetry, which can be used at temperatures up to 700°C, are reviewed.

N7 (CERN-71-16 (Vol. 1 and 2)). DOSIMETRY OF HEAVY CORPUSCULAR RADIATION ($Z \geq 2$) BY MEANS OF A NUCLEAR EMULSION AND SOLID TRACK DETECTORS. Haseganu, D.; Nicolae, M. (Institutul de Fizica Atomica, Bucharest (Romania)). pp 250-70. (In French).

The dosimetry of heavy corpuscular radiation is important in evaluating radiation risks around accelerators and in space flight. A problem in this work is that the abundance, though small, of particles having a very high LET makes the discrimination of heavy particles and hence the correct calculation of exposure difficult. Methods using nuclear emulsions and dielectric track detectors have been proposed, but they each have certain difficulties. In this work a method using both kinds of detectors together was developed; it should cover a large ionization range and eliminate, up to a point, previous difficulties. In order to diminish the fading of the latent image during exposures of long duration, an emulsion of high sensitivity is used, along with a discriminatory method of development that permits the development of all particles having a specific energy loss greater than a certain threshold. Experiments using these detectors are described. This method, which permits dividing the spectra of ions into ionization groups, covers an interval large enough for the energy spectra of ions present in primary cosmic rays. It is more sensitive than cellulose nitrate, being able to detect particles with $Z = 12$, while at the same time eliminating the proton background.

N8 (CERN-71-16(Vol. 1 and 2)). USE OF SOLID VISUAL DETECTORS IN DOSIMETRY OF HIGH-ENERGY RADIATIONS. Dutrannois, J. (European Organization for Nuclear Research, Geneva (Switzerland)). pp 271-81. (In French). (26 Apr. 1971).

The use of solid visual detectors (in particular, Makrofol E) for the dosimetry of high-energy radiation is discussed. Plastic detectors are extremely valuable in monitoring of personnel near accelerators because of their low sensitivity to gamma rays, electrons, and protons. A response curve for this detector for alpha particles between 0.15 and 2.7 MeV is given. The development procedure always involves a previous ozonization, followed by etching. Several bases could be used; not only does the speed of the etching increase with the coefficient of dissociation, but also the number of identifiable tracks increases rapidly following the same law. The sensitivity of Makrofol E was measured, and the results are compared with other methods.

N9 (ORNL-4720). APPLIED DOSIMETRY RE-SEARCH. Becker, Klaus; Cheka, J.S.; Crase, K.W.; Gammage, R.B.; Gillespie, F.E.; Moreno-Moreno, A.; Sohrabi, M. (Oak Ridge National Lab., Tenn.). pp 95-106. (Oct. 1971).

In Health Physics Division annual progress report for period ending July 31, 1971.

RAD DET, DIELECTRIC TRACK—particle track etching studies at ORNL, p. 104-106.

RADIATION DOSIMETERS, EXOELECTRON—development and research on BeO, at ORNL, p. 95-103

RAD DOS, THERMOLUMINESCENT—development and research at ORNL, p. 103-104.

N10 DOSIMETRIC APPLICATIONS OF TRACK ETCHING. Becker, K. (Oak Ridge National Lab., TN). pp 79-142 of *Topics in Radiation Dosimetry*. Attix, F.H. (ed.). New York: Academic Press, Inc. (1972).

Topics include damage mechanisms, latent track stability, etching procedures and detector materials, track counting, fission fragment registration, alpha particle and recoil nuclei registration, and outlook. (extensive list of references).

N11 (NASA-TM-X-2440). EXPERIMENTAL ACTIVE- AND PASSIVE-DOSIMETRY SYSTEMS FOR THE NASA SKYLAB PROGRAM. Schneider, Marion F.; Janni, Joseph F.; Ainsworth, Glenn C. (Air Force Weapons Lab., Kirtland AFB, N. Mex.). pp 958-73. (Jan. 1972).

Active and passive dosimetry instrumentation to measure absorbed dose, charged particle spectra, and linear energy transfer spectra inside the command module and orbital workshop on the NASA Skylab Program in 1972 has been developed and tested. The active dosimetry system consists of one integral unit employing both a tissue equivalent ionization chamber and silicon solid state detectors. The instrument measures dose rates from 0.2 millirad/hour to 25 rads/hour, linear energy transfer spectra from 0.8 to 42.4 keV/micron, and the proton and alpha particle energy spectra from 0.5 to 75 MeV. The active dosimeter is equipped with a portable radiation sensor for use in astronaut onbody and spacecraft shielding surveys during passage of the Skylab through significant space radiations. Data are transmitted in real time or are recorded by an on-board spacecraft tape recorder for rapid evaluation of the radiation levels. The passive dosimetry systems consist of twelve (12) hard-mounted assemblies, each containing a variety of

passive radiation sensors which are recoverable at the end of the mission for analysis. The passive dosimeters consist of calcium and lithium fluoride thermoluminescent dosimeters, special discharge ionization chambers, activation foils, Ilford G.5 and K.2 nuclear emulsions and plastic heavy particle track dosimeters. The passive dosimeters record the total mission dose from 5 millirads to 5000 rads and the linear energy transfer spectra from 0.20 to >85 keV/micron.

N12 INVESTIGATION OF DOSE FIELDS OF A CLINICAL PROTON BEAM BY MEANS OF X-RAY DEFECTOSCOPIC TRACK DETECTORS. Lomanov, M.F.; Shimchuk, G.G.; Yakovlev, R.M. *At. Energ. (USSR)*; 34: No. 3, 185-190 (Mar. 1973). (In Russian).

An application of x-ray defectoscopic track detectors for the measurement of dose distributions in clinical proton beams for therapy and neurosurgery is described. The method is based on the count of ^{238}U fission fragments producing damage tracks in a glass plate. Absorbed dose distributions in narrow beams are obtained with a resolution close to 0.2 mm. For dose measurements outside the beam, where a significant neutron background is present, it is shown that the number of fission fragments per cm^2 is nearly proportional to an equivalent dose (i.e., in terms of man roentgen-equivalent — rem) over a wide range of proton and neutron energies.

N13 NEW TECHNIQUES FOR DOSIMETRY: ETCH PIT METHOD. 1. ITS HISTORY, FUNDAMENTALS, AND FUTURE. Sakanoue, M. (Kanazawa Univ., Japan). Hoken Butsuri; 7: No. 2, 93-98 (June 1972). (In Japanese).

Since solid state track detectors have advantages which cannot be substituted by others, e.g., they are simple and detectable to fine structure, and are easily available, application has rapidly developed to many fields. The application to dosimetry in personnel and environmental control because of advantages of good selectivity for each particle beam and less background influence is discussed. Also, its use for the component analysis of heavy ions and in the search for super-heavy elements in cosmic rays is discussed.

N14 NEW TECHNIQUES FOR DOSIMETRY: ETCH PIT METHOD. 2. NEUTRON DOSIMETRY WITH SOLID STATE TRACK DETECTOR. Tsuruta, T. (Kyoto Univ., Kumatori, Japan). Hoken Butsuri; 7: No. 2, 99-103 (June 1972). (In Japanese).

The use of solid state track detectors with fission, recoil, and (n, α) reactions for neutron dosimetry is

discussed. Applications include neutron flux measurements in reactors and near the target of 14-MeV neutron generators. Commonly used plastics are discussed.

N15 (IFA-PN-26) DOSIMETRY OF HEAVY PARTICLE RADIATION ($Z \geq 2$) WITH NUCLEAR EMULSIONS AND SOLID TRACK DETECTORS.

Haseganu, D.; Nicolae, M. (Institutul de Fizica Atomica, Bucharest (Romania)). 12 p. (1972). (In French).

A method for the dosimetry of heavy particle radiation was developed using nuclear emulsions and cellulose nitrate track detectors. In order to decrease the fading of the latent image during long exposures, the use of a high-sensitivity emulsion, associated with a discriminatory development method, is proposed. The discrimination development method is described. This method for the dosimetry of heavy particle radiation, which permits the ion spectra to be divided into ionization groups, covers a very wide interval of the energy spectrum of the ions present in primary cosmic radiation. The nuclear emulsion method with the discriminatory development is superior to the cellulose nitrate method. This method can detect relativistic particles beyond $Z = 12$, even in group III, whereas the relativistic threshold of the nitrate is at $Z = 26$. The method also avoids the background of relativistic protons.

N16 HEAVY ION MONITORING OF BIOLOGICAL TARGETS BY MEANS OF NUCLEAR TRACK DETECTORS.

Benton, E.V. (Univ. of San Francisco); Curtis, S.B.; Lyman, J.T.; Tobias, C.A.; Yang, T.C.H. Ref. J47 pp 585-590. (1970).

Plastic nuclear track detectors are being utilized in heavy ion irradiation monitoring of biological targets. Recent experiments performed at the Hilac accelerator indicate that accurate extrapolation of particle trajectories from the detector into the target are possible. This allows the determination of the number and the location of particle hits in the target. Other important features of this method are discussed.

N17 STUDIES OF THE NEGATIVE PION BEAMS BY MEANS OF PLASTIC NUCLEAR TRACK DETECTORS.

Benton, E.V. (Univ. of San Francisco); Curtis, S.B.; Raju, M.R.; Tobias, C.A. Ref. J46 pp 423-428. (1970).

Plastic nuclear track detectors, cellulose nitrate, cellulose triacetate, and polycarbonate have been exposed to fast and stopping beams of negative pions. It has been ascertained that the detectors will be

useful in measuring the high LET particles emitted in the capture of the negative pions by light elements.

N18 EXPOSURE OF IONOGRAPHIC EMULSIONS AND PLASTIC DETECTORS AT THE ISR.

Research on the Magnetic Monopole and Antiparticles. Annoni, H. (CNRS, Strasbourg); Cordaillat, A. Ref. J46 pp 259-262. (1970). (In French).

The use of nuclear emulsions and dielectric track detectors for elementary particle detection at the intersection region of the CERN ISR is considered. Stopped particle detection, star production, and magnetic monopole detection are briefly discussed.

N19 (IFA-PN-26-1972) DOSIMETRY OF HEAVY CORPUSCULAR RAYS ($Z \geq 2$) WITH THE ASSISTANCE OF A NUCLEAR EMULSION AND SOLID TRACK DETECTORS.

Haseganu, D.; Nicolae, M. (Institutul de Fizica Atomica, Bucharest (Romania)). 12 p. (In French).

A method for the dosimetry of heavy corpuscular rays is presented. It is based on the use of mixed packages of nuclear emulsions and solid track detectors of cellulose nitrate. In order to reduce the fading of the latent image during exposures of long duration, the use of an emulsion of high sensitivity associated with a discriminatory development method is proposed. This allows the development of all the particles having a specific energy loss higher than a given threshold value. In this method the ion spectrum is divided into ionization groups. A very large interval of the energy spectrum of the ions present in primary cosmic rays is covered.

N20 DETECTION AND DOSIMETRY OF IONIZING PARTICLES. Cellulose Nitrate Based Type II

Kodak LR 115 Film. Barbier, J. (Societe Kodak-Pathe, Paris). Radioprotection; 8: No. 1, 51-57 (1973). (In French).

A new solid track detector consisting of Type II Kodak LR 115 film is described. Instructions for its use are given together with its limitations. A sensitivity testing method was proposed in view of the requirements encountered in the measurement of very low activities when performing human dosimetry of weakly radioactive substances. The extreme sensitivity of this film and its selectivity in relation to certain radiations and ionizing particles enable its use to be envisaged in various domains, such as, uranium prospecting or in conjunction with a neutron beam for the mapping of boron or lithium inside mineral or organic samples.

C. COSMIC RAY STUDIES

O1 (AFOSR-3030) DELINEATION OF TRACKS OF HEAVY COSMIC RAYS AND NUCLEAR PROCESSES, WITHIN LARGE CRYSTALS OF SILVER CHLORIDE. Childs, Charles B. (North Carolina. Univ., Chapel Hill and National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md.) and Lawrence M. Slifkin (North Carolina. Univ., Chapel Hill). 20p. (July 1962).

Traces of energetic charged particles, such as heavy primary cosmic rays and the products of nuclear collisions, were made visible within the interior of large, transparent crystals of silver chloride. The tracks are delineated by photoelectric formation of metallic silver along them. The technique may be useful as a convenient and distortion-free method for the study of heavy primaries and fission fragments.

O2 (AFOSR-J1553) RADIATION DETECTION BY DECORATION IN SILVER CHLORIDE CRYSTALS. Childs, Charles B. and Slifkin, Lawrence M. (North Carolina. Univ., Chapel Hill). 29p. (1963).

A review is given of the decoration of imperfections in silver halides with emphasis on volume decoration used in radiation detection. The selection, preparation, and decoration of silver chloride crystals are discussed with illustrations of decorated imperfections. Examples of primary cosmic ray particles and high energy proton collisions in silver chloride crystals are presented. The unique features of these crystals as radiation detectors are absence of humidity effects, absence of distortion, nonchemical development at room temperature, delineation of tracks in less than two hours, and crystal thicknesses greater than 3000 microns.

O3 (NASA-TN-D-1547) DELINEATION OF TRACKS OF HEAVY COSMIC RAYS AND NUCLEAR PROCESSES WITHIN LARGE SILVER CHLORIDE CRYSTALS. Charles B. Childs (North Carolina. Univ., Chapel Hill and National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Md.) and Lawrence M. Slifkin (North Carolina. Univ., Chapel Hill). Mar. 1963. 8p.

Tracks of energetic charged particles, such as heavy primary cosmic rays and the products of nuclear collisions, have been made visible within the interior of large, transparent crystals of silver chloride. The tracks are delineated by photoelectric formation of metallic silver along them. This technique may be useful as a

convenient and distortion-free method for the study of heavy primaries and fission fragments. Tracks of the same particle in emulsion and in the crystal are displayed.

O4 SIMPLE DETECTORS FOR NEUTRONS OR HEAVY COSMIC RAY NUCLEI. Fleischer, R.L.; Price, P.B.; Walker, R.M. (General Electric Co., Schenectady, N.Y.). *Rev. Sci. Instrum.*, 37: 525-7 (Apr 1966).

An amplification scheme is described for making visible the paths of heavily ionizing particles in thin sheets of certain dielectric solids. The technique makes it possible to measure a thermal dose as low as 1 neutron 1 cm^2 ($\pm 1\%$), to locate the paths of a small number of heavy particles per square meter of detector, and to produce high contrast alpha or fission autoradiographs of samples with a low activity.

O5 POSSIBLE STUDY OF THE INTENSITY OF PRIMARY COSMIC RADIATION FROM THE TRACKS OF NUCLEAR PARTICLES IN METEORITES AND TEKTITES. L.L. Kashkarov and L.I. Genaeva. *Izv. Akad. Nauk SSSR, Ser. Fiz.*, 30(11), 1799-801 (1966) (Russ).

O6 TRACKS OF IRON IONS IN OLIVINE CRYSTALS. P. Horn and W. von Oertzen. *Z. Naturforsch. (Germany)*, Vol. 22, No. 10, 1630-1 (Oct. 1967).

O7 (NASA-CR-105978) ON THE POSSIBILITY OF INVESTIGATION OF PRIMARY COSMIC RADIATION BY TRACKS OF NUCLEAR PARTICLES IN METEORITES AND TEKTITES. Kasharov, L.L.; (and others). Translated from *Izv. Akad. Nauk SSSR, Ser. Fiz.*; 30: 1790-1801 (1967). 5p.

It is shown that the investigation of primary cosmic radiation by the tracks of nuclear particles in meteorites and tektites is possible on the basis of the study of the depth of tracks and the results of measurements of the age of tektite hardening.

O8 (USNRDL-TR-67-112) CHARGED PARTICLE TRACKS IN POLYMERS. NO. 6: A METHOD FOR CHARGE DETERMINATION OF HEAVY, MULTI-CHARGED COSMIC RAY PARTICLES. E.V. Benton, and R.P. Henke. Naval Radiological Defense Lab San Francisco, Calif. 31 Oct 67, 25p.

O9 ATTEMPTS TO DETECT RELATIVISTIC

HEAVY NUCLEI WITH PLASTICS. Rama; Sundararajan, R.; Tamhane, A.S. (Tata Inst. Fundam. Res., Bombay, India). Proc. Symp. Cosmic Rays, Elem. Particle Phys. Astrophys., 10th 1967 (Pub. 1968), 92-5. Cosmic Ray Comm.: Bombay, India.

O10 A NEW METHOD FOR CHARGE DETERMINATION OF HEAVY, COSMIC RAY PARTICLES. Benton, E.V.; Henke, R.P. (Naval Radiological Defense Lab., San Francisco). Nucl. Instrum. Methods, 58: 241-4 (Jan 1968).

A method of particle track analysis is presented for accurately (± 1 in Z) measuring the charge spectrum of cosmic rays using stacks of dielectric detectors.

O11 CHEMICAL COMPOSITION OF NUCLEI OF $Z > 22$ IN COSMIC RAYS USING METEORITIC MINERALS AS DETECTORS. Lal, D.; Rajan, R.S.; Tamhane, A.S. (Tata Inst. of Fundamental Research, Bombay). Nature (London), 221: 33-7 (Jan. 4, 1969).

New techniques are discussed, which considerably extend the usefulness of meteoritic minerals in the study of the composition of prehistoric cosmic radiation.

O12 PRELIMINARY REPORT ON THE MONITORING OF HIGHLY IONIZING CHARGED PARTICLES ABOARD APOLLO VIII. Benton, E.V. (Naval Radiological Defense Lab., San Francisco); Henke, R.P.; Richmond, R.G. Ref. J18. pp V.32-40. (1969).

Each of the nine passive dosimetry packets worn by the crew of Apollo VIII contained two 190 micron layers of Lexan polycarbonate plastic. The plastics served as threshold type, heavy charged particle track detectors. Upon recovery the detectors were first sensitized using the recently discovered photo-oxidation technique, and then etched to reveal tracks of particles whose restricted energy loss rate exceeded 2.10^3 MeV cm^2/g . A flight average of about 1 tr/cm^2 was observed. In tracing tracks through from one layer to the next it is possible to say whether a particle stops in the plastic, determine the sense and direction of travel, and in many cases make estimates of Z to ± 1 unit of charge. All the particles observed had a charge in excess of 10, and 30% came to rest in the plastic. The measurements demonstrate that plastic track detectors can be conveniently and easily utilized in accurately monitoring the astronauts high LET radiation exposure on extended space missions lasting up to several years.

O13 PRELIMINARY RESULTS OF MEASUREMENTS ON TRACKS OF HEAVY COSMIC RAYS IN PLASTIC DETECTORS. Enge, W. (Univ., Kiel); Bartholoma, K.P.; Fukui, K.; Filz, R.C. Ref. J17. pp IV.52-7 of Proceedings of the International Topical Conference on Nuclear Track Registration in Insulating Solids and Applications. (1969).

A stack of 30 plastic sheets (18,250 μ thick and four 125 μ thick Zelux-polycarbonate sheets and eight 250 μ thick Daicel cellulose nitrate sheets) was flown in 1.5 g/cm^2 altitude for 10 hours from Fort Churchill, Canada. 8% of the area was covered on both sides by 600 μ thick Ilford G5 emulsions. The goal was to measure the charge spectrum and flux of all particles stopping within the stack, i.e. from Ne-ions of 110 to 190 MeV/Nuc up to Fe-ions of 180 to 320 MeV/Nuc, of all relativistic particles of $Z \geq 32$ in cellulose nitrate and of all relativistic particles of $Z \geq 55$ in Zelux. The charge of the particle can be determined by measuring its primary ionization rate as a function of its residual range in the plastic sheets. The calibration of this method is achieved for lower charges (Ne and Ar) by ions of accelerators and for higher charges by heavy primaries penetrating the emulsions and the plastic sheets. Furthermore the critical energy at higher charges can be measured. Two $10 \times 15 \text{ cm}^2$ pieces of 30 plastic sheets have been etched. In one of the pieces 40 stopping particles were found and analyzed in the plastic sheets and the emulsions. This method as well as preliminary results are discussed.

O14 STUDY OF LOW-ENERGY, HEAVY COSMIC RAYS USING A PLASTIC CHARGED-PARTICLE DETECTOR. Peterson, David Dee. Troy, N.Y.; Rensselaer Polytechnic Inst. 111p. (1969).

A new, high-resolution, charged-particle detector is used to study low-energy, heavy cosmic rays. The detector consists of thin films of Lexan polycarbonate plastic in which latent track images of penetrating charged particles can be developed to a size suitable for viewing in an optical microscope. The detector is a particular application of a discovery made near the beginning of this decade that nearly all dielectric materials have the ability to record and retain the damage produced by the passage of an energetic charged particle. Two important characteristics exist for these detectors. First, all track recording dielectric materials, including Lexan, are characterized by a threshold damage density below which charged particle tracks are not developed. The development of tracks in

plastics occurs by a chemical etching process whereby the etchant preferentially attacks the damage region along a particle path and produces an etch pit. This leads to the second characteristic, which is that for some plastics, including Lexan, the track attack rate has been related to the damage density which thus forms a basis for charged particle identification. In this work, cosmic ray nuclei provided data for which the above relation was established. In regard to this, the etch pit length and residual range are shown to be a unique function of the charge and mass of the incident charged particle. Due to the recent development of these detectors, there has existed a need to more clearly define the limitations of the detector with regard to charged particle identification. Therefore, various environmental effects on the latent track images in Lexan have been studied in detail, including the effects of age, ultraviolet light, and temperature. The development of tracks by chemical etching processes is studied in detail as well as the development of a high resolution, high magnification, optical microscope system for measuring the length of etch pits. The Lexan detector was used to determine the first elemental abundance of low energy (150 to 250 MeV/nucleon) cosmic rays with $16 \leq Z \leq 30$, which was not done previously for lack of high resolution detectors. These detailed results are compared with the more general results of various investigators and found to be in excellent agreement. And finally, the results of this work form the basis for high-resolution charged-particle identification using plastic detectors, in particular, Lexan.

O15 COMPOSITION OF COSMIC RAYS OF ATOMIC NUMBER 12 TO 30. Price, P.B. (General Electric Research and Development Center, Schenectady, N.Y.); Peterson, D.D.; Fleischer, R.L.; (and others). *Acta Phys. Acad. Sci. Hung.*; 29: Suppl. 1, 417-22(1970).

Improvements in the chemical processing of Lexan polycarbonate track detectors have made it worthwhile to collect new data on the elemental abundances of cosmic rays with $Z \geq 12$ and with energies below 300 MeV/nucleon. Lexan stacks were exposed in July, 1968, at a residual pressure of 1.8 mbar over Ft. Churchill. The new abundance distribution is consistent with the one reported by the authors previously, but the resolution is higher ($\Delta Z \approx 0.3$ charge unit, $\Delta A \approx 2$ amu at the 1 σ level) and the even-Z to odd-Z ratio is larger (≈ 4.5). The high abundance of Mn at low energy is confirmed (Mn/Fe ≈ 0.5). These measurements in

the region $Z \leq 30$ and $0.1 < \beta < 0.45$ are used to predict curves of response of Lexan to cosmic rays with $Z > 30$ and β up to 0.95.

O16 PARTICLE-TRACK IDENTIFICATION: APPLICATION OF A NEW TECHNIQUE TO APOLLO HELMETS. Fleischer, R.L.; Hart, H.R. Jr.; Giard, W.R. (General Electric Research and Development Center, Schenectady, N.Y.). *Science*; 170: 1189-91(11 Dec 1970).

The Apollo helmets are being used to record the dose of heavy particles to which astronauts are exposed on space missions. An improved method for examining and identifying the etched tracks of heavy charged particles consists of replicating tracks and measuring the etching rate as a function of position along the track. Tracks have been observed in Apollo helmets that correspond to ionized atoms heavier than iron.

O17 INVESTIGATION OF COSMIC-RAY-INDUCED TRACKS IN METEORITIC MINERALS. Kashkarov, L.L.; Genaeva, L.I.; Malishev, V.V.; Satarova, L.M.; Lavrukina, A.X. (Inst. of Geochemistry and Analytical Chemistry, Moscow). *Acta Phys. Acad. Sci. Hung.*; 29: Suppl. 1, 449-52(1970).

Two basic cosmic-ray track sources are considered: heavy primaries ($Z \geq 22$) and secondary spallation and fission products by high-energy proton interactions in meteoritic constituents. Experimental data on calibration of track lengths in meteoritic silicate minerals are presented. The investigated minerals were irradiated in the heavy ion and high-energy proton accelerators in Dubna. The results of measuring fossil track densities and length distribution in olivine crystals sampled from several regions of the pallasite Ilmaes are reported. The relation V_{VH}/VH cosmic-ray nuclei $\approx 2 \times 10^{-4}$ was obtained.

O18 CALIBRATION OF PLASTIC TRACK DETECTORS FOR USE IN COSMIC-RAY EXPERIMENTS. Blanford, G.E. Jr.; Walker, R.M.; Wefel, J.P. (Washington Univ., St. Louis). *Contracts Z800587; NAS 9-8352. Radiat. Eff.*; 5: 41-5(Aug 1970).

The response of plastic track detectors to heavy charged particles from the HILAC was determined. The rates of track etching as a function of particle charge and velocity are presented for cellulose triacetate and cellulose acetate butyrate plastic and are compared to previously measured response curves of Lexan polycarbonate and cellulose nitrate plastics. Application of these data to the determination of nuclear charges by

the method proposed by Price and coworkers is discussed. A variant of this method based on measurements of track diameters is also presented. Finally, data on the change in calibration for plastics exposed to different environmental conditions prior to etching are presented. No effect of gamma irradiation is observed up to a total dose of 18,000 roentgen. In contrast, there is a marked effect on the rate of track etching between samples stored in air at different temperatures after irradiation.

O19 PRELIMINARY REPORT ON THE MONITORING OF HIGHLY IONIZING CHARGED PARTICLES ABOARD APOLLO VIII. Benton, E.V. (Univ. of San Francisco); Henke, R.P.; Richmond, R.G. *Radiat. Eff.*; 3: 39-42 (May 1970).

Each of the nine passive dosimetry packets worn by the crew of Apollo VIII contained two 190 μ layers of Lexan polycarbonate plastic. The plastics served as threshold type, heavy charged particle track detectors. Upon recovery the detectors were first sensitized using the recently discovered photo-oxidation technique, and then etched to reveal tracks of particles whose restricted energy loss rate exceeded 2×10^3 MeV cm²/g. A flight average of about 1 tr/cm² was observed. In tracing tracks through from one layer to the next it is possible to say whether a particle stops in the plastic, the sense and direction of travel, and in many cases make estimates of z to ± 1 unit of charge. All the particles observed had a charge in excess of 10^3 , 30% came to rest in the plastics. The measurements demonstrate that plastic track detectors can be conveniently and easily utilized in accurately monitoring the astronauts' high LET radiation exposure on extended space missions lasting up to several years.

O20 (NASA-CR-114804) APOLLO HELMET DOSIMETRY EXPERIMENTS. Final Report. Comstock, G.M.; Fleischer, R.L.; Hart, H.R. Jr. (General Electric Co., Schenectady, N.Y. Research and Development Center). Nov 1970.

Recent reports by Apollo astronauts of lines of light apparently seen with the eyes closed have caused concern for the possible biological effects of heavily ionizing particles that penetrate the shielding of the spacecraft or space suit. A dosimetry experiment consists of using plastic Apollo helmets as recorders of heavy cosmic ray particles directly incident on the face and heads of the astronauts. Particle tracks are revealed by chemically etching the interior of the Lexan polycarbonate helmet to produce cone-shaped holes, which are later counted.

O21 PRIMARY COSMIC-RAY PARTICLES WITH $Z > 40$. Blanford, G.E. Jr. (Washington Univ., St. Louis); Fleischer, R.L.; Fowler, P.H.; (and others). *Acta Phys. Acad. Sci. Hung.*; 29: Suppl. 1, 423-7 (1970).

Cosmic particles with $Z > 40$ were identified by their tracks in interleaved nuclear photographic emulsions and plastic detectors. Preliminary results are presented from high altitude balloon flights of 40 hr duration, which carried a total detector area of 20 m².

O22 CHARGE DETERMINATION OF COSMIC-RAY TRACKS IN POLYCARBONATE PLASTIC DETECTORS. Enge, W. (Univ., Kiel); Bartholomae, K.P.; Fukui, K. *Trans. Amer. Nucl. Soc.*; 13: 523 (Nov 1970).

O23 PRELIMINARY RESULTS OF MEASUREMENTS ON TRACKS OF HEAVY COSMIC RAYS IN PLASTIC DETECTORS. Enge, W. (Institut fuer Reine und Angewandte Kernphysik, Kiel); Bartholomae, K.P.; Fukui, K.; Filz, R.C. *Radiat. Eff.*; 5: 123-4 (Aug 1970).

A stack of Zelux polycarbonate and Daicel cellulose nitrate sheets was flown to 1.5 g/cm² altitude. In preparation for particle identification by track measurement, the etching of Zelux (stress-relieved Lexan) and Lexan by NaOH solution was studied; the two materials were found to be identical in etching characteristics. The method was calibrated by measuring the etching rate of 10.2-MeV Ne and Ar ion tracks in Zelux as a function of restricted energy loss.

O24 HEAVY PARTICLE APOLLO ASTRONAUT DOSIMETRY. Benton, E.V. (Univ. of San Francisco, Calif.); Henke, R.P.; Richmond, R. *Trans. Amer. Nucl. Soc.*; 13: 419 (Jun-Jul 1970).

O25 IDENTIFICATION OF TRACKS OF SUPER-HEAVY COSMIC RAYS IN PLASTICS. Price, P.B.; Fleischer, R.L.; Nichols, G.E. (General Electric Research and Development Center, Schenectady, N.Y.). *Acta Phys. Acad. Sci. Hung.*; 29: Suppl. 1, 411-16 (1970).

Tracks of 70 cosmic rays with $Z \geq 40$ in stacks of plastics + nuclear emulsions flown over Palestine, Texas, were identified in three ways: by the rate of lengthening of conical etch pits along tracks in calibrated Lexan polycarbonate and in Eastman cellulose triacetate (CTA) and by the optical density of the same tracks in emulsion. CTA responds to relativistic nuclei with $Z \geq 38$ and Lexan to relativistic nuclei with $Z \geq 54$. The responses of Lexan and CTA to nuclei with $Z > 54$ correlate very well and provide evidence for a Pb peak and for one event with $Z \approx 90$. The correlation between

measurements in the plastics and in the emulsion is not as good. The charge assignment in emulsion is usually higher than that in the plastics by an amount that increases with Z . Further experiments are being planned to explain the discrepancy.

O26 PRELIMINARY RESULTS OF MEASUREMENTS ON TRACK OF HEAVY COSMIC RAYS IN PLASTIC DETECTORS. Enge, W. (Univ., Kiel); Bartholomae, K.-P.; Fukui, K.; Filz, R.C. *Acta Phys. Acad. Sci. Hung.*; 29: Suppl. 4, 391-5(1970).

A stack of 30 plastic sheets was flown at 1.5 g/cm² altitude for 10 hours from Fort Churchill, Canada. 8% of the area was covered on both sides by 600 μ m thick Ilford G5 emulsions. The aim was to measure the charge-spectrum and flux (a) of all particles stopping within the stack, i.e. from Ne-ions of 110 to 190 MeV/nucleon up to Fe-ions of 180 to 320 MeV/nucleon, (b) of all relativistic particles of $Z \geq 32$ and (c) of all relativistic particles of $Z \geq 55$. A part of the stack has been etched; 103 stopping particles were found and analyzed in the plastic sheets and the emulsions. This method as well as preliminary results are discussed.

O27 (CERN-71-16 Vol.1 and 2) PRELIMINARY RESULTS OF MEASUREMENTS OF HEAVY PRIMARIES IN THE REGION OF SUPERSONIC TRANSPORT USING PLASTIC STACKS. Aukofer, O.C.; Enge, W.; Heinrich, W.; Roehrs, H. (Kiel Univ. (West Germany). Institut fuer Reine und Angewandte Kernphysik). 512-13.(26 Apr 1971).

Intensities of thin-down hits are determined for heavy primaries with charges $Z \geq 6$ for different energy regions, e.g. for different deep layers in the plastic stack. The frequencies of thin-down hits on the surface and in the interior of the body (embryo) for an SST traveler can be determined from these results. The thin-down intensities measured in the deeper layers of the plastic stack can be directly compared with the intensities in tissue in the interior of the body, since the fragmentation probabilities and the interaction mean free paths for heavy ions can be assumed to be equal in plastic and in tissue. If the thin-down intensity in the interior of the body is calculated by replacing the tissue by an equivalent amount of g/cm² air, then values must be obtained which are too low since fragmentations occur more frequently in air than in tissue.

O28 (NASA-CR-101881) STUDY OF HIGH RESOLUTION PLASTIC TRACK DETECTORS OF HEAVY COSMIC RAYS. Final Report. Price, P.B.; Fleischer, R.L.; Miller, A.A. (General Electric Co., Schenectady,

N.Y. Research and Development Center). 63p. Aug. 1969.

Effects of ionizing radiation on surface etching rates by plastic films as a function of irradiation dose are evaluated by weight loss per unit area after the processed films are dried in a vacuum. Of the numerous plastics studied, Lexan polycarbonate in 250 μ thick sheets and Kodacel unplasticized cellulose triacetate in 125 μ sheets show the following acceptable qualities: (1) uniformity of response; (2) absence of flaws that etch preferentially; (3) retention of latent tracks; (4) outstanding optical quality of etched tracks; (5) increased etch rates at high ionization rates; (6) ultimate shelf life; and (7) sensitivity and resolving power for relativistic particles from $Z \approx 30$ up to at least 100. None of the cellulose nitrates and polyesters studied perform as well as the above mentioned plastics.

O29 RESOLUTION OF HIGH ENERGY EXTREMELY HEAVY COSMIC RAYS IN PLASTIC DETECTORS. O'Sullivan, D.; Kobetich, E.J.; Shirk, E.K.; Price, P.B. (Univ. of California, Berkeley). *Phys. Lett.*; 34B: 49-50(18 Jan 1971).

Measurements of etch pit length in Lexan plastic sheets along the trajectory of a nucleus ($Z \approx 78$, $E > 3$ GeV/nucleon) that penetrated a 10.2 g/cm² stack without interacting attest to the reliability of the response of Lexan to highly relativistic extremely heavy nuclei. For events whose velocity is known to be $> 0.9 c$, it is possible to identify nuclei with $Z \geq 70$ using only a few sheets of Lexan.

O30 IDENTIFICATION OF ENERGETIC HEAVY NUCLEI WITH SOLID DIELECTRIC TRACK DETECTORS: APPLICATIONS TO ASTROPHYSICAL AND PLANETARY STUDIES. Price, P.B. (Univ. of California, Berkeley); Fleischer, R.L. *Annu. Rev. Nucl. Sci.*; 21: 295-334(1971).

Background information on current methods of particle identification by means of dielectric track detectors is given, and the advances in knowledge of the composition of galactic and solar energetic nuclei made by using the unique features of these nuclei are discussed. Track formation and elements of particle identification from track geometry are considered. Specific detectors may be made of plastic (e.g., lexan polycarbonate, cellulose nitrate, cellulose triacetate, or cellulose acetate butyrate), glass, or minerals. Data on the composition of present-day and ancient galactic cosmic rays and of energetic solar flare particles are then presented. The use of these detectors in the search for particles with magnetic

charge and in identification of products of nuclear reactions is discussed.

031 COSMIC-RAY TRACKS IN PLASTICS: THE APOLLO HELMET DOSIMETRY EXPERIMENT. Comstock, G.M.; Fleischer, R.L.; Giard, W.R.; (and others) (General Electric Research and Development Center, Schenectady, N.Y.). *Science*; 172: 154-7 (9 Apr 1971).

Counts of tracks from heavy cosmic-ray nuclei in helmets from Apollo missions 8 and 12 show variations caused by solar modulation of the galactic cosmic-ray flux. Specific estimates of the biological damage to certain nonreplaceable cells by track-forming particles during these space missions indicate that the fraction of deactivated cells could range from a lower limit of 3×10^{-7} to an upper limit of 1.4×10^{-4} .

032 CALIBRATION AND USE OF PLASTIC TRACK DETECTORS IN THE STUDY OF EXTREMELY HEAVY COSMIC RAYS. Blanford, George Emmanuel Jr. St. Louis; Washington Univ. (1971). 205p. University Microfilms Order No. 72-9319

Different types of plastic track detectors were used in five high altitude balloon flights to collect extremely heavy cosmic rays. The detectors were flown from Palestine, Texas where their flight paths were characterized by an average vertical cut-off rigidity of 4.6 GeV. In a total exposure of $1.4 \times 10^7 \text{ m}^2 \text{ sr sec}$, 546 altitude events were observed. Two additional balloon flights were made at low geomagnetic cut-offs to collect stopping cosmic rays to calibrate the response of plastics to ionizing particles. Calibrations were also done using accelerated heavy ions. It was found that the track etching rate V_t for high energy particles is consistent with a power function $V_t = A J^m$ of the ionization J . The ionization J is given by the expression $J = C_1 (Z^{*2}/\beta^2) [\ln(\beta^2/1 - \beta^2) - \beta^2 + C_2]$ where Z^* is the effective charge of the particle, β is the ratio of the particle velocity to the velocity of light and C_2 is a term that is determined empirically. It is found that $C_2 = 30 \pm \frac{1}{2}$ for Lexan, and $C_2 = 16.2 \pm \frac{1}{2}$ for two different cellulose plastics. The ionization equation and the response function were used to determine the atomic number of 256 altitude events. These events were divided into several groups and the cosmic ray fluxes were found. The relationship of these values to present theories of cosmic ray origin is discussed. An additional 88 altitude tracks were unexpectedly found to slow down or stop in the detectors. The origin of these particles is unknown.

033 NUCLEAR TRACK RECORDINGS OF THE ASTRONAUTS' RADIATION EXPOSURE ON THE FIRST LUNAR LANDING MISSION APOLLO XI. Schaefer, H.J.; Benton, E.V.; Henke, R.P.; Sullivan, J.J. (Naval Aerospace Medical Research Lab., Pensacola, Fla. Univ. of San Francisco). *Radiat. Res.*; 49: No. 2, 245-71 (Feb 1972).

Small radiation packs containing nuclear emulsions and plastic foil detectors carried by the Apollo XI astronauts furnished a detailed record of the astronauts' radiation exposure. The exposure was found to result mainly from nuclear particles, with electrons and gamma rays contributing only about 15% to the total dose equivalent. A mission dose of 201 mrad corresponding to 402 mrems was found. By far the largest part of the dose was due to trapped protons encountered in two passes of the radiation belt on transunar and trans-Earth injection. Orientation of the plane of orbit to the geomagnetic equator was extremely favorable on both passages, resulting in very peripheral crossings of the inner belt. Mission doses on lunar missions in general, therefore, can be expected to be substantially larger. This has been borne out subsequently by Apollo XIV, which had to go through the core of the inner belt on transunar injection and accumulated a total mission-dose equivalent slightly above 1,000 mrems.

034 COSMIC RADIATION AND EVOLUTION: A LUNAR EXPERIMENTAL TEST. R. Gold, *Radiation Effects*, Vol. 1, (37, 173) 1969.

035 SOLAR PARTICLE TRACKS IN GLASS FROM THE SURVEYOR 3 SPACECRAFT. G. Croxaz and R.M. Walker, *Science*, Vol. 171, 1237 (1971).

036 TRACK ANALYSES AND URANIUM CONTENTS OF APOLLO-14 GLASSES. D. Storz, G.A. Wagner (MAX PLANCK INST-GERMANY); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15

037 DEVELOPMENT OF PLASTIC DETECTORS AND THEIR APPLICATION IN THE BIOSTACK (APOLLO 16). Enge, W. *Atomkernenergie*; 20: No. 3, 231-234 (Dec 1972). (In German).

Specific etching and analysis procedures have been developed to use industrially manufactured plastic sheets such as cellulose nitrate and Lexan polycarbonate as particle detectors. In a bio-physical experiment, called Biostack, on board Apollo 16, single biological

objects hit by heavy cosmic ray nuclei could be identified using plastic detectors. The charge and isotope spectrum of the cosmic ray nuclei with $Z = 4$ to 8 of the energy 100 to 200 MeV/Nuc has been measured using cellulose nitrate sheets. The charge spectrum of nuclei $Z = 12$ to 28 was measured with Lexan sheets.

038 (UCB-34-P-189-X-3) ASTROPHYSICAL AND SUPERHEAVY ELEMENT STUDIES WITH NUCLEAR TRACKS IN SOLIDS. Progress Report, September 1, 1971–August 31, 1972. Price, P.B. (California Univ., Berkeley, Dept. of Physics). 13 Aug 1972. 6p.

Work is reported in the following areas: nuclear reactions with relativistic heavy ions at the Bevatron, high- Z cosmic rays, heavy particles emitted in solar flares, particle-identification techniques, and theoretical astrophysics. The results of the work have been presented at conferences and submitted to appropriate journals.

039 PLASTIC TRACK DETECTORS FOR IDENTIFYING COSMIC RAYS. Price, P.B., Fleischer, R.L., Peterson, D.D., O'Ceallaigh, C., O'Sullivan, D., and Thompson, A. Can J. Phys., 46, S1149 (1968)

Abstract not available.

040 MEASUREMENT OF MULTICHARGED, LOW ENERGY, PRIMARY COSMIC RAY PARTICLES ABOARD APOLLO. Benton, E.V.; Henke, R.P. (Univ. of San Francisco). 339–346 Ref. J462 1970.

Measurements have been made of the multicharged ($Z \geq 10$), low energy (≤ 200 MeV/nucleon), primary cosmic particles during the lunar and earth orbital flights of the Apollo. The detectors consist of either two or three layers of Lexan plastic, making up the total collecting area of about 100 cm^2 per flight. Preliminary results of Apollo VIII-X flights are presented.

041 MEASUREMENTS OF TRACKS OF HEAVY COSMIC RAYS IN POLYCARBONATE PLASTIC DETECTORS. Enge, W. (Univ., Kiel); Bartholomae, K.P.; Fukui, K. 397–401 Ref. J462 1970.

Charged particle determination in polycarbonate track detectors using the restricted energy loss criterion is discussed. The charge and energy of neon ions of 110 to 190 MeV/ μc up to iron ions of 180 to 320 MeV/ μc were measured in a stack of Zelux polycarbonate plastic. The etching procedure and the method of charge determination are discussed.

042 PRELIMINARY REPORT ON THE MONITORING OF HIGHLY IONIZING CHARGED PARTICLES ABOARD APOLLO 8. Benton, E.V. Radiat. Eff., 3, p39 (1970)

Abstract not available.

043 DOSIMETRY OF SPACE RADIATIONS. Kaiser, R. (Centre de Recherches Nucleaires, Strasbourg). 591–610 Ref. J47 1970. (In French).

The requirements and factors to be considered in the selection of dosimeters for use in space are discussed. Characteristics of specific dosimeters are discussed including thermoluminescent dosimeters (lithium fluoride, calcium fluoride, and lithium borate), nuclear emulsions, and dielectric track detectors. Experimental results are given for the Mercury, Gemini and Apollo missions as well as several Soviet missions. Soviet and US dosimetric techniques are compared. Results of measurements of radiation doses in various US and USSR space missions are tabulated. The heavy ion flux measured on Apollo VII and VIII space flights are given.

044 MEASUREMENTS OF ISOTOPES IN CELLULOSE NITRATE PLASTIC DETECTORS. Beaujean, R.; Enge, W. (Univ., Kiel). 233–237 Ref. J46 1970.

To calibrate a large area stack of plastic detectors flown in Ft. Churchill to measure cosmic rays, small stacks of the same material (Daicel cellulose nitrate) were exposed to ^{10}B , ^{11}B , and ^{12}C ions of the Yale Heavy Ion Accelerator. After etching these stacks at 50°C in a 6N NaOH solution, the track lengths as a function of the residual range were measured. It is shown that in the case of small calibrated sheets, a mass resolution between ^{10}B and ^{11}B is possible. The track etching rate of Daicel cellulose nitrate is presented.

045 STUDIES OF COSMIC RADIATION AND FRAGMENTATION REACTIONS CARRIED OUT WITH VISUAL DETECTORS. Schmitt, R. (CNRS, Strasbourg). 365–384 Ref. J46 1970. (In French).

From 7th International conference on corpuscular photography and visual solid detectors; Barcelona, Spain (7 Jul 1970).

Topics include cosmic particle track discrimination owing to measurements of granularity, discrimination of relativistic tracks using absorbers and particle separation using superconducting magnetic fields. Also, fragmentation of cosmic ions, spallation reactions in ionographic emulsions, and spallation reactions in homogeneous targets are discussed.

046 STUDY OF ISOTOPES OF HEAVY COSMIC RAY NUCLEI BY MEANS OF TRACKS IN PLASTICS. Price, P.B. (Univ. of California, Berkeley). pp 63-78 of *Isotopic Composition of the Primary Cosmic Radiation*. Lyngby, Denmark; Danish Space Research Institute (1971).

A method of studying isotopic composition of cosmic rays by examination of etch pit lengths in plastic is described. It has been found that this length is dependent on ionization rate. A plot of residual range vs. cone length over the whole energy range gives a straight line plot with different slopes for each isotope, enabling analysis of the composition. Experiments in an accelerator beam, using cellulose nitrate, showed that it is possible to separate ^{10}B from ^{11}B in this way. For cosmic-ray experiments, lexan was used, being a more reproducible, though less sensitive, substance. Favorable separation of the heavier nuclei, from ^{20}Ne up to ^{238}U was achieved. For these nuclei a power law dependence of etching velocity, V_r , on ionization, I , $V_r = I^{1.5}$ is seen, though no explanation of this has yet been found.

047 (AFWL-TR-72-5). HIGH-Z PARTICLE COSMIC-RAY EXPOSURE OF APOLLO 8-14 ASTRONAUTS. Technical Report, November 1961-December 1971. Benton, E.V.; Henke, R.P. (San Francisco Univ., California (USA). Dept. of Physics). Jun 1972. 44p.

On Apollo missions, individual astronaut high Z particle exposure was measured by means of Lexan foils located in the passive dosimetry packs carried on the chest, thigh, and ankle of each astronaut. The report deals with measurements obtained on Apollo flights 8 to 14. Data are presented on the high Z track fluences, the stopping particle densities, and the particle integral LET spectra. The LET spectra, in turn, are used to calculate the fractional cell loss, FCL, of the human kidney (TI) cells arising from the high Z particle exposure. The measurements, on subsequent missions, show a consistent and a significant increase in the observed high Z particle exposure.

048 Technical Report No. 26 HEAVY COSMIC-RAY EXPOSURE OF APOLLO 17 ASTRONAUTS. Benton, E.V., and Henke, R.P. Department of Physics, University of San Francisco (1973)

Abstract not available.

P. GEOLOGICAL AND ARCHAEOLOGICAL STUDIES

P1 FOSSIL TRACKS OF CHARGED PARTICLES IN MICA AND THE AGE OF MINERALS. P.B. Price and R.M. Walker (General Electric Research Lab., Schenectady, N.Y.). J. Geophys. Res., 68: 4847-62 (Aug. 15, 1963).

After a summary of what has been learned about the registration and development of charged particle tracks from previous accelerator and reactor experiments, observations on natural background tracks are described. Tracks can occur randomly throughout a sample and in clusters, which are usually, but not always, associated with an identifiable structural feature such as an inclusion. Track densities vary from an unobservably low value to $>5 \times 10^4/\text{cm}^2$. The tracks appear most frequently in biotites and phlogopites, less often in muscovites, and still less often in lepidolites. Various possible origins of the background tracks are discussed, and it was concluded that spontaneous fission of uranium impurities is the most likely source. If the tracks arise in this way, track

counts before and after reactor irradiation give, in principle, a measure of the age of the mica specimens. Ages determined in this way for two specimens were in approximate agreement with geologic ages, thus giving strong experimental confirmation of the spontaneous fission origin of the tracks. The results also indicate that the time constant for track fading must be $>10^6$ years. The possible use of the new technique as an accurate method of dating mica samples is discussed. Track densities also give a measure of U concentrations, and values ranging from approximately 10^{-8} to 10^{-11} atom fraction, exclusive of U in inclusions and grain boundaries, which shows that the solubility of U in mica is very small were found. Calculations also indicate that cosmic-ray-induced tracks should be found in certain specimens that have very low U concentrations and that have been at a depth less than that equivalent to 1 km of H_2O for long periods of time. The picture developed for mica applies equally well to other systems.

P2 STUDY OF FOSSIL FISSION TRACES IN MICA. M. Maurette, P. Pellas, and R.M. Walker (Faculte des Sciences, Orsay, France and Laboratoire de Mineralogie du Museum, Paris). *Bull. Soc. Franc. Mineral. Crist.*, 87: 6-17 (Jan.-Mar. 1964). (In French)

Cleaved mica samples were subjected to attack by hydrofluoric acid after neutron irradiation, rendering the tracks produced by uranium fission products observable by optical microscopy. The ages of the minerals were calculated from the ratio between the densities of old traces and new traces induced by the neutron irradiation. Of eleven micas studied, only one gave an age verifying that obtained by classical dating. The other ten micas gave ages far too recent, the discrepancies increasing with the actual age. These divergences can be explained by enrichment in uranium of the micas after crystallization and thermal restoration of regions damaged by fission fragments.

P3 TECHNIQUES FOR GEOLOGICAL DATING OF MINERALS BY CHEMICAL ETCHING OF FISSION FRAGMENT TRACKS. R.L. Fleischer and P.B. Price (General Electric Research Lab., Schenectady, N.Y.). *Geochim. Cosmochim. Acta*, 28: 1705-14 (Nov. 1964).

Suitable chemical etching treatments are described for revealing fission tracks in a variety of minerals, and rules are given for distinguishing fission tracks from dislocation and other defects. Dating results are given for two hornblendes and an apatite as examples of the procedures. Track studies also give a sensitive measure of the present and past distribution of uranium atoms in minerals.

P4 (64-RL-3635M) TECHNIQUES FOR GEOLOGICAL DATING OF MINERALS BY CHEMICAL ETCHING OF FISSION FRAGMENT TRACKS. Fleischer, R.L.; Price, P.B. (General Electric Co., Schenectady, N.Y. Research and Development Center). Apr. 1964. 20p.

Experiments on mica and natural glasses have shown that the number of irradiation damage tracks created by spontaneous fission of uranium atoms in these materials is a useful measure of geological time. To extend this technique to other minerals it is necessary to be able to observe and identify fission tracks. Suitable chemical etching treatments are described for revealing such tracks in a variety of minerals, and rules are given for distinguishing fission tracks from dislocations and other defects. Dating results are given for

two hornblendes and an apatite as examples of the procedures. Track studies also give a sensitive measure of the present and past distribution of uranium atoms in minerals.

P5 A NEW METHOD FOR DETERMINATION OF THE ABSOLUTE AGE OF STONES. Umschau Wiss. Tech., 64: 314-15 (May 15, 1964). (In German).

Age of uranium-containing stones were determined by comparing fossil track of uranium fission products through the material with fresh tracks for nuclear fission after irradiation of the sample in a reactor. Photographs of microscopic images were used for the comparisons.

P6 COSMIC RAY EXPOSURE AGES OF TEKTITES BY THE FISSION-TRACK TECHNIQUE. R.L. Fleischer (General Electric Research Lab., Schenectady, N.Y.), C.W. Naeser, P.B. Price, R.M. Walker, and M. Maurette. *J. Geophys. Res.*, 70: 1491-6 (Mar. 15, 1965).

Tektites exposed to primary cosmic radiation will contain distinctive, readily identifiable, induced-fission tracks, a large fraction of which will survive the heating that occurs as tektites fall to earth. A search for such events in samples from each of the four chronological tektite groups failed to reveal such events and thereby indicates an average cosmic-ray exposure age of less than 300 yr. By further work a space exposure of 20 yr or less could be detected.

P7 AGE DETERMINATION OF TEKTITES AND OTHER NATURAL GLASSES BY MEANS OF TRACKS OF THE SPONTANEOUS FISSION OF ^{238}U (FISSION-TRACK METHOD). Wagner, Guenther A. (Max-Planck-Institut fuer Kernphysik, Heidelberg). *Z. Naturforsch.*, 21a: 733-45 (June 1966). (In German).

The fission-track age-determination method is described. A rapid and simple technique for dating natural glass is verified by experiment. Tektites and crater-glasses are dated by this method. The fission-track ages of samples of the same origin were found to be within 10%. Most of the measured ages are in good agreement with the known K-Ar ages. Explanations for the remaining discrepancies are given. The absolute ages of the natural glasses are compared with their stratigraphic ages. The classification of the tektites into four groups, according to their K-Ar ages, is corroborated by the fission-track ages. The genetic relationship between the Nördlinger Ries and the moldavites from Czechoslovakia is confirmed.

P8 AGE DETERMINATIONS OF MICAS USING FISSION TRACKS OF U. I. Berzina, I.B. Berman, and I.M. Zlotova. *Izv. Akad. Nauk SSSR, Ser. Geol.* 31(9), 10-25(1966) (Russ).

P9 ANALYTICAL METHOD FOR URANIUM AND THE AGE-DETERMINATION PROCEDURE BY USING TRACKS OF CHARGED PARTICLES. Makoto Shima, Sadayo Amano, and Akihiko Okada (Inst. Phys. Chem. Res., Tokyo). *Rika Gaku Kenkyusho Hokoku* 42(5), 205-10 (1966)(Japan).

P10 DATING BY FISSION FRAGMENT TRACKS. Hasegawa, Shunichi; Sakimura, Masahiko. (Waseda Univ., Japan). *Waseda Daigaku Rikogaku Kenkyusho Hokoku*, No. 36, 97-103 (Sept. 1966). (In Japanese).

The method of determining the ages of natural minerals by spontaneous fission fragment tracks of ^{238}U has been tested on natural muscovite mica. The development of the method as a tool for exploring the early history of the planetary system is described. Various alternative experimental procedures have shown it to be useful for improving the accuracy of the calculated age. Statistical method of measuring the tracks has newly been introduced. Stability of the tracks should be examined much more carefully than preceding experiments. The annealing dissipation from the one end of a track to the other implies the original track form. The method looks promising in spite of all the problems.

P11 ETCHABLE LINE DEFECTS IN CRYSTALS ARE NOT NECESSARILY DISLOCATIONS. Fleischer, R.L.; Walker, R.M. (General Electric Research and Development Center, Schenectady, N.Y.). *Phil. Mag.*, 13: 1083-4(May 1966).

Etch pits in natural minerals can result from radiation damage tracks due to spontaneous fission of uranium-238. Observed etch pits therefore cannot be assumed to be dislocations without satisfying various criteria

P12 OBSERVATION OF FOSSIL α -PARTICLE RECOIL TRACKS AND THEIR IMPLICATIONS FOR DATING MEASUREMENTS. Huang, W.H.; Maurette, M.; Walker, R.M. (Washington Univ., St. Louis). pp 415-29 of *Radioactive Dating and Methods of Low-Level Counting*. Vienna, International Atomic Energy Agency, 1967.

Samples that have been etched to reveal fossil fission tracks contain an accompanying high density of shallow etch pits that are clearly visible using phase con-

trast optical microscopy. A number of lines of evidence demonstrates conclusively that these shallow pits are produced by the heavy recoil nuclei accompanying α -decay of U and Th impurities. Measurement of the density of fossil α -recoil tracks, coupled with measures of the track densities induced by separate slow and fast neutron irradiations, gives a new track dating method. The new method is somewhat more complicated than the previously discovered fission track method, but is some 3×10^3 times more sensitive. Because of this enhanced sensitivity, the α -recoil method of dating has a number of potential interesting applications. It should prove particularly useful in connection with the problem of extinct isotopes in meteorites.

P13 DETERMINATION OF URANIUM CONCENTRATION AND DISTRIBUTION IN ROCKS AND MINERALS. I.G. Berzina, I.B. Berman, M. Yu. Gurvich, G.I. Flerov and Yu. S. Shimelevich. *Atomnaya Energiya (USSR)*, Vol. 23, No. 6, 520-7 (Dec. 1967). In Russian.

P14 INFLUENCE OF EXPERIMENTAL FACTORS ON DATING NATURAL AND MAN-MADE GLASSES BY THE FISSION TRACK METHOD. Kaufhold, J.; Herr, W. (Univ. of Cologne). pp 403-13 of *Radioactive Dating and Methods of Low-Level Counting*. Vienna, International Atomic Energy Agency, 1967.

In age determination work by counting fission tracks the precision, besides the statistical counting error of spontaneous and induced tracks, largely depends on exact determination of the neutron dose and close maintenance of etching conditions. Slight variations in temperature and concentrations of etch baths may lead to considerable deviations. By dating several "Early Victorian" U-stained glasses the authors discovered the fact that the spontaneous fission decay constant $\lambda_{\text{sp.f.}}$ is still not known with sufficient accuracy. Since an age of ≤ 150 yr can be inferred from the style of these glasses, the most probable value of $\lambda_{\text{sp.f.}}$ should lie closely to $8 \times 10^{-17} \text{ yr}^{-1}$. In establishing the coincidence of two geological events the uncertainty of $\lambda_{\text{sp.f.}}$ may be less important. The agreement in the age of moldavites $(14.9 \pm 1.6) \times 10^6 \text{ yr}$ and the Ries Crater glass $(14.9 \pm 1.5) \times 10^6 \text{ yr}$ was confirmed.

P15 FISSION TRACKS ON (1010) CLEAVAGES OF NATURAL APATITE CRYSTALS. A.R. Patel, M.K. Agarwal and C.C. Desai. *J. Phys. Soc. Japan*. Vol. 23, No. 3. 553-5 (Sept. 1967).

P16 A COMPARISON BETWEEN ETCHED FISSION TRACK DENSITIES ON INTERNAL AND EXTERNAL GLASS SURFACES AFTER NEUTRON IRRADIATION. Edwards, J. (Univ. of Liverpool). *Geophys. J.*, 13: 541-3 (Nov. 1967).

Fission track densities, revealed in an obsidian by etching, have been studied as a function of etching time after the obsidian had been irradiated by neutrons in a reactor. Whereas the etched fission track density observed in an external surface increases at first with progressive etching, the fission track density revealed on what was an internal surface during irradiation remains more or less independent of etching treatment.

P17 URANIUM DISTRIBUTION IN ROCKS BY FISSION-TRACK REGISTRATION IN LEXAN PLASTIC. Kleeman, J.D.; Lovering, J.F. (Australian National Univ., Canberra). *Science*, 156: 512-13 (Apr. 28, 1967).

When Lexan plastic is used to register fission tracks from thermal neutron-induced fission of uranium in rocks, a print of the rock texture is formed on the plastic surface after chemical etching. This print allows positive, rapid location of uranium-bearing phases in the rock and accurate determination of uranium abundances.

P18 THERMAL STABILITY OF URANIUM FISSION FRAGMENT TRACKS IN MUSCOVITE SINGLE CRYSTALS (EFFECT OF ANISOTROPY). Geguzin, Ya. E.; Vorob'eva, I.V.; Berzina, I.G. (Gorky State Univ., USSR). *Sov. Phys.-Solid State* (Eng. Transl.), 10: 1431-4 (Dec. 1968). Translated from *Fiz. Tverd. Tela*, 10: 1819-23 (June 1968).

An experimental study is made of the rate of change of length of regions formed in specimens of mica (muscovite) by the passage through the crystal of ^{235}U fission fragments, the regions being exposed by a corrosive etchant. The experiments involved isothermal anneals at four different temperatures: 440, 470, 500, and 530°C. It is shown that there is a pronounced dependence of the rate of shortening of a damaged region (track) on the angle (θ) between the orientation of the track and the natural cleavage plane of the crystal. The anisotropy displayed by the track healing rates is related to the anisotropy of the diffusion coefficient D in the crystal by $\nu(\theta) \sim D(\theta + \pi/2)$. A possible mechanism of track healing is suggested.

P19 ETCH FIGURES OF RADIATIONAL DEFECTS IN MINERALS. Komarov, A.N.; Skovorodkin, N.V. (Inst. Geol. Geokhronol. Dokembriya, USSR). *Dokl. Akad. Nauk SSSR* 1968, 181(3), 671-4 (Russ).

P20 TECHNIQUES FOR PROPER REVELATION AND VIEWING OF ETCH-TRACKS IN METEORITIC AND TERRESTRIAL MINERALS. Lal, D. (Tata Inst. of Fundamental Research, Bombay); Murali, A.V.; Rajan, R.S.; Tamhane, A.S.; Lorin, J.C.; Pellas, P. *Earth Planet. Sci. Lett.*, 5: 111-19 (Oct. 1968).

The revelation of fossil charged-particle tracks due to very heavy cosmic-ray nuclei ($Z > 22$) in meteoritic minerals and due to spontaneous fission fragments (^{238}U and ^{252}Cf) in terrestrial minerals was experimentally studied. Sodium hydroxide was found to be the ideal etchant for the entire group of plagioclase feldspars and several pyroxene species. Controlled etching at 120 to 160°C reveals "proper" tracks in these minerals. The tracks formed are nearly cylindrical with sharply defined tips allowing reproducible and accurate track length measurements. A useful outcome of these experiments was the observation that controlled etching can fairly unambiguously help ascertain the position of a mineral species of a single given crystal in the solid solution series under consideration: the dispersion in etching times for normal development of known terrestrial or meteoritic mineral species is small enough (in most cases) to distinguish neighboring species. As an aid to easy and complete optical viewing of etch tracks, a concentrated blue dye solution was injected into the track holes. This considerably increases the optical contrast. Coloring of etch tracks allows reliable measurements of track lengths and easy counting of track densities in the neighborhood of 10^3 to $10^4/\text{cm}^2$, as often encountered for terrestrial minerals.

P21 STUDY OF FISSION TRACES IN ZIRCON. NAGAI Jiro (Kyoto Univ. Faculty of Science). *Mem Fac Sci, Kyoto Univ, Ser Geol Mineral*, 35 (2) Dec 1968, 119-130

P22 CHARGED PARTICLE TRACKS; TOOLS FOR GEOCHRONOLOGY AND METEORITE STUDIES. Fleischer, R.L.; Price, P.B.; and Walker, R.M. in *Radiometric dating for geologists* (E.I. Hamilton; R.M. Farquhar, ed.), p. 417-435, illus., Intersci. Publ., London-New York-Sydney, 1968.

P23 THERMAL STABILITY OF TRACKS OF FISSION FRAGMENTS OF URANIUM NUCLEI IN MUSCOVITE SINGLE CRYSTALS (ANISOTROPY EFFECT). Ya. E. Geguzin, I.V. Vorob'eva, and I.G. Berzina. *Fiz. Tverdogo Tela (USSR)*, Vol. 10, No. 6, 1819-23 (June 1968). In Russian, English translation in: *Soviet Phys. Solid State (USA)*.

P24 (GEOLOGICAL AGE DETERMINATION BY THE METHOD OF FISSION FRAGMENTS TRACKS). Danis, S., Oncescu, M. and Sandru, P. *St. cerc. geol. geofiz. geogr. Geofiz.*, 7, No. 2, 151-62, 1969.

P25 ELECTRON-MICROSCOPIC OBSERVATION OF ARTIFICALLY PRODUCED ALPHA-RECOIL TRACKS IN ALBITE. Turkowsky, C. (*Technische Hochschule, Munich*). *Earth Planet. Sci. Lett.*, 5: 492-6 (Mar. 1969).

It is shown that recoil nuclei produced by alpha-decay give etchable tracks on albite (010) surfaces. After a short etching in 200°C NaOH small triangular pits are revealed in samples exposed to alpha-gravity. The pits are observed in an electron microscope. A very high natural background of similar pits was also found in unirradiated samples. The density of these background pits appears to be too high to explain as fossil alpha-recoil tracks; and they are probably caused by other defect processes in the albite.

P26 SPATIAL DISTRIBUTION AND DETERMINATION OF THE CONCENTRATION OF BORON IN MINERALS AND ROCKS. Berzina, I.G.; Malinko, S.V. (*Vses. Nauch.-Issled. Inst. Yad. Geofiz. Geokhim., Moscow, USSR*). *Dokl. Akad. Nauk SSSR* 1969, 189(4), 849-51 [*Mineral*] (Russ).

P27 CORRECTION METHOD FOR THERMALLY LOWERED FISSION TRACK AGES. Storzer, D.; Wagner, G.A. (*Max-Planck-Institut fuer Kernphysik, Heidelberg*). *Ref. J18* pp VI.20-5 (1969).

Owing to natural annealing effects, fission track ages are often lower than other radiometric ages. In long time laboratory experiments the annealing conditions were simulated for different glasses. With increasing duration or temperature applied, both number and diameter of the etched tracks decrease in a characteristic manner. By measuring the size of the fission track etch pits in a natural sample the track number reduction can be inferred and thermally lowered fission track ages may be corrected. In addition to the age correction, size distributions of fission track etch

pits reveal the thermal history of a sample. This correction method was successfully applied to tektites, related glasses, and other natural glasses. Preliminary results indicate applicability for apatites also.

P28 FISSION TRACK DATING OF ARCHAEOLOGICAL GLASS MATERIALS FROM JAPAN. Watanabe, N.; Suzuki, M. (*Tokyo Univ.*). *Nature (London)*, 222: 1057-8 (June 14, 1969).

This method of dating depends on the observation of fission tracks due to the spontaneous fission of ^{238}U atoms contained in the glass. These tracks disappear if the glass is heated above a critical temperature. It may be assumed that the density of the tracks is proportional to the lapse of time after the glass was either produced or last heated above the critical temperature, and to the density of the ^{238}U atoms in the glass. The latter can be determined from the density of tracks from ^{235}U atoms induced by bombarding the glass with a known dose of thermal neutrons. Application of the method to a piece of obsidian spearhead from Hokkaido is described and to an obsidian arrowhead and an obsidian flake from the same neighborhood, both having been subjected to a high temperature during their history. A further specimen investigated was a potsherd of a glazed bowl from Honshu. Details of the technique are given. Etching was carried out with HF, conical pits being formed where fission tracks intersected the polished surface. The density of spontaneous fission tracks was determined by counting the number of etch pits with an optical microscope. The same piece of specimen was then irradiated with thermal neutrons and the induced fission track density determined. The critical temperature for disappearance of fission tracks was also determined. Results are tabulated and discussed.

P29 FISSION TRACKS ON (001) CLEAVAGES OF TOPAZ. Patel, A.R.; Patel, M.M. (*Sardar Patel Univ., Gujarat, India*). *Indian J. Pure Appl. Phys.*; 7: 491-3 (Jul 1969).

Etching on (001) cleavages of natural topaz single crystals from Ropp Tin Mines, Nigeria, has shown two types of pits: with trails and without trails. The pits with the trails have been found to be comparatively larger in size than those without the trails. It has been observed that on matched pairs these pits have one-to-one correspondence in position, size and structure. When the negatives of matched pairs have been superposed the trails have been found to run along the same straight line. Correspondence in the

etch patterns on the two sides of an etched thin (260 μ thick) plate of the crystal has been established with respect to pits without the trails. The etch patterns have been found to be displaced with respect to each other. A cleavage face has been successively etched for different periods and the etch patterns produced have been studied at each stage of etching. The implications are discussed.

P30 SOME ANNEALING CHARACTERISTICS OF HEAVY ION TRACKS IN SILICATE MINERALS.

Maurette, M. (Washington Univ., St. Louis). Ref. J17 pp IV. 40-51 (1969).

The thermal annealing of fossil tracks stored in hypersthene crystals of the Johnstown meteorite was studied. The annealing of the tracks depends on their initial length and therefore of the charge of the incident ions. The shortest tracks are annealed at a lower temperature than the longer ones. These long tracks in turn have been found to be less thermally stable on the average than fission fragment tracks. Some difficulties in the study of the annealing of heavy ion tracks in solids were pointed out and the possibility of a thermal annealing experiment to identify the origins of the tracks stored in naturally or artificially irradiated silicate minerals, is discussed.

P31 NEW FISSION TRACK AGES OF TEKTTITES AND RELATED GLASSES. Gentner, W.; Storzer, D.; Wagner, G.A. (Max-Planck-Institut fuer Kernphysik, Heidelberg). *Geochim. Cosmochim. Acta*, 33: 1075-81 (Sept. 1969).

Fission track dating was applied to a large number of australites, Muong Nong type tektites, Darwin glasses, and Libyan Desert glasses. It was found that these glasses often have lowered fission track ages due to annealing effects. The same specimens also have smaller fission track etch pits. According to the diminishing percentage of etched fossil fission track diameters, lowered fission track ages are corrected. A mean age of 0.7 M yr was found for eleven australites, six Darwin glasses and seven Muong Nong type tektites (from Laos and Thailand), indicating a related genesis of these glasses. Uncorrected fission track ages of five Libyan Desert glasses (26.6 ± 6.3 M yr) and two bediasites (33.2 ± 8.3 M yr) were found to be different. An interrelationship between these two groups of glasses seems to be improbable from the results.

P32 CORRECTION OF THERMALLY LOWERED FISSION TRACK AGES OF TEKTTITES. Storzer, D.; Wagner, Guenther A. (Max-Planck-Inst. Kernphys., Heidelberg, Ger.). *Earth Planet. Sci. Lett.* 5(7), 463-8 1969.

P33 ETCHING FISSION TRACKS IN ZIRCONS. Naeser, C.W. (Astrogeol. Stud. Br., U.S. Geol. Surv., Menlo Park, Calif. Science 165(3891), 388 1969.

P34 ANNEALING OF FISSION TRACKS IN TEKTTITES: CORRECTED AGES OF BEDIASITES. Durrani, S.A.; Kahn, H.A. (Univ. of Birmingham, Eng.). *Earth Planet. Sci. Lett.*; 9: 431-45(11 Nov 1970).

Systematic annealing experiments have been carried out in an endeavor to obtain quantitatively reliable correction factors for the ages of tektites which may have been subjected to heat. The standardization of etching conditions, which is a prerequisite for making such corrections, is described. The application of the correction factors so obtained to a differentially-annealed bediasite gives self-consistent results. Inferences as to the possible thermal history of the bediasite are drawn from a careful analysis of the etch-pit diameter vs. track density histograms of natural as well as freshly irradiated samples. The mechanism of track shrinkage and fading is examined in some detail.

P35 CORRECTION METHOD FOR THERMALLY LOWERED FISSION TRACK AGES. Storzer, D.; Wagner, G.A. (Max-Planck-Institut fuer Kernphysik, Heidelberg). *Radiat. Eff.*; 5: 129-31 (Aug 1970).

To study track fading in glasses, one australite, one Libyan Desert glass, and one microscope slide were irradiated with thermal neutrons and then annealed for varying times between 100 and 650°C. After etching in 48% HF, the resulting track density was compared with that in unannealed samples. It was found that the track density decreases with annealing time and temperature, and that the activation energy of this effect increases with the degree of annealing. The diameter of the fission track etch pits also becomes smaller with annealing, and this effect may be used to correct fission track ages anomalously low due to partial annealing. Before annealing, the sizes of spontaneous and induced fission track etch pits are identical, but after annealing, the spontaneous ones are smaller than the induced ones. The method was used to correct thermally lowered fission track ages of tektites and related glasses, and to discover unusual thermal events.

P36 STUDY OF AGE DETERMINATION METHOD ON SOME MINERALS AND GLASSES BY FISSION-TRACK REGISTRATION. Nishimura, Susumu (Kyoto Univ.). Gansaki Kobutsu Koshō Gakkaishi; 64: No. 6, 173-81 (Dec 1970). (In Japanese).

Recent developments in the fission track method have provided geologists and archaeologists with a promising new tool with which various igneous rocks or many baked relics can be dated. However, in actual analysis of fission tracks, several questions still remain. There, the effects of various geophysical variables on track formation and stability were studied. It was found that the replica method can be used for identification of the fission tracks. Impurities in etching solution sometimes speed up the etching process, so that it is necessary to use fresh etching solutions. Fading of range distribution due to surrounding temperature to which samples have been exposed for ages, can be corrected if it is small. It was found that mica is unstable in the determination of fission track age if it has been under partial pressure. Correction to effect of natural radiation is also mentioned.

P37 LEXAN PLASTIC PRINTS: HOW ARE THEY FORMED? Kleeman, J.D.; Lovering, J.F. (Australian National Univ., Canberra). Radiat. Eff.; 5: 21-6 (Aug 1970).

Lexan plastic prints are formed when a rock section is irradiated, with a sheet of plastic held against it, in a predominantly thermal neutron flux. The print texture is made up of varying densities of tiny etch pits, which are formed when the plastic is chemically etched after irradiation. The pits are formed from short trails caused by the passage of either α particles or recoil ions from the rock material. Observed pit densities are correlated with the mineral phases producing them, and calculations of the elemental concentration of B, Li, and O required to produce them are made. The present ideas of the print formation are compared with a previous suggestion that they are produced by recoiling OH ions.

P38 SOME ANNEALING CHARACTERISTICS OF HEAVY ION TRACKS IN SILICATE MINERALS. Maurette, M. (Washington Univ., St. Louis). Contracts NAS 9-8165; Z80058T. Radiat. Eff.; 5: 15-19 (Aug 1970).

The thermal annealing of fossil tracks stored in hypersthene crystals of the Johnstown meteorite was studied. It was observed that the annealing of the tracks depends on their initial length and therefore on the charge of the incident ions. The shortest tracks are

annealed at a lower temperature than the longer ones. These long tracks in turn were found to be less thermally stable, on the average, than fission-fragment tracks. After some difficulties in the study of the annealing of heavy ion tracks in solids are pointed out, the possibility of using thermal annealing to identify the origins of the tracks stored in naturally or artificially irradiated silicate minerals is discussed.

P39 AGE DETERMINATION OF THE GLASS PORTION OF EFFUSIVE ROCKS USING SPONTANEOUS NUCLEAR FISSION TRACKS OF ^{238}U . Kraushaar, Juergen; Ackermann, Wilhelm. Aufschluss; 21: No. 9, 284-93 (1970). (In German).

Increasing interest in the fission-track method of dating prompts this report on the present state of the method. The theory and its application to geologic materials, the technology, sources of error, and some results obtained on volcanic glasses are discussed. Although the errors are still very high, here and there quite good agreement was found with the results of other dating methods. The present investigations appear to justify the hope that in the future, with consideration of the requirements for choosing the samples to be measured, this dating method will provide trustworthy results, and conversely, that reliable corrections may be established empirically for some still uncontrollable sources of error.

P40 DISTRIBUTION OF URANIUM IN URANIUM-SERIES DATED FOSSIL SHELLS AND BONES SHOWN BY FISSION TRACKS. Szabo, Barney J.; Dooley, J.R., Jr.; Taylor, Richard B.; Rosholt, John N. (U.S. Geol. Survey Denver, Colo.). U.S., Geol. Surv., Prof. Pap. No. 700-B, 90-2 (1970).

P41 CHARGED-PARTICLE TRACK REGISTRATION IN AMBER. Uzgis, E.E.; Fleischer, R.L. (General Electric Co., Schenectady, N.Y.). Nature (London); 234; No. 5323, 28-30 (5 Nov. 1971).

Amber samples may have recorded rare cosmic-ray events, such as the passage of magnetic monopoles; also, if ^{238}U spontaneous-fission-fragment trails are preserved in the amber for a sufficiently long time, then the track-dating technique should be applicable to the dating of amber deposits. The technique of etching fission-fragment tracks in this material is described, and data are given on the ionization damage threshold for track registration, on the annealing of formed tracks, and on the abundance of ^{238}U . $\text{K}_2\text{Cr}_2\text{O}_7$ in H_2SO_4 was found to be a satisfactory etching solution for amber at 40°C . Amber, being a resinous

material, could be expected to have a lower threshold than minerals or glasses, but it was to have a very high threshold. The track-formation properties of amber relative to mica as studied, using slowed ^{252}Cf fission fragments, are indicated. No tracks were formed by ion beams of ^{20}Ne at 10 MeV/amu or ^{37}Cl at 2 MeV/amu at normal incidence. Track fading is discussed, and data are given on annealing effects, from which it is concluded that tracks from ^{238}U fission would remain from the fossilisation period to the present time. The use of amber for registering monopoles is discussed. The ^{238}U content in amber samples was determined and found to be very variable. The oldest track storage age consistent with both the annealing curve and the measured ^{238}U abundance is about 350,000 yr, but they may be older.

P42 OLIVINES: REVELATION OF TRACKS OF CHARGED PARTICLES. Krishnaswami, S.; Lal, D.; Prabhu, N.; Tamhane, A.S. (Tata Inst. of Fundamental Research, Bombay). *Science*; 174: No. 4006, 287-91 (15 Oct. 1971).

A one-step, three-compound aqueous etchant was developed for revealing the tracks of charged particles in olivine. The etchant reveals tracks of small cone angle, which are equally well developed in all the crystallographic directions. The scope of fossil cosmic-ray track studies in extraterrestrial samples has thus been increased, because olivine is often an abundant constituent and because it has a higher threshold ionization for track registration and has lower uranium, thorium, and trace-element concentrations as compared with pyroxenes and feldspars. The etchant does not attack any of the principal rock-forming minerals in normal etching time, which allows a nondestructive study of fossil tracks in thin-section mounts. The study of fossil cosmic-ray tracks in olivine is particularly valuable for investigations of very, very heavy cosmic-ray nuclei and for highly irradiated samples such as those found in the lunar regolith.

P43 DETERMINATION OF U AND Th IMPURITIES IN MICA BY FISSION TRACK METHOD IN ORDER TO USE THIS MINERAL AS A DETECTOR OF HEAVY PARTICLES. Sandru, P.; Danis, Ana (Inst. of Atomic Physics, Bucharest). *Rev. Roum. Phys.*; 16: No. 1, 95-103 (1971).

Several advantages of the muscovite mica as compared to other dielectrics used in the detection of heavily ionizing particles are shown. The methods of the U determination are described and the advantages of the induced-fission track method over the fossil-fission

track method are presented. Also, the method of Th impurity determination is described. Low U and Th concentrations have been determined in this way for biotite and muscovite mica samples and values of 10^{-10} to 10^{-8} (at. U or Th/at. mica) have been found. The possibilities of measuring a U concentration of 10^{-15} (at. U/at. mica) are shown also.

P44 EVOLUTION OF THE KAPOETA HOWARDITE BASED ON FOSSIL TRACK STUDIES. Wilkening, Laurel; Lal, D.; Reid, Arch M. (Univ. of California, San Diego, La Jolla). *Earth Planet. Sci. Lett.*; 10: 334-40 (Feb. 1971).

A detailed study was made of the occurrence of high-particle-track densities in the gas-rich howardite, Kapoeta. In addition to the high-track-density pyroxene grains previously reported, feldspar grains were found with track densities and track density gradients identical with those in the pyroxenes. The spatial distribution of track-rich grains in the dark gas-rich portion of the meteorite is random. Grains that are track-rich are not a chemically distinct group; they show the same range of compositions as grains with normal track densities. The low-energy cosmic radiation that produced the high track densities and the enrichment in rare gases occurred during the extensive brecciation and mixing of Kapoeta parent materials.

P45 ASSAM: A GAS-RICH HYPERSTHENE CHONDRITE. Schultz, L. (Federal Inst. of Tech., Zurich); Signer, P.; Pellas, P.; Poupeau, G. *Earth Planet. Sci. Lett.*; 12: No. 1, 119-23 (Sept. 1971).

Concentrations and isotopic compositions of He, Ne, and Ar as well as track densities due to galactic and solar flare irradiations were determined in light and dark fractions of the L-chondrite Assam. The investigation showed Assam to be a gas rich dark-light structured hypersthene chondrite. Two percent of the L-group chondrites are now known to contain solar light noble gases (H-group: 12%, LL-group: 8%).

P46 OBSIDIAN SOURCE IDENTIFICATION BY FISSION TRACK ANALYSIS. Durrani, S.A. (Univ. of Birmingham, Eng.); Khan, H.A.; Taj, M.; Renfrew, Colin. *Nature (London)*; 233: No. 5317, 242-5 (24 Sept. 1971).

Fission track analysis was used to determine the age and uranium content of obsidians (volcanic glasses) from sources in southeast Europe and Anatolia, and from archaeological deposits in mesolithic levels at the Franchthi Cave in southern Greece. It was confirmed that the Franchthi obsidian came from the Aegean

island of Melos. This is the earliest positive indication available for maritime travel, and carries the history of seafaring back a thousand years.

P47 FISSION-TRACK AGES OF SOME INDIAN BIOTITES. Gupta, M.L.; Mehta, P.P.; Nagpaul, K.K. (Kurukshetra Univ., India). *Indian J. Pure Appl. Phys.*; 9: No. 7, 466-9 (July 1971).

Some biotite pegmatites from Bihar, Rajasthan, and Andhra Pradesh were dated by fission-track method. Attention is drawn to the necessity of measuring uranium concentration only on tight cleavages and also using samples of uniform uranium distribution. The ages thus determined agree with the ages determined using muscovite samples, as well as with the ages of orogenic metamorphic cycles delineated by other radiometric methods.

P48 DISTRIBUTION OF URANIUM AND SODIUM IN FOSSIL TRIDACNA SHELL STUDIED THROUGH FISSION TRACK METHOD AND ACTIVATION AUTO-RADIOGRAPHY. Nakanishi, T., Omura, A., Sakanoue, M., and Konishi, K. *FOSSILE*, 21, 6 (1971).

P49 URANIUM VARIATIONS IN BOVID TEETH OF THE OLDUVAI GORGE. Seitz, M.G. *Carnegie Institute Year Book* 1971.

P50 DETERMINATION OF URANIUM CONTENTS IN SOME ROCKS BASED ON FISSION TRACK METHOD. Hashimoto, Tetsuo, Hayashi, Seiju and Iwata, Shiro, *Japan Analyst*, Vol. 19 (1970).

P51 FISSION-TRACK-ALBER von DURANGO-APATITE, MEXICO. Mark, E., Pahl, M., and Mark, T.D., *Contr. Mineral. and Petrol.* 32 (1971).

P52 SPALLATION RECOIL TRACKS IN METEORITIC WHITLOCKITE, Seitz, M.G. *Carnegie Institute Year Book* (1971).

P53 PARTITIONING OF URANIUM IN THE Di-Ab-An SYSTEM BY FISSION TRACK MAPPING. Seitz, M.G. and Shimizu, N. *Carnegie Institute Year Book* (1971).

P54 FISSION TRACK LENGTH REDUCTIONS IN MINERALS AND THE THERMAL HISTORY OF ROCKS. Wagner, G.A., and Storzer, D. (Max Planck Inst. - Germany); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

P55 EFFECT OF IONIC SOLUTIONS ON FISSION TRACK STABILITY IN APATITE. Burchart, Jan, and Reimer, G.M. (Univ. of Pennsylvania); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

P56 FISSION TRACK ANNEALING BEHAVIOR OF APATITE. Mark, E., Pahl, M. and Mark, T.D. (Inst. Atomphysik-Austria); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

P57 THE GEOLOGICAL INTERPRETATION OF FISSION TRACK AGES, Wagner, Gunther A. (Max Planck Inst.-Germany); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

P58 HEAVY-ION RADIATION STUDIES IN TERRESTRIAL AND EXTRATERRESTRIAL MATERIALS. Seitz, Martin George. St. Louis; Washington Univ. (1972). *University Microfilms Order No. 72-17, 959. 132 p.*

Analysis of radiation effects is undertaken to identify changes from solar and galactic radiation that might be expected in extra-terrestrial samples. X-ray observations reveal macroscopic crystal distortion in terrestrial samples of pyroxenes, feldspars, quartz, apatite, epidote, and muscovite irradiated with 10.4-MeV/amu argon ions to doses of $2.0 \times 10^{13} \text{ cm}^{-2}$. No distortion is seen in olivine. The distortion occurs to a lesser degree with 10.4-MeV/amu neon and not at all with 7-MeV/amu helium irradiations to doses of 4.0×10^{13} and $9 \times 10^{15} \text{ ions/cm}^2$, respectively. The distortion increases with decreasing energy of the irradiation, and, at any energy, is proportional to dose. Using a model of crystal distortion, the experimental results are better explained by the damage being proportional to the primary rate of ionization of the incident ions rather than to the number of displacements produced by close nuclear encounters. Some irradiated minerals show lattice-parameter changes. Sometimes, crystal fracturing results from severe distortion or from strain caused by the ions that have come to rest in the minerals. The minerals show different sensitivities to radiation and are classified accordingly. Except for fracturing, radiation effects recover by annealing. Both lunar and meteoritic materials show crystal distortion similar to that produced by heavy-ion irradiations. However, the distortion does not anneal, demonstrating that it is not of radiation origin. The other radiation effects are not observed in any of

the lunar materials, including the very fine material (~20 microns) of the lunar soil where the largest radiation effects are expected. This lack of pronounced radiation effects is consistent with current ideas of the radiation history of lunar and meteoritic materials. In the second part of the thesis (fission tracks in lunar samples), apatite, whitlockite, and zircon appear to be of equal importance as uranium sources in the heterogeneous rock 12013. A new titanium-zirconium phase is estimated to contain about 10% of the rock's uranium. The more chemically equilibrated rock 12040 has about 80% of the uranium in whitlockite. Baddeleyite and the new zirconium-titanium phase contain most of the remaining uranium. The potassium-rich residual liquids of rock 12040, with ~7 ppm uranium, contain most of the uranium-bearing grains; thus the well-defined potassium-uranium correlation in whole lunar rocks is valid for 12040 on a microscopic scale as well. Thorium-uranium ratios in minerals of 12013 range from 0.2 to 20 while whitlockites of 12040 have thorium-uranium ratios near 3.7, close to the natural abundance ratio. If plutonium acts chemically like thorium, some previously measured plutonium-uranium ratios for the early solar nebula may be too high. Fossil-track densities in whitlockite of four lunar rocks are found to be higher than expected from primary cosmic rays and spontaneous fission of uranium. Proton irradiations at 28 GeV show that the excess tracks are accountable for from high-energy spallation products. Plastic replicas of the fossil densities are able to isolate primary cosmic rays and fission tracks and allow fission-track dating. This dating technique promises to be an important tool for the search for exotic rock fragments of the lunar soil.

P59 P7-6495. ON THE ORIGIN OF TRACKS OF FISSION FRAGMENTS IN LEAD GLASSES. Flerov, G.N., Perelygin, V.P., Otgonsuren, O.

P60 REMARKS ON FISSION-TRACK DATING IN DIELECTRIC SOLIDS. Somogyi, G.; Nagy, M. (Magyar Tudományos Akadémia Atommag Kutató Intézete, Debrecen, Hungary). *Radiat. Eff.*; 16: No. 3-4, 223-231 (Oct. 1972).

Some factors (long etching and annealing effects) are experimentally and theoretically studied, neglect of which has resulted in low ages in the fission track datings of geological samples. The empirical correction methods, proposed by Storzer and Wagner (Earth

Planet. Sci. Letters; 5:463 (1969)) concerning these factors, are reinvestigated. It is shown that these corrections can also be calculated theoretically. The problem is considered in fuller detail for glass samples. A new method is proposed for the correction of the thermally reduced fission-track ages of glasses. The same method involves also the possibility of differentiating the fossil tracks from the spontaneous fission of uranium and super-heavy nuclei in the case of fragments entering the glasses at arbitrary angles.

P61 SEARCH FOR SUPERHEAVY ELEMENTS IN TERRESTRIAL MINERALS AND COSMIC RAY INDUCED FISSION OF HEAVY ELEMENTS. Geisler, F.H. St. Louis; Washington Univ. (1972). 175 p. University Microfilms Order No. 73-5039.

A new low-level nuclear fission counting technique was developed. The counting method employed thin Kimfol plastic detectors to record the fission fragments. The etched fission tracks were located by a pulse sparking technique. This technique has an improved signal to noise ratio over previous techniques of three million times with respect to spurious background tracks in the plastic. The low-level counting in the superheavy element search was performed deep underground. Forty samples, comprising a wide class of minerals, were examined. No spontaneous fission events above the background level were observed. An upper limit of 6×10^{-13} g/g was set in a typical sample for the concentration of any such nuclei with a half-life of 10^8 years. Three uranium determination methods were developed. The following upper limits on the decay rate of spontaneous fission can be set from the upper limits on the activity of the heavy element minerals: $(2.6 \pm 2.6) \times 10^{-23}$ yr⁻¹ for lead, $(2.6 \pm 1.6) \times 10^{-23}$ yr⁻¹ for mercury, and $(4.2 \pm 4.2) \times 10^{-21}$ yr⁻¹ for thorium. Additional low-level fission counting experiments were performed at sea level and at a small depth underground. The theoretically predicted cosmic-ray-induced fission rate of lead agrees with the measured rate; however, there is a large discrepancy in the two thorium values, which implies a smaller cosmic-ray neutron flux in the 1 MeV to 50 MeV region than has been calculated theoretically. Spontaneous fission activity observed by CERN scientists in a heavy element target bombarded with high-energy protons has been previously interpreted as evidence for superheavy element production; however, the upper limit on the

spontaneous fission activity of a similarly prepared sample in this experiment suggests that contamination was the source of the activity observed in the CERN work. Previous Russian work detected fossil fission events in old lead glass; however, this experiment casts doubt on the assignment of the fission decays to a superheavy element.

P62 FISSION TRACK DATING, TECHNIQUES AND PROBLEMS. Fleischer, R.L., and Hart, H.R. Gen. Electr. REP. 70-C-328 (1970).

Abstract not available.

P63 GLASS DATING BY FISSION FRAGMENT TRACKS. Fleischer, R.L., and Price, P.B. J. Geophys. Res., 69, p331 (1964).

Abstract not available.

P64 Fleischer, R.L., Price, P.B., and Walker, R.M. 7th International Congress on Glass (Gordon & Breach, New York). International Commission on Glass, Vol. 2, Paper 224 (1965).

Title and abstract not available.

P65 URANIUM CONTENTS OF ANCIENT MAN-MADE GLASS. Fleischer, R.L., and Price, P.B. Science, 144, p841 (1964).

Abstract not available.

P66 URANIUM DISTRIBUTION STUDIES BY FISSION TRACK REGISTRATION IN LEXAN PLASTIC PRINTS. Kleeman, J.D., and Lovering, J.F. Atom. Energy Aust., 10 (4), 3 (1967).

Abstract not available.

Q. STUDY OF EXTRATERRESTRIAL MATERIALS

Q1 HEAVY ION TRACKS IN THE MINERALS OF THE SAINT SEVERIN CHONDRITE. Cantelaube, Y. (Laboratoire de Mineralogie du Museum d'Histoire Naturelle, Paris); Maurette, M.; Pellas, P. pp 215-29 of Radiosactive Dating and Methods of Low-Level Counting. Vienna, International Atomic Energy Agency, 1967. (In French).

Heavy ion tracks have been detected, after chemical treatment, in hypersthene, plagioclase and whitlockite crystals contained in the stony meteorite (amphoterite) which fell on June 27, 1966, at Saint Severin (Charente). By studying the variations in track density with depth, the geometrical characteristics of the tracks and the uranium concentrations in the crystals, it was possible to distinguish the tracks due to heavy ions from the primary flux of cosmic radiation ($Z > 20$) from those due to fragments produced by the spontaneous fission of ^{238}U and the extinct nuclide ^{244}Pu . On the basis of the data on the variation with depth of track densities in the hypersthene, it was possible to make an evaluation of the ablation rate in the Earth's atmosphere ($\approx 30\%$) the maximum value corresponding to a spatial erosion rate of zero—as well as of the upper limit of the erosion rate in space ($< 0.5 \text{ cm}/10^6 \text{ yr}$) for the minimum ablation rate. By measuring the spontaneous fission track densities in whitlockite crystals shielded from the effects of the heavy ions from the primary flux, the value of ΔT_0 was estimated, the time interval between the end of nucleosynthesis and the moment when the whitlockite crystals begin to retain the spon-

taneous fission tracks. The estimated value was $400 \times 10^6 \text{ yr}$.

Q2 DISCOVERY OF AN EARLY IRRADIATION OF METEORITE CRYSTALS USING SCANNING ELECTRON MICROSCOPY. Poupeau, G.; Pellas, P.; Lorin, J.C. (Museum National d'Histoire Naturelle, Paris. CNRS, Paris) Ref. J18. pp VII.26-40. (1969) (In French).

Heavy-ion tracks recorded in meteoritic crystals (from Kapoeta and Jodzie howardites) were studied using scanning electron microscopy. Track densities measured by this method are shown to be the same as those observed with high-magnification optical microscopy. Specific techniques for track revelation in crystals are given as well as criteria for track identification. Improved resolution gives more information on characteristics of the low-energy particle irradiation found recently in dark portions of gas-rich meteorites. This low-energy particle flux (in the MeV/n range) is thought to have been registered in pyroxene crystals $\approx 4.5 \text{ b.y. ago}$ and to be of solar origin.

Q3 NUCLEAR INTERACTION TRACKS IN MINERALS AND THEIR IMPLICATIONS FOR EXTRATERRESTRIAL MATERIALS. Crozaz, G.; Hair, M.; Maurette, M.; Walker, R. (Washington Univ., St. Louis). Ref. J18. pp VII.41-54. (1969).

The geometrical characteristics and the thermal stability of the interaction tracks by protons and α particles in mica and also in minerals found in meteorites or which are likely to be found in lunar materials

were studied. The energy and the fluxes of the ions were chosen to simulate exposures of $>10^3$ years in the light component of solar-flare cosmic rays. This study is the first part of a general survey that should help to predict the characteristics of the track distribution that can be expected from an exposure of meteoritic or lunar materials to solar cosmic rays.

Q4 FOSSIL PARTICLE TRACKS IN EXTRA-TERRESTRIAL MATERIALS. Walker, R.M. (Washington Univ., St. Louis). Ref. J18. pp VII.2-25. (1969).

After reviewing the current state of knowledge for meteorites, the study of tracks in lunar samples is considered. New kinds of tracks, yielding completely new kinds of physical information can be expected. Perhaps the greatest promise is the possibility of tracing out the past history of solar activity.

Q5 HIGH-VOLTAGE ELECTRON MICROSCOPE STUDIES OF FOSSIL NUCLEAR-PARTICLE TRACKS IN EXTRATERRESTRIAL MATTER. Borg, J. (CNRS, Orsay, France); Dran, J.C.; Durrieu, L.; Joubert, C.; Maurette, M. *Earth Planet. Sci. Lett.*; 8: 379-86 (Jul 1970).

Fossil nuclear-particle tracks in lunar and meteoritic materials were searched for with the 1-MeV electron microscope of the Institut d'Optique Electronique du C.N.R.S., Toulouse, both before and after a chemical etching of the samples. Evidences for very high densities of nonetchable tracks of two different kinds have been observed only in the finest fraction (<400 mesh) of the lunar soil from the Apollo 11 and 12 missions but not in the type I carbonaceous chondrite Orgueil, in the dark part of the solar type gas-rich Pessanoe enstatite achondrite, or in crystals extracted from lunar rock 10047. These track densities can exceed by a factor of 100, the densities of etched tracks measured in the same lunar soil samples. Some implications of the present results concerning lunar and meteoritic matter, the ancient fluxes of solar particles, and solid-state physics are briefly discussed.

Q6 ACCELERATOR IRRADIATIONS OF MINERALS: IMPLICATIONS FOR TRACK FORMATION MECHANISMS AND FOR STUDIES OF LUNAR AND METEORITIC MATERIALS. Seitz, M. (Washington Univ., St. Louis); Wittels, M.C.; Maurette, M.; Walker, R.M.; Heckman, H. Ref. J18. pp VII.55-67. (1969).

Natural crystals of feldspars, pyroxenes, quartz, and

apatite were irradiated in the Berkeley HILAC with neon and argon ions of up to 10.2 MeV/amu with maximum doses of 1.6×10^{13} argon ions/cm² and 4.0×10^{13} neon ions/cm², respectively. The samples were thinned to thicknesses near 30 microns, stacked to form the target, and then immersed completely in the ions beams. X-ray and optical observations revealed: a crystal distortion and curvature with the argon irradiation similar to that produced in mica; a lesser effect from neon bombardment; a fracturing of the crystal samples, which depended on the total dose and energy of the incident ion; polygonized structures produced when either neon or argon ions (with sufficiently high concentration) were trapped within the crystals. The interpretation of the measurements, their correlation with the mechanisms of track formation, implications concerning the alteration of the lunar surface due to solar particles, and the exposure of lunar and meteoritic material to solar-flare cosmic rays are discussed.

Q7 NUCLEAR TRACK STUDIES IN EXTRA-TERRESTRIAL MATERIALS. R.M. Walker (Washington U.) Transactions 1972 Annual Meeting of The American Nuclear Society, Vol. 15

Q8 FOSSIL PARTICLE TRACKS IN EXTRA-TERRESTRIAL MATERIALS, R.M. Walker, *Radiation Effects*, Vol. 3, 239 1970.

Q9 CHARGED PARTICLE TRACK STUDIES IN LUNAR ROCK 12013, D.S. Burnett, M. Monnin, M. Seitz, R. Walker, D. Woolum and D. Yuhas, *Earth and Planetary Science Letters* 9 (2), 127 (1970).

Q10 NUCLEAR TRACK STUDIES OF ANCIENT SOLAR RADIATIONS AND DYNAMIC LUNAR SURFACE PROCESSES, G. Crozaz, U. Haack, M. Hair, M. Maurette, R. Walker and D. Woolum, *Proceedings of the Apollo 11 Lunar Science Conference*, Vol. 3 1970.

Q11 NUCLEAR TRACK STUDIES OF DYNAMIC SURFACE PROCESSES ON THE MOON AND THE CONSTANCY OF SOLAR ACTIVITY, G. Crozaz, *Proceedings of the Second Lunar Science Conference*, Vol. 3, 1971.

Q12 LUNAR ASTROLOGY-U-Th DISTRIBUTIONS AND FISSION-TRACK DATING OF LUNAR SAMPLES, D. Burnett, M. Monnin, M. Seitz, R. Walker, and D. Yuhas, *Proceedings of the Second Lunar Science Conference*, Vol. 2, (1971).

Q13 ANGULAR AZIMUTHAL DISTRIBUTIONS OF HIGH-ENERGY COSMIC RAYS IN LUNAR SILICATE MINERALS. Van Loon, L.G. (Univ. of New South Wales, Kensington). *Lett. Nuovo Cim.*, 2: No. 23, 1179-82(4 Dec 1971).

An examination of pieces of a lunar rock with a major axis of 15 cm and a minor axis of a cm has shown the presence of an abundance of cosmic-ray tracks. The sharply defined directions and their occurrence in multiple parallel beams open up the possibility of measuring distributions of primary cosmic rays in lunar materials by means of the interactions they cause. The experimental procedure, track distribution, interesting events, and cosmic-ray spectrum are described.

Q14 DATING OF MECHANICAL EVENTS BY DEFORMATION-INDUCED ERASURE OF PARTICLE TRACKS. Fleischer, R.L.; Comstock, G.M.; Hart, H.R. Jr. (General Electric Research and Development Center, Schenectady, N.Y.). *J. Geophys. Res.*, 77: No. 26, 5050-3(10 Sep 1972).

Natural fine-scale plastic deformation of lunar pyroxenes has been observed to fragment pre-existing charged-particle tracks. An observer using only an optical microscope would see only the tracks formed later and hence would measure the time when deformation occurred. In one sample the deformation was estimated to have occurred 20 to 25 Myr ago.

Q15 STUDY OF THE VESTIGIAL RECORDS OF COSMIC RAYS IN LUNAR ROCKS USING A THICK SECTION TECHNIQUE. Bhandari, N.; Goswami, J.N.; Lal, D.; Macdougall, D.; Tamhane, A.S. (Tata Inst. of Fundamental Research, Bombay). *Proc. Indian Acad. Sci., Sect. A*, 76: No. 1, 27-50(Jul 1972).

An experimental technique has been developed for systematic measurements of fossil tracks along selected planes cut from grains and rocks. With controlled etching, the technique allows successive revelation of

tracks in different minerals in the same section, a typical sequence being olivine, anorthite, clinopyroxene. It thus becomes possible to study precisely the cosmic-ray track density variations over dimensions much greater than those of individual crystals. The technique also provides accurate information on the relative recording characteristics of different minerals present in a rock and cosmic-ray tracks can be studied with a minimum interference of tracks due to spontaneous fission of uranium and transuranic elements.

Q16 URANIUM DISTRIBUTION IN BASALT FRAGMENTS OF FIVE LUNAR SAMPLES. Thiel, K.; Herr, W.; Becker, J. (Univ., Cologne). *Earth Planet. Sci. Lett.*, 16: No. 1, 31-44 (Sep 1972).

The U-distribution in selected basaltic fragments from lunar fines 10084, rocks 12021 and 12053, and breccias 14305 and 14321 was studied by means of fission tracks in mica detectors. U-enriched mineral phases were localized with an accuracy of better than 1 μ m by applying a photographic mapping technique. Identification and elemental analysis were carried out using an electron microprobe. Phases of high U-content were identified as apatite (30 to 280 ppm), SiO₂-rich glasses (3 to 150 ppm) or fine-grained Zr-containing minerals of grain sizes < 1 μ m (50 to 450 ppm). These U-enriched phases preferentially occur in the mesostasis. An inverse relationship was found between the U-concentration and the volume of the mesostasis regions. The ratio of the U-contents of the residual liquid and the major phases is comparable with that found in terrestrial basalts.

Q17 VERY HEAVY SOLAR COSMIC RAYS: ENERGY SPECTRUM AND IMPLICATIONS FOR LUNAR EROSION. Fleischer, R.L., Hart, H.R. Jr., and Comstock, G.M. *Science*, 171, p1240 (1971)

Abstract not available.

R. REACTOR APPLICATIONS

R1 (KAPL-M-6556). ASSESSMENT OF INHOMOGENEITY OF SOLID REACTOR FUELS BY FISSION-TRACK COUNTING. Covert, A.S.; Schultz, W.W. (Knolls Atomic Power Lab., Schenectady, N.Y.). 13 p. (Apr. 1966).

A new method for measuring homogeneity of U and/or Th in nuclear fuels was developed. The method was applied to mixed oxide fuels. Fission tracks in

insulating materials are used as the basis for the measurement. Statistical methods of testing for randomness are suggested.

R2 (GEAP-5002). FISSION FRAGMENT DAMAGE TO TYPE-304 STAINLESS STEEL FUEL CLADDING. Rosenbaum, H.S.; Armijo, J.S.; Wolff, U.E. (General Electric Co., San Jose, Calif. Atomic Power Equipment Dept.). 33 p. (Jan. 1966).

During the examination of irradiated cladding from experimental fuel rods, the inner surface of the type-304 stainless steel cladding was found to have a duplex-layered structure 5 to 10 μ thick. This structure is within the range of recoiling fission fragments and is believed to be a fission-damaged zone. Examination of the zone by metallography, electron microscopy, and with colloidal magnetite showed that both layers of the duplex structure are austenitic and have the same crystallographic orientation as the underlying austenitic matrix. Both layers are harder than the underlying matrix, yet they are readily distinguished by their different etching characteristics. Possible reasons for the existence of the duplex, rather than a single layer, are discussed.

R3 SOLID-STATE NUCLEAR TRACK DETECTORS IN REACTOR PHYSICS EXPERIMENTS. Tuyn, J.W.N. (Institutt for Atomenergi, Kjeller, Norway). Nucl. Appl., 3: 372-4 (June 1967).

Solid-state nuclear track detectors can be used in various reactor physics experiments to measure fission density distributions and fast- and thermal-neutron flux distributions. The use of a microdensitometer to determine track densities on the surface of irradiated detectors has proven to be very convenient. For fast neutron detection, comparison with activation detectors shows a higher sensitivity for the solid-state nuclear track detectors.

R4 (ANL-7310) ACCURATE FISSION RATE MEASUREMENTS BY FISSION TRACK COUNTING. Armani, R.J., Gold, R., Roberts, J.H. Reactor Physics Division Annual Report, July 1, 1966 to June 30, 1967 (1968). S.380-3.

R5 (ANL-7410). EXPERIMENTAL TECHNIQUES AND FACILITIES. (Argonne National Lab., Ill.). pp 339-86.

COMPUTERS - modifications to ANL Reactor Physics Laboratory DDP-24 on-line data collection, description of

-electronics for proton-recoil proportional counting using, description of

CRITICAL ASSEMBLIES - neutron fission rate measurements in fast Assembly 5 of ZPR-6, use of solid state track recorders for
-control of, equations for time-optimal direct digital

DATA PROCESSING SYSTEMS - circuits for sampling-oscilloscope, ANL Reactor Physics Laboratory

-circuit diagrams for neutron spectra, preamplifier and discriminator

GAMMA SPECTROSCOPY -measurements for continuous incore, Compton recoil continuum

NEUTRONS - fission rate measurements in ZPR-6 Assembly 5, results of solid state track recorder

-flux measurements in reactors, schematics for line-timer corrections for foil-counting data for

PHOTOMULTIPLIER TUBES - noise characteristics of, method for evaluating optimum

-timing characteristics of, method for evaluating

PREAMPLIFIERS-circuits for nuclear detector data-processing, noise-minimization input

PULSE DISCRIMINATORS - circuits for absolute coincidence, timing characteristics for

RADIATION DETECTORS - efficiency for single and coincidence counting, derivation of equations for
-line-timer automatic count corrections for, circuits for

RADIATION DETECTORS, DIELECTRIC TRACK-neutron fission rate measurements in ZPR-6 Assembly 5 using uranium foil - mica

RADIATION DETECTORS, PROPORTIONAL - neutron spectral measurements using proton-recoil, description of electronics for in-core
-finite-size effects in proton-recoil, spectral distortion from

REACTOR CONTROL SYSTEMS - dynamic characteristics of computerized, use of polarity-correlation algorithm for

REACTORS - core for, formulation of equations for use of Compton recoil continuum in continuous γ spectroscopy in
-neutron flux measurements in, schematics for line-timer corrections for foil-counting data for

R6 (KR-134) MEASUREMENT OF INTRACELL FISSION DENSITY AND FAST NEUTRON FLUX DISTRIBUTIONS IN THE NORA REACTOR WITH SOLID STATE NUCLEAR TRACK DETECTORS. Tuyn, J.W.N. (Institutt for Atomenergi, Kjeller (Norway). Reactor Centrum Nederland, Petten). 49 p. (Mar. 1969).

Solid state nuclear track detectors of silver-activated phosphate glass and polycarbonate plastic have provided intracell fission density and fast neutron flux distributions in the NORA reactor. The fission density distributions were measured in a clean lattice and within fuel elements in the vicinity of grey absorber control elements. The measured intracell fast neutron flux

distributions were used for the evaluation of the so-called fast advantage factors (fuel-to-moderator neutron flux ratios at fission energies). Integral measurements of the fast advantage factors were performed by foil activation. As far as the experimental results presented could be compared with theoretical calculations, a good agreement was found. The use of a microdensitometer to determine the track density distributions on the surface of irradiated detectors has proved to be very convenient. A simple model for the development of tracks in solid state nuclear track detectors was constructed. (15 references).

R7 USE OF SOLID STATE NUCLEAR TRACK DETECTORS IN REACTOR PHYSICS EXPERIMENTS. Tuyn, J.W.N. (Reactor Centrum Nederland, The Hague). Ref. J18. pp IX. 12-33. (1969).

Solid state nuclear track detectors of silver-activated phosphate glass and polycarbonate plastic have provided intracell fission density and fast neutron flux distributions in the zero-power critical facility NORA (Institut for Atomenergi, Kjeller, Norway). The fission density distributions were measured in a clean lattice and within fuel elements in the vicinity of grey absorber control elements. The measured intracell fast neutron flux distributions were used for the evaluation of the so-called fast advantage factors (fuel-to-moderator neutron flux ratios at fission energies). Integral measurements of the fast advantage factors were performed by foil activation. As far as the experimental results presented here could be compared with theoretical calculations a good agreement was found. For the measurement of the track density distributions along the detector surface a method was developed which replaces the counting procedure of tracks under a microscope. This method is based upon the relation between track density and intensity of transmitted light through irradiated and etched detectors, whereby a microdensitometer is used for the measurement of the light transmission. Some remarks about the fast neutron sensitivity of Makrofol polycarbonate plastic are made.

R8 MEASUREMENT OF NEUTRON FLUX IN NUCLEAR REACTOR BY MEANS OF FISSION TRACK METHOD. Sakanoue, Masanobu; Nakanishi, Takashi (Kanazawa Univ., Japan). Nippon Genshiryoku Gakkaishi, 11: 332-9 (1969). (In Japanese).

Measurements of thermal and fast neutron fluxes in a mixed radiation field have been carried out by etching technique applied to fission tracks on a mica detector. As fissionable material, use was made of

electrochemical deposits — on Au-coated Cu-plate or stainless steel plate — of ^{232}Th , ^{231}Pa , natural U, depleted U, ^{232}U , ^{237}Np , ^{239}Pu and ^{239}Pu . The atomic density of the fissionable material on the plate was measured by α -spectrometry. These plates were placed in contact with muscovite mica, and exposed to neutron flux in a TRIGA Mark-II nuclear reactor, both with and without thermal neutron absorber of Cd. After the irradiation, the mica was etched by hydrofluoric acid solution, and the track density counted on a microphotograph. The values of the thermal and fast neutron fluxes were obtained from the mean cross-section of the fission reactions undergone by the different nuclides present. The resulting flux values showed reasonably good agreement with the values obtained by other methods. A discussion is given on the nuclear data obtained for several nuclides. A proposal is presented also on a simple and practical method for determining high track density by photometer with dark-field illumination. (19 references).

R9 (AEEW-M-881) PROGRESS IN THE APPLICATION OF SOLID-STATE TRACK RECORDERS TO REACTOR PHYSICS EXPERIMENTS. Besant, C.B.; Ipson, S.S. (Atomic Energy Establishment, Winfrith (England)). 39 p. (Mar. 1969).

Strain energy fields produced by heavily ionizing particles passing through insulating materials may be observed directly with an electron microscope or, after etching, the tracks may be seen with an optical microscope. This technique was applied to detecting fission fragments from fissions taking place in a thin source of fissile material. The source, together with the insulating material, is termed a solid-state track recorder and was applied to the measurement of fission ratios in the fast critical assembly ZEBRA at Winfrith. The main disadvantage of the technique has been in counting tracks by eye, which is laborious and subject to the human element. This has been overcome by counting tracks with a Quantimet-Computer Image Analyzer. Absolute fission rate measurements are also discussed, and it has been found that measurements to an accuracy of better than $\pm 1\%$ should be possible with this technique.

R10 RESEARCH WITH THE IRT REACTOR AT SOFIA USING FISSION FRAGMENT DIELECTRIC TRACK DETECTORS. Kachoukeev, N.T. (Bylgarska Akademiya na Naukite, Sofia). Ref. J18 pp IX. 56-60. (1969). (In French).

The results obtained in research carried out with

fission fragment dielectric track detectors at the nuclear research center of Sofia in 1967 are given. The main topics covered are: the recording of neutron beams and the dosimetry of neutron fluxes; the determination of extremely small quantities of uranium in various substances; the dating of rock samples; and nuclear research.

R11 (INR-1097) USE OF THE SOLID STATE PARTICLE TRACK DETECTORS IN REACTOR MEASUREMENTS. Jozefowicz, Krystyna (Institute of Nuclear Research, Warsaw, Poland). 13 p. (1969).

Dielectric track detectors can be used for neutron detection by registering charged particles from interactions of neutrons with matter. Fission fragments as well as light recoil atoms and alpha-particles can be recorded and distinguished in some polymers. The use of particle track detectors in reactor measurements by (n, f) and (n, α) reactions and recoil atoms is discussed. The results of measurements of fast neutron flux relative distributions in WWR-SM cores are shown in comparison with sulphur activation results. Further possibilities of the method for absolute and spectral neutron measurements are pointed out.

R12 APPLICATION OF SOLID STATE TRACK RECORDERS FOR NEUTRON SPECTRA MEASUREMENTS IN A REACTOR IRRADIATION FACILITY.

Koehler, Wilfried (International Atomic Energy Agency, Vienna). Ref. J18 pp IX. 7-11. (1969).

In connection with the IAEA-neutron seed irradiation program, a standard neutron irradiation facility was constructed. The application of solid state track recorders for fast neutron spectra measurements inside this facility is discussed. Fissionable targets of ^{235}U , ^{239}Pu , ^{237}Np , ^{238}U and ^{232}Th will be used, and an approximative solution for the incident neutron spectrum will be obtained by a five group method.

R13 USE OF SOLID-STATE NUCLEAR TRACK DETECTORS IN REACTOR PHYSICS EXPERIMENTS.

Tuyn, J.W.N. (Reactor Centrum Nederland, Petten, Netherlands). Radiat. Eff.: 5: 75-84 (Aug. 1970).

Solid state nuclear track detectors of silver-activated phosphate glass and polycarbonate plastic have provided intracell fission density and fast neutron flux distributions in the zero-power critical facility NORA. The fission density distributions were measured in a clean lattice and within fuel elements in the vicinity of grey absorber control elements. The measured intracell fast neutron flux distributions were used for the evaluation

of the so-called "fast advantage factors" (fuel-to-moderator neutron flux ratios at fission energies). Integral measurements of the fast advantage factors were performed by foil activation. As far as the experimental results could be compared with theoretical calculations, a good agreement was found. For the measurement of the track density distributions along the detector surface, a method was developed which replaces the counting procedure of tracks under a microscope. This method is based upon the relation between track density and intensity of transmitted light through irradiated and etched detectors, whereby a microdensitometer is used for the measurement of the light transmission. Some remarks about the fast neutron sensitivity of Makrofol polycarbonate plastic are made.

R14 REACTOR NEUTRON MEASUREMENTS WITH FISSION FOIL-LEXAN DETECTORS. Rago, P.F.; Goldstein, N.; Tochilin, E. (Naval Radiological Defense Lab., San Francisco). Nucl. Appl. Technol.; 8: 302-9 (Mar. 1970).

A fission foil-Lexan detector system has been developed to monitor reactor neutrons. It is similar to the system based on counting fission γ rays but has some advantages: i.e., permanently recorded tracks that can be read any time after exposure; integrated recording; microgram amounts of fissionable material needed; and the elimination of specialized γ -ray counting equipment. Fission product damage tracks in the Lexan (or mica) are counted under an optical microscope. For thick foils, fluence is determined from the sensitivity factor of 1.16×10^{-5} tracks/neutron-barn. Fluence measurements with the two systems are compared for several reactor environments while dose measurements are compared with tissue-equivalent calorimeter values. The use of ^{232}Th to replace ^{238}U as the fissionable isotope for the energy interval of 1.5 to 3 MeV, and of ^{235}U to replace ^{239}Pu for energies below 600 keV, was also investigated. Neptunium is retained as the fissionable material for the energy interval 600 keV to 1.5 MeV and the sulfur activation detector for energies above 3 MeV.

R15 ACCURATE ABSOLUTE DETERMINATION OF FISSION DENSITIES IN FUEL RODS BY MFANS OF SOLID-STATE TRACK DETECTORS. de Coster, M.; Langela, D. (SCK-CEN, Mol, Belg.). Nucl. Appl. Technol.; 9: 229-32 (Aug. 1970).

It is shown that an accurate determination of the fission rate in fuel elements can be obtained by the technique of solid state track detectors. The method

gives: (1) the radial variation; (2) the absolute value of the fission rate, by application of the measured value of the mean path length of the fission products in the fuel. The quality of the results is independent of the neutron spectrum during the irradiation. In a particular case (thermal flux), results deduced from measurements performed with solid state track detectors are compared with those obtained by the fissile detector (activation) technique. The agreement is excellent.

R16 EFFECTIVE NEUTRON TEMPERATURES IN REACTOR CORE MEASURED BY FISSION TRACK DETECTORS. Su, C.S.; Liu, T.C. (National Tsing Hua Univ., Hsinchu, China). Nucl. Instrum. Methods; 89: 233-6 (1970).

The effective neutron temperature of a thermal reactor can be measured by directly counting the fission tracks of two fissile materials, ^{239}Pu and ^{235}U , irradiated in the reactor simultaneously. Glass slides were used as the fission track detectors. The effective neutron temperatures were measured at the reactor core of the open pool reactor. Results show that the effective neutron temperatures were 104°C at the positions near the control rods and 71°C at the center of the core, when reactor was operated at one kilowatt.

R17 MEASUREMENT OF FISSION RATIOS IN ZERO POWER REACTORS USING SOLID-STATE TRACK RECORDERS. Besant, C.B. (Imperial Coll. of Science and Tech., London); Ipson, S.S. J. Nucl. Energy; 24: 59-69 (Apr. 1970).

Fission ratio measurements provide information in studies of the neutron events in both thermal and fast reactors. Commonly induced fission product activity in fissile foils is counted. The use is described of a technique for counting fission tracks in plastic films which were etched after irradiation to make tracks visible. The tracks were counted using standard microscopy techniques and an automatic technique. Both methods are potentially of high accuracy, and the latter removes the laborious work of counting tracks by eye.

R18 MEASUREMENT OF RADIAL PROFILES OF FISSIONABLE MATERIALS AND FISSION PRODUCTS IN THE COATING LAYERS OF FUEL PARTICLES FOR HIGH-TEMPERATURE REACTORS. Bildstein, H.; Angelberger, P.; Muellner, P. (Reaktorzentrum, Seibersdorf, Austria). Mikrochim. Acta; No. 5, 905-13 (1970). (In German).

A combination of recoil technique and chemical etching allows a determination of surface U/Th con-

tamination and contamination profiles in coated fuel particles for HTGR. The release of fission products by diffusion through the coating is studied by evaluating their radial concentration profiles.

R19 FLUX MONITOR UTILIZING TRACK-ETCH FILM FOR UNATTENDED SAFEGUARDS APPLICATION. Weidenbaum, B.; Lovett, D.B.; Kosanke, H.D. (General Electric Co., Pleasanton, Calif.). Trans. Amer. Nucl. Soc.; 13: 524-6 (Nov. 1970).

From Meeting of the American Nuclear Society, Washington, D.C.

R20 MEASUREMENT OF $^{238}\text{U}/^{235}\text{U}$ FISSION RATIOS IN ZEBRA USING SOLID STATE TRACK RECORDERS. Jowitt, D. (Atomic Energy Establishment, Winfrith, Eng.). Nucl. Instrum. Methods; 92: 37-44 (1971).

The application of solid-state recorders to the determination of fission ratios in a zero power fast reactor is demonstrated. Although measurements of limited accuracy may be made by counting tracks visually, automatic track counting using a "Quantimet B" television image analyzer is shown to be capable of a precision comparable with that of the conventional foil activation technique. Measurements of the $^{238}\text{U}/^{235}\text{U}$ fission ratio in several assemblies have shown no significant difference between the results obtained by the two methods.

R21 MEASUREMENT OF REACTOR POWER BY DETERMINATION OF ^{17}N NEUTRONS IN THE COOLING MEDIUM WITH TRACK DETECTORS. Nedelk, A.; Gruenwald, H. (ASTRA-Reaktor Institut, Seibersdorf, Austria). Atomwirt., Atomtech.; 16: No. 6, 301 (June 1971). (In German).

The power of ASTRA, a 5 MW pool reactor, was measured with a special track detector. Several pellets of highly enriched uranium oxide were attached to glass slides and placed on the outlet of the primary cooling system. Moderation of the ^{17}N neutrons from the $^{17}\text{O}(n,p)^{17}\text{N}$ reaction produced sufficient thermal neutrons to cause fission in the uranium pellets. Following etching, fission product tracks in the glass could be easily counted under the microscope. The dosimeter yielded 70 tracks/cm²/MWh. The simple inexpensive dosimeter proved suitable for assessment of reactor power.

R22 (JAERI-Memo-4337) MEASUREMENT OF THE FAST NEUTRON FLUXES IN AN EXPERIMENTAL CRITICAL ASSEMBLY. I. FEASIBILITY

STUDY OF THE DOPED GLASS DOSIMETER.

Nomura, Masayuki; Yokota, R.; Imagawa, H.; Muto, Y.; Tomishima, H. (Japan Atomic Energy Research Inst., Tokyo). 20 p. (Jan. 1971). (In Japanese).

The metaphosphate glass doped with fissionable material, a kind of fission track detector, is capable of measuring monoenergetic fast neutron fluxes even at a low dose rate. The applicability of this method, however, is not confirmed yet for fast neutron fluxes having an energy distribution. A metaphosphate glass detector doped with natural uranium, depleted uranium, or thorium was prepared. With this detector, the fast neutron fluxes over an energy range were measured in the JMTRC of low power (Max. 10W) with a neutron energy distribution. The detector developed was found to be able to measure the fluxes with an accuracy of $10^6 \text{ n/cm}^2 \cdot \text{sec} \pm 30\%$ corresponding to the flux of energy over 1 MeV.

R23 APPLICATION OF FISSION TRACK DETECTORS AS REACTOR NEUTRON TEMPERATURE MONITOR. Liu, T.C.; Su, C.S. (National Tsing Hau Univ., Hsinchu, Taiwan). *Int. J. Appl. Radiat. Isotop.*; 22: 227-32 (Apr. 1971).

Application of fission track detectors to measure the effective neutron temperature in a thermal reactor is proposed. This technique showed a number of advantages in comparison with ordinary methods. Glass slides were used as fission track detectors to register the total fission events of ^{239}Pu and ^{235}U irradiated simultaneously in the reactor. The effective neutron temperature can then be calculated from the ratio of fission tracks. Examples are given for the temperature measurements at the water region close to the reactor core and at the thermal column of the Open Pool reactor. Results show that the effective neutron temperatures differed more from the medium temperatures as the irradiation positions came closer to the reactor core.

R24 MEASUREMENT OF NEUTRON FLUX IN NUCLEAR REACTOR BY MEANS OF FISSION TRACK METHOD. Sakanoue, M., and Nakanishi, T. *Journal of the Atomic Energy Society of Jap.* 33: 332 (1969).

R25 FISSION RATE MEASUREMENTS IN LOW-POWER FAST CRITICAL ASSEMBLIES WITH SOLID-STATE TRACK RECORDERS. Roberts, J.H., and Huang, Song-Teh, *Nuclear Applications*, Vol. 5, 247 (1968).

R26 USE OF SOLID TRACK DETECTORS IN REACTOR EXPERIMENTS. Kuznetsov, V.A.; Mogil'ner, A.I.; Koroleva, V.P.; Samovarov, V.S.; Chernov, L.A. *At. Energ. (USSR)*; 32: No. 6, 481-3 (June 1972). (In Russian).

Methods of utilizing nitrocellulose for recording α particles (from ^{10}B and ^6Li) and mica for recording ^{235}U fission fragments were investigated. The nitrocellulose was in the form of motion picture film or x-ray film, for which the following etching conditions are suggested: 30% NaOH, 60°C, for 15 min. Etching of the mica was conducted with 40% HF, 60°C, for 30 min.

R27 USE OF SOLID STATE TRACK RECORDERS FOR THE MEASUREMENT OF FISSION RATE RATIOS IN REACTOR LATTICES. Richmond, R.; Ruegger, B. (Federal Inst. for Reactor Research, Wuerenlingen, Switzerland). *Neue Tech.*; No. 10, 1-8 (1971).

A series of measurements of the neutron physics properties of fast reactor lattices is about to begin in the reactor PROTEUS. These measurements include the determination of the relative fission rates in the fissile nuclides in the fuel elements. Each fission rate is measured by means of a solid state track recorder which is inserted into a fuel element adjacent to a foil of fissile material and records a track density proportional to the fission rate in the foil. The need to count large numbers of tracks in order to obtain adequate counting statistics rules out the possibility of counting by eye and the only automatic method of sufficient accuracy is automatic image analysis. A Quantimet 720 is used to determine the fission track densities. An investigation of the various sources of error arising in the measurement has shown that it is possible to obtain the ratio of the track densities on two recorders with an error of the order of $\pm 1\%$. One of the most important factors in achieving this accuracy is the correct determination of the fraction of counts lost as a result of track overlapping and it has been demonstrated that this loss correction can be determined with adequate accuracy for track densities up to $2000/\text{mm}^2$. (8 references).

R28 (ANL-7910). EXPERIMENTAL TECHNIQUES AND FACILITIES. pp 337-426. (Jan. 1972).

Measured integral reactor physics parameters are necessary for either direct introduction into reactor design calculations or for comparison with values obtained analytically using basic microscopic cross

section data. In the latter case the objective is to verify either the cross section data or the calculational techniques. Reactor integral parameters are obtained using special measurement techniques in exponential or critical facilities. The papers presented deal largely with the development of such special techniques, facilities, and radiation detection devices. Included also are papers which describe specially developed equipment useful in obtaining microscopic nuclear data.

R29 (KURRI-TR-89). MEASUREMENT OF NEUTRON FLUX IN REACTORS BY MEANS OF PARTICLE TRACKS ON DIELECTRIC MATERIALS. Hashimoto, T. (Kyoto Univ.). pp 71-79 (1971). (In Japanese).

An application of the fission track method using dielectric materials for the measurement of reactor neutron flux is presented. The preparation of a thin uniform fissile target was first carried out by an electrodeposition on an aluminium plate and a lacquer method with cellulose nitrate-ethyl acetate solution containing uranyl dibenzoyl methane. From the observation of the fission tracks using muscovite, it was verified that both methods gave suitable targets for this experiment. The electrodeposited U and Th-targets with muscovite and polycarbonate film as a track recording material were used for the determination of neutron flux in the various irradiation facilities of KUR (Kyoto University Reactor). The results showed a good agreement with the data obtained from Au-foil activation method. Then, a comparison of the sensitivity for the detection of neutron was performed for the (n,α) and the (n,f) reaction of each nuclide from the calculation using the known nuclear data.

R30 MEASUREMENT OF FISSION DENSITY DISTRIBUTION WITHIN FUEL ELEMENTS IN THE VICINITY OF GREY ABSORBER CONTROL ELEMENTS. Tuyn, J.W.N. *Nukleonik*, 12, p183 (1969).

Abstract not available.

R31 MEASUREMENT OF INTRACELL FISSION DENSITY AND FAST FLUX DISTRIBUTION IN THE

NORA REACTOR WITH SOLID-STATE NUCLEAR TRACK DETECTORS. Tuyn, J.W.N. *REP. NORA Int. At. Energy Ag., Kjeller, Norway* (1969).

Abstract not available.

R32 Fleischer, R.L.; Price, P.B., and Walker, R.M. J. Nucl. Sci. Eng., 22, p153 (1965).

Title and abstract not available.

R33 MEASUREMENT OF FAST FISSION RATIOS IN URANIUM CARBIDE RODS. Guardini, S., Tassan, S., and Boluf, A. *Energia Nucleare*, 14 (4), p217 (1967).

Abstract not available.

R34 APPLICATION OF THE IONOGRAPHIC TECHNIQUE TO ANALYSIS OF THE DISTRIBUTION OF FISSION EVENTS IN FUEL ELEMENTS. Mourgues, M.; Renavot, J.M. (CEN, Cadarache, France), pp 627-650 of *Dosimetry in Agriculture, Industry, Biology and Medicine*. Vienna; International Atomic Energy Agency (1973). (In French).

Ionographic techniques provide a means of studying interactions between ionizing particles and certain dielectric media on a microscopic scale and in a very selective manner. They permit such fine-structure analysis of fuel as the measurement of neutron flux gradients over a distance as small as the radius of the Rapsodie fuel pins (a few millimeters); this is done by using thin Makrofol detectors to record fission fragments emitted by the plane faces of uranium oxide slugs. A new technique for using ionographic detectors has been developed in order to broaden the field of application of this analytical technique; it is based on the analysis of radiographic films by densitometry (Marius high-temperature reactor experiments). The characteristic feature of the ionographic detection method is that the effect studied is recorded directly, without the occurrence of appreciable interaction with the neutron flux, and, therefore, without disturbance of the latter. Mention is also made of the insensitivity of Makrofol to other sources of radiation, particularly alpha particle emission from fissionable fuels.

S. RADIOGRAPHY AND AUTORADIOGRAPHY

S1 (ANL-7299) AUTORADIOGRAPHY. Koprowski, B.J., Brown, F.L., Gebo, C.H. Annual Progress Report for 1966, Metallurgy Division S.192, (1966)

S2 URANIUM MICROMAPS: TECHNIQUE FOR IN SITU MAPPING OF DISTRIBUTIONS OF FISSIONABLE IMPURITIES, Robert L. Fleischer, California Inst of Tech Pasadena. Rev Sci Instr 37, 12 1738-9(Dec 1966.)

S3 (AERE-R-5474) A NEW APPROACH TO AUTORADIOGRAPHY IN THE LIFE SCIENCES. Hamilton, E.I.; Holmes, A.: The Determination of Radionuclides in Materials of Biological Origin. Proceedings of a Symposium held at A.E.R.E., Harwell, 20th and 21st April, 1967. S. 154-62 a, (1967)

S4 TRACK-ETCH PLASTIC-FILM TECHNIQUE FOR NEUTRON IMAGING. Berger, Harold; Kraska, I.R. (Argonne National Lab., Ill.). Trans. Amer. Nucl. Soc., 10: 72-3(June 1967).

S5 HIGH-RESOLUTION AUTORADIOGRAPHY OF TRACE BORON IN METALS AND SOLIDS. Hughes, J.D.H.; Rogers, G.T. (United Kingdom Atomic Energy Authority, Wantage, Eng.). J. Inst. Metals, 95: 299-302(Oct. 1967).

An autoradiographic method of determining the spatial distribution of boron in solids with a resolution of 2 μ m was demonstrated over a boron concentration range of 20% to 1 ppm. The products from the $^{10}\text{B}(n,\alpha)^7\text{Li}$ reaction produce tracks in a cellulose acetate replica exposed to a thermal-neutron flux while in contact with the specimen. The tracks are revealed by etching in aqueous KOH at 50°C. Track density is proportional to boron content at a given irradiation down to < 10 ppm. Some latent-image fading was observed with irradiations of > 100 h.

S6 THE REGISTRATION OF CHARGED PARTICLES IN SOLIDS: AN ALTERNATIVE TO AUTORADIOGRAPHY IN THE LIFE SCIENCES. Hamilton, E.I. (Radiological Protection Service, Sutton, Eng.). Int. J. Appl. Radiat. Isotop., 19: 159-61 (Feb. 1968).

Most insulator solids, e.g., glass, natural silicates, apatite and plastics, record the passage of charged particles as narrow trails of radiation damaged material. The width of these linear damaged regions is ≈ 10 nm and direct observation is only possible by means of electron microscopy. Chemical etching techniques have

been described, however, whereby the damaged trails are preferentially dissolved to produce tubes about 1 μ m in diameter. When viewed in transmitted light the tubes appear black. As the etching solution penetrates the matrix the hole is enlarged to produce a well defined track, which narrows with depth. The terminal portions of the tracks have a characteristic cone shape, which is easily distinguished from most linear imperfections that may exist in the sample. Under conditions of optimum etching the track holes can be enlarged and easily viewed with a conventional optical microscope. This method can therefore be used to detect the passage of charged particles, such as fission fragments or alpha particles, emitted from a sample in various solid detectors. The method has been used by the author to determine the distribution of uranium and plutonium in thin sections of animal tissue, plants, and natural waters. Polycarbonate plastic was used as detector and the tracks were etched in NaOH. Irradiations were carried out in the BEPO reactor at Harwell.

S7 (TID-24730) MONTHLY REPORT NO. 2. Berger, Harold (Argonne National Lab., Ill.). Sept. 1968. 10p.

The research program which will be carried out at the Center d'Etudes Nucleaires de Grenoble (CENG) which is a study of image detection methods for fast neutron radiography is described. Accelerator and radioisotope neutron sources are considered, and various detection systems are discussed including x-ray fluorescent screens and x-ray films, scintillation counters, threshold detectors, and track-etch detectors.

S8 (IAERU 6902) NEUTRON RADIOGRAPHY BY FISSION TRACK METHOD AND TRACK METHOD. KO Hidemi, KATO Kagetaka, et al. (Rikkyo Univ., Yokosuka, Kanagawa. Inst. for Atomic-Energy). Oct 1969, 4p.

S9 AUTORADIOGRAPHY OF IRRADIATED NUCLEAR CERAMIC FUELS. Gruber, W.J. (Pac. Northwest Lab., Battelle Mem. Inst., Richland, Wash.). Proc. Conf. Remote Syst. Technol. 17, 21-5 (1969)

S10 INVESTIGATIONS ON ALPHA RADIOGRAPHY WITH PLASTIC TRACK DETECTORS. Somogyi, Gy.; Srivastava, D.S. ATOMKI (At. Kut. Intez.) Kozlem., 12: 101-17(Nov 1970). (In Hungarian).

The features of translucency observed in plastics (cellulose nitrate, cellulose acetate and polycarbonate)

irradiated with α -particles with high track density ($>10^5$ alphas/cm²) have been studied. Quantitative data are presented for the correlation between the optical density, etching time and track density for dielectric track detectors of different sensitivity under different irradiation conditions. A few aspects of the requirements for revealing the α -particle tracks in plastics have been theoretically investigated using an observed exponential relationship for the variation of etch rate along the particle's trajectory. The part played by some parameters (irradiation geometry, particle energy, environmental conditions etc.) in the observed α -ray patterns have also been examined. It has been found that one can make energy-selective α -radiography by using less sensitive plastics like polycarbonate. The effect of irradiation in vacuum on the optical density curves has also been studied. From these investigations it was concluded that the presence of oxygen during α -particle irradiation plays an important role in track formation. The method used for these investigations offers itself as a quick and reliable method for finding the relative sensitivities of dielectric track detectors and any change in them due to environmental conditions.

S11 (ANL-7615) APPLICATION OF CELLULOSE NITRATE FILMS FOR ALPHA AUTORADIOGRAPHY OF BONE. Cole, Alan; Simmons, D.J.; Cummins, Helen; Congel, F.J.; Kastner, Jacob (Argonne National Lab., Ill.). 1-3.

Cellulose nitrate can be used to record the tracks of alpha particles from bone and may have some advantages over nuclear emulsions. The tracks are made visible by etching the cellulose nitrate film with NaOH and no darkroom is required. Beta rays and electrons do not produce tracks, so background fogging is eliminated. The etching process makes visible only those alpha particle tracks that penetrate the film, so the attainable resolution may be better than that of nuclear emulsions. Finally, the alpha tracks are enlarged and so may be more easily counted by a photoelectric scanner.

S12 (ANL-7760(Pt.2)) APPLICATION OF CELLULOSE NITRATE FILMS FOR ALPHA AUTORADIOGRAPHY OF BONE. II. RESOLUTION AND SENSITIVITY OF CELLULOSE NITRATE FILMS. Simmons, D.J.; Fitzgerald, K.T. (Argonne National Lab., Ill.).

High resolution autoradiographs of thin line ²³⁹Pu sources were prepared with several nuclear emulsions and cellulose nitrate (CN) films. The CN detector films made by the dipping method afforded better resolution

of alpha tracks (after chemical etching) than Kodak Type A plates or AR-10 stripping film. Resolution could be improved by using thicker (30 μ) rather than thinner (15 μ) detector films. Tentative correction factors for alpha track counting in the CN films are presented.

S13 APPLICATION OF CELLULOSE-NITRATE FILMS FOR ALPHA AUTORADIOGRAPHY OF BONE. Cole, A.; Simmons, D.J.; Cummins, H.; Congel, F.J.; Kastner, J. (Argonne National Lab., Ill.). *Health Phys.*; 19: 55-6(Jul 1970).

High resolution autoradiographs of bone containing ²³⁹Pu were prepared by coating sections with their cellulose nitrate detector films that are selectively sensitive to alpha particles. The radiation damaged sites in the polymer were developed by etching with NaOH. The cellulose nitrate method provides an alternative to autoradiography with nuclear emulsions. It does not require darkroom facilities. The films are very stable and will not fog during long exposures at room temperature.

S14 NONPHOTOGRAPHIC α -PARTICLE AUTORADIOGRAPHY AND NEUTRON-INDUCED AUTORADIOGRAPHY. Becker, Klaus; Johnson, Dennis Raymond (Health Phys. Div., Oak Ridge Nat. Lab., Oak Ridge, Tenn.). *Science* 167(3923), 1370-2 (1970).

S15 USE OF CELLULOSE NITRATE FOR ALPHA AUTORADIOGRAPHY IN METALLOGRAPHY. Kegley, T.M. Jr. (Oak Ridge National Lab., Tenn.). *Trans. Amer. Nucl. Soc.*; 13: 528(Nov 1970).

S16 NONPHOTOGRAPHIC ALPHA AUTORADIOGRAPHY AND NEUTRON-INDUCED AUTORADIOGRAPHY. Pilcher, Carl B. (Massachusetts Inst. of Tech., Cambridge); Chapman, Clark R.; Lebofsky, Larry A.; Kieffer, Hugh H. *Science*; 167: 1370-3(6 Mar 1970).

With a new combination of two techniques, (i) alpha-particle or fission fragment registration in thin polymer foils by etching and (ii) automatic counting and magnification of the etched perforations by local evaporation of a thin metal layer with an electric spark, the sensitivity of conventional photographic methods for determining quantity and spatial distribution of alpha emitters, fissile materials, and of elements undergoing (n, α) reactions can be drastically improved, without need for darkroom processing and microscopic evaluation.

S17 ALPHA RADIOGRAPHY WITH PLASTIC TRACK DETECTORS. Somogyi, G.; Srivastava, D.S. (Inst. of Nuclear Research, Debrecen, Hungary). *Int. J. Appl. Radiat. Isotop.*; 22: No. 5, 289-99 (May 1971).

S18 SOME RECENT PROGRESS IN NEUTRON RADIOGRAPHY AND IONIZING PARTICLE DOSIMETRY USING CELLULOSE NITRATE AS RECORDING MATERIAL. Barbier, J. (Kodak-Pathe Research Labs., Vincennes, France). *J. Photogr. Sci.*; 19: No. 4, 108-12 (Jul-Aug 1971).

Improvements in the composition of cellulose nitrate as a detector of alpha particles and certain fission products are presented. Methods of contact printing from the exposed and etched cellulose sheets are described and the use of this new plastic material for neutron radiography and radiation dosimetry is discussed.

S19 APPLICATION OF SOLID STATE TRACK DETECTORS FOR AUTORADIOGRAPHY, USING INDUCED RADIOACTIVITY. Baumbach, H. (Zentralinstitut fuer Isotopen- und Strahlenforschung, Leipzig). *ATOMKI (At. Kut. Intez.) Kozlem.*; 13: No. 3, 93-9 (Nov 1971). (In German).

A number of elements (e.g. B, N, O, Al) have no radionuclides applicable for autoradiographic investigations. To study distributions of these one can use, among other things, recordings by solid state track detectors (SSTD) of the alpha radiation obtained from nuclear reactions induced in these nuclei. Taking into account available literature of the last two years, a brief summary is given of the conditions of recording of charged particles by SSTD. On the basis of experimental work performed in Leipzig (Zentralinstitut für Isotopen und Strahlentechnik), the factors influencing the autoradiographic images obtainable by silver halide emulsions and SSTD's are dealt with. For the case of B distribution in Si the lower limit of detectability is estimated. Mention is made of experiments carried out in ATOMKI on influencing SSTD sensitivity during the process of exposure as well as before and during track etching. The possibility of automatic evaluation of induced autoradiograms by such electronic aids as DENSITRON (Zfi, Leipzig) and QUANTIMET (Metals Research Ltd, Cambridge) is also considered.

S20 IMPROVED SENSITIVITY AND CONTRAST, TRACK ETCH THERMAL-NEUTRON RADIOGRAPHY. H. Berger and N.P. Lapinski (ANL); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15

S21 TWO TECHNIQUES TO INCREASE CONTRAST OF TRACK ETCH NEUTRON RADIOGRAPHS, James A. Morley (NASA-LEWIS-SANDUSKY); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15

S22 TWO NEW METHODS TO INCREASE THE CONTRAST OF TRACK-ETCH NEUTRON RADIOGRAPHS, James Morley, NASA Technical Memorandum, June 1972.

S23 METHODS FOR IMPROVING RADIOGRAMS IN PLASTIC DETECTORS. Somogyi, G.; Gulyas, J. (Inst. of Nuclear Research, Debrecen, Hungary). *Radioisotopy*; 13: No. 3, 549-68 (1972).

Experiences relating to the improvement of the quality and evaluation of autoradiograms using plastic track detectors are described. The effect of some parameters (etching condition, ozone atmosphere) on track contrast was studied. A spark discharge method was applied to the evaluation of radiograms of samples containing fissile atoms.

S24 INDUZIERTER RADIOGRAPHIE. Medveczky, L., and Somogyi, G. *Atommag Kut. Intez. Kozlem.*, 12, p191 (1970)

Abstract not available.

S25 ALPHA AUTORADIOGRAPHIC TECHNIQUE FOR IRRADIATED FUEL. Davies, J.H., and Darmitzel, R.W. *Nucleonics*, 23 (7), p86 (1965)

Abstract not available.

S26 Berger, H. *Brit. J. Non-Destruct. Test.*, 10 (2), p26 (1968)

Title and abstract not available.

S27 TRACK-ETCH RADIOGRAPHY: ALPHA, PROTON, AND NEUTRON. Berger, H. (Argonne National Lab., IL). *Nucl. Technol.*; 19: No. 3, 188-198 (Sep 1973).

Several polycarbonate plastics and cellulose nitrate have been studied for radiographic imaging studies with alpha particles, protons, fast neutrons, and thermal neutrons. Comparisons, made with conventional film-detection methods in terms of exposure requirements, spatial resolution, contrast, and convenience, show that track-etch techniques can give comparable or better results. Comprehensive results for thermal-neutron radiography indicate that total thermal-neutron exposures in the range of 2×10^7 to 4×10^8 n/cm² provide radiographs which display a contrast sensitivity of

1 to 3% and a spatial resolution of $\sim 25 \mu\text{m}$. A scattered-light enlargement technique provides a simple means to improve visual contrast of track-etch images.

S28 ALPHA RADIOGRAPHY. Srivastava, D.S. Sci. Rep.; 10: No. 5, 225-226(May 1973).

The principle, methods, and prospects for plastic track detectors providing a quick and simple method for making alpha-ray patterns of alpha-active samples in thin plastic foils, even in the presence of a large flux of beta particles and gamma-rays to which they are insensitive, are described. The method does not require any dark room treatment. This method has proved to be effective for checking the uniformity of alpha sources and for finding the diffusion of plutonium in the reactor

fuel rods and their containers. It is expected that this simple method can advantageously replace photoemulsions in the works related with the study of radioactivity of crystal faces, autoradiography of alloys, study of diffusion of radioactive materials in porous media, and in many biological applications such as localization of lead, bismuth, polonium, astatine, uranium, plutonium and other transuranic elements. The best etching solutions and temperatures for quick alpha radiographic work are listed.

S29 HEAVY-PARTICLE RADIOGRAPHY. Benton, E.V., Henke, R.P. and Tobias, C.A. Science, 182 474-476 (1973)

Abstract not available.

T. METALLURGY AND ANALYSIS OF TRACE ELEMENTS.

T1 (BNWL-SA-58) DETECTION OF PLUTONIUM IN BIOASSAY PROGRAMS USING NONELECTRICAL FISSION FRAGMENT TRACK DETECTORS. Brackenbush, Larry W.; Baumgartner, William V. (Battelle-Northwest, Richland, Wash. Pacific Northwest Lab.). 11 p. (June 7, 1965).

A bioassay program for plutonium or other fissionable materials using nonelectrical solid state fission fragment track detectors is described. The method is very sensitive, rapid, and reasonably accurate. Lexan plastic disks placed upon electrodeposited bioassay disks, exposed to an integrated thermal neutron flux of 10^{15} neutrons/cm², and etched in a caustic solution are used to detect less than 0.01 dis/min of plutonium alpha activity. This is five times lower than the present Hanford detection limit of 0.05 dis/min using NTA emulsion; the method can be extended to even smaller quantities by using a higher neutron flux or larger track counting areas. Studies of sample preparation techniques point out the need for total contamination control if such low detection levels are to be meaningful. Significant cross contamination and residual activity are detected when using equipment that was used previously in the deposition of about 1 dis/min of plutonium alpha activity. A TV monitoring system coupled to an optical microscope provides a display of the etch pits from the fission fragment tracks. This system greatly reduces the eyestrain and the time required for track counting. The definition of the etch pits is good and track counting is quickly and accurately performed. The use of these non-electric fission frag-

ment detectors with other fissionable materials offers unique and practical solutions to many health physics problems.

T2 DETERMINATION OF URANIUM CLARKEITE CONCENTRATIONS IN IONIC CRYSTALS. Berzina, I.G.; Berman, I.B.; Gurvich, M. Yu. At. Energ. (USSR), 22: 504-5 (June 1967). (In Russian).

The very low clarkeite concentrations in ionic crystals may be determined on the basis of tracks formed by artificially fissioned uranium; these tracks may be rendered visible by etching. The etched surfaces of crystal specimens were subjected to neutron bombardment and the uranium concentration determined by the formula $C = 2\rho\mu/N_0Jn\sigma k dRe$, where ρ represents the fission-product track density due to the irradiation; μ is the molecular weight of the material; N_0 is Avogadro's number; J the isotopic concentration of ^{235}U ; σ is the effective fission cross section of ^{235}U for thermal neutrons; n is the integral thermal neutron flux; k is the number of atoms per molecule; d is the specific weight; R is the effective track of a fission fragment; and e is the efficiency of development of tracks. An integral dose of 10^{15} was used; the fission of ^{238}U by fast neutrons was found to be negligible. The value of e , determined by irradiating the crystal with a collimated beam of ^{244}Cm fission products, was found to be 60, 50, 65, and 70% for NaCl, KCl, LiF, and CaCO_3 , respectively. The concentrations found amounted to 5.2×10^{-9} in natural NaCl, 4.4×10^{-10} in synthetic NaCl, 6.1×10^{-10} in synthetic KCl,

1.5×10^{-6} in fine-grained CaCO_3 , 3.8×10^{-10} in the coarse grained material, and 1.3×10^{-9} LiF in units of atom per atom. The error is estimated at 50%.

T3 THE POSSIBILITY OF ELICITING THE MIGRATION OF URANIUM AND ITS DECAY PRODUCTS IN MINERALS. Bertzina, I.G., Stolyarova, A.N., Flerov, G.N. and Shimelevich, Yu. S. Dokl. Akad. Nauk SSSR 177 (5), 1062-4 (1967) (Russ).

T4 MICROSTRUCTURE OF IRRADIATED URANIUM DIOXIDE. Ishi, Bumpai, and Seki, Yoshinobu. J. Nucl. Sci. Technol. v4, No. 3, p 37-42. (March 1967).

T5 FISSION-TRACK ETCHING AS A METALLOGRAPHIC TOOL. Rosenbaum, H.S.; Armijo, J.S. (General Electric Co., Pleasanton, Calif.). J. Nucl. Mater., 22: 115-16 (1967).

Track etching was applied to studies of the distribution of atoms in metallic alloy specimens. A polycarbonate polymer was chosen to record the tracks of the fission fragments because its etching characteristics were known. The metallographic sections with their polymer detectors were irradiated. The polycarbonate detectors were then lifted mechanically from the specimens and etched in 6N NaOH at 53°C. This etching treatment developed the tracks of fission fragments without removing the replicated surface topography.

T6 URANIUM AND BORON CONTENT OF WATER BY PARTICLE TRACK ETCHING. Fleischer, R.L. (California Inst. of Tech., Pasadena); Lovett, D.B. Geochim. Cosmochim. Acta, 32: 1126-8 (Oct. 1968).

Track activation techniques make the measurement of the content of specific impurities in water particularly simple. By choosing detectors of the proper sensitivities, elements giving (n,f) reactions, such as uranium and plutonium, and those giving (n, α) reactions, such as boron and lithium, can be determined.

T7 DETERMINATION OF THE CONCENTRATION OF FISSIONABLE MATERIALS IN SOLIDS. Abdullaev, Kh.; Kapustinsk, A.; Otgonsuren, O.; Pereygin, V.P.; Chultem, D. (Joint Inst. for Nuclear Research, Dubna, USSR). Prib. Tekh. Eksp., No. 2, 73-5 (Mar.-Apr. 1968). (In Russian).

A method for the determination of the concentration of fissionable materials with a precision up to $\pm 10\%$ in solids of known chemical composition was developed. The method is based on the use of dielectric detectors for charged particles: muskovite mica, silicate glass,

lavan, and polycarbonates. For each of these the dependence of the effective range of fragments on the atomic number of the medium studied was obtained.

T8 EFFECTS OF IRRADIATION ON MICROSTRUCTURE OF SWAGED UO_2 . Ishi, B., and Takahashi, S., J Nuclear Science & Technology 5, 6 pp. 292-7 (June 1968).

T9 APPLICATIONS OF FISSION FRAGMENT ETCH PIT TECHNIQUES IN URANIUM DETECTION. Elleman, Thomas S.; Kesler, Donald C. (North Carolina State Univ., Raleigh). Nucl. Appl., 7: 170-8 (Aug. 1969).

Formation of fission fragment etch pits in glass was investigated with emphasis on the application of the method to the measurement of uranium distributions in solids and to low flux neutron dosimetry. The feasibility of using the method for determining uranium distributions in both small and large specimens was illustrated using specimens approximately 450 μm in diameter and large, uranium doped cesium iodide crystals. Upper and lower detection limits for uranium and neutron fluence were established for the glass slides employed. The purpose of the research was to illustrate the applicability of etch pit techniques to a range of problems in nuclear technology.

T10 CONTROL OF ENRICHMENT OF URANIUM IN ^{235}U BY MEANS OF TRACKS PRODUCED BY ALPHA PARTICLES IN CELLULOSE NITRATE. Chapuis, A.-M. (CEN, Fontenay-aux-Roses, France); Francois, H.; Nicodeme-Gerard, N. Radioprotection; 4: 203-14 (1969). (In French).

Cellulose nitrate registers the passage of α particles, and is insensitive to light, β particles, and electromagnetic radiations. These properties make it suitable for the control of the ^{235}U enrichment in metallic U samples. In order to facilitate the measurement and to make visible the α tracks for enumeration by optical microscopy, the samples are developed in a special bath and the number of tracks per surface unit is evaluated as a function of the changes of the reflective power of the sample. The principles of the method, characteristics of the ionographic detector, determination of the specific activity of a thick source, the reading procedure, and the evaluation of the enrichment rate are described.

T11 CONTROL OF ENRICHMENT OF METALLIC URANIUM BY MEANS OF CELLULOSE NITRATE. Chapuis, A.-M. (CEN, Fontenay-aux-Roses, France); Francois, H.; Gerard-Nicodeme, N. Radiat. Eff.; 5: 91-7 (Aug 1970). (In French).

Cellulose nitrate can be used for the registration of α -tracks and therefore for the measurement of the specific activity of thick radioactive sources. This characteristic is applied to the determination of ^{235}U enrichment rate of metallic uranium samples. For the measurement of track density, a method is developed which replaces the counting procedure under a microscope. The samples are etched in special solutions and track density is evaluated from the diffuse reflecting power of the samples. The main advantages of this method are its rapidity, ease, and low cost.

T12 NEW TECHNIQUE FOR DETERMINING THE CONCENTRATION AND DISTRIBUTION OF LEAD IN MATERIALS. Hamilton, E.I. (Radiological Protection Board, Sutton, Eng.). *Nature* (London); 231: No. 5304, 524-5 (25 Jun 1971).

A method is described for determining trace quantities of Pb, such as in bone and biological tissues. Compacted powders of the material to be analysed, in the form of thin sections or briquettes, are irradiated with about 30-MeV α particles, whereby Pb isotopes are converted to Po isotopes by (α, n) reactions. The α particles emitted by the Po are registered as tracks in sheet cellulose nitrate, which is insensitive to the other active nuclides that are also produced. Only ^{210}Po is important, because of its relatively high capture cross section and short half-life. The advantage of the technique lies mainly in the method of registering the α particles, and the detection can be improved by prolonged contact of the irradiated sample with the cellulose nitrate detector. Fading of the latent track image does not appear significant. Details of the technique are given, together with precautions. For the examples given the exposure period was 6 weeks. The number of tracks produced is proportional to the lead concentration and the sample density. NaOH was used for detector etching purposes. A suitable Pb standard was used for comparison purposes. More precise measurements can be made, however, if another element is used as an internal flux monitor, for example employing the $^{44}\text{Ca}(\alpha, p)^{47}\text{Sc}$ reaction or $^{59}\text{Co}(\gamma, n)^{58}\text{Co}$. Comparisons are made with activation analysis for several specimens.

T13 THE MICROANALYTICAL ESTIMATION OF BORON IN STEEL USING THE $^{10}\text{B}(n, \gamma)^{11}\text{Li}$ REACTION. B.A. Loveridge and C.A.J. McInnes, the *Microscope* Vol. 16 (1968).

T14 RAPID SEPARATION OF NATURAL RADIO-NUCLIDES BY PAPER ELECTROMIGRATION AND

A NEW DETECTION METHOD OF THESE ALPHA EMITTERS BASED ON ALPHA PARTICLE TRACK, Tetsuo Hashimoto and Shiro Iwata, *Japan Analyst*, Vol. 18 (1969).

T15 A NEW METHOD BASED ON ALPHA PARTICLE TRACK FOR DETECTION OF RADIO-NUCLIDES ON ELECTROMIGRATED PAPER, Tetsuo Hashimoto and Shiro Iwata, *Japan Analyst*, Vol. 18 (1969).

T16 A COMPARISON OF FISSION TRACK METHOD AND ALPHA PARTICLE METHOD FOR DETECTION OF ACTINIDE NUCLIDES, Tetsuo Hashimoto, *Japan Analyst* Vol. 19 (1970).

T17 DETERMINATION OF THE URANIUM CONTENT IN SEA WATER BY A FISSION TRACK METHOD WITH CONDENSED AQUEOUS SOLUTION, Tetsuo Hashimoto, *Analytica Chimica Acta*, 56, 347 (1971).

T18 RAPID METHOD OF CONFIRMATION OF FISSIONABLE MATERIALS WITH ETCH-PICT COUNTING METHOD, Yasushi Nishiwaki, Hiroshi Kawai, Hiroshige Morishima, Shiro Iwata, Takao Tsuruta, *International Symposium on Rapid Methods for Measuring Radioactivity in the Environment*, July 1971.

T19 QUANTITATIVE APPLICATIONS OF THE NUCLEAR TRACK TECHNIQUE, B.S. Carpenter, *Microscope* (1972).

T20 NEUTRON ACTIVATION ANALYSIS FOR OSMIUM, RUTHENIUM, AND IRIIDIUM IN SOME SILICATE ROCKS AND ROCK-FORMING MINERALS, R. Gijbels, *Institute for Nuclear Chemistry, State University, B-9000 Chent, Belgium*, H.T. Millard, Jr., G.A. Desborough, and A.J. Bartel, *U.S. Geological Survey, Denver, Colorado 80225*.

T21 NITROGEN DETERMINATION IN BIOLOGICAL SAMPLES USING THE NUCLEAR TRACK TECHNIQUE, B.S. Carpenter and P.D. LaFleur (NBS); *Transactions 1972 Annual Meeting of The American Nuclear Society*, Vol. 15.

T22 TESTING SOLID-STATE TRACK DETECTORS WITH A VIEW TO THEIR USE IN RADIO-TOXICOLOGICAL LABORATORIES, Jeanmarie, L.; Ballada, J. (CEN, Fontenay-aux-Roses, France). pp 267-81 of *Assessment of Radioactive Contamina-*

tion in Man. Vienna: International Atomic Energy Agency (1972). (In French).

Tests carried out to see whether solid-state track detectors can be considered as useful new laboratory tools are described. The tests were carried out with a detector sensitive to fissions (Makrofol) and another one sensitive to alpha radiation (cellulose nitrate). The fission detector would appear suitable for analyzing traces of uranium and the cellulose nitrate detector extremely useful for all alpha emitters. Both types of detectors seem likely to be useful for tissue autoradiography.

T23 A SIMPLE METHOD OF MEASURING LOW URANIUM CONCENTRATIONS IN NATURAL MINERALS. Price, P.B., and Walker, R.M. Appl. Phys. Lett., 2, p23 (1963).

Abstract not available.

T24 Abdullaev, K., Zakhvatayev, B.B., and Pereygin, V.P. Radiobiologiya, 8, p765 (1968).

Title and abstract not available.

T25 URANGEHALTS-BESTIMMUNG von WASSER MIT HILFE DER FESTORPERSPUR-METHODE. Dorschel, B. and Stolz, W. Radiochem. Radionat. Lett., 4, p277 (1970).

Abstract not available.

T26 Bertine, K.K., Chan, L.H., and Turekian, K.K. Geochim. Cosmochim. Acta, 34, p641 (1970).

Title and abstract not available.

T27 Murali, A.V., Parekh, P.P., and Sankardas, M. Anal. Chim. Acta, 50, p71 (1970).

Title and abstract not available.

T28 TRACE DETERMINATION ON URANIUM IN BIOLOGICAL MATERIAL BY FISSION TRACK COUNTING. Carpenter, B.S., and Cheek, C.H. Anal. Chem., 42, p121 (1970).

Abstract not available.

T29 THE CONCENTRATION AND DISTRIBUTION OF URANIUM IN HUMAN SKELETAL TISSUES. Hamilton, E.I. To Be Published (1972).

Abstract not available.

T30 Chrenko, R. M. Nature 229, 105 (1965).

Title and abstract not available.

T31 EFFECT OF THERMAL-NEUTRON IRRADIATION ON THE SUPERCONDUCTING PROPERTIES OF Nb₃Al and U₃Si DOPED WITH FISSION-ABLE IMPURITIES. Bean, C.P., Fleischer, R.L.,

Swartz, P.S., and Hart, H.R.Jr. J. Appl. Phys., 37, p2218 (1966).

Abstract not available.

T32 Aitken, E.A., Evans, S.K., Rosenbaum, H.S., and Wadekammer, D.C. Trans. Amer. Nucl. Soc., 13 (2), p602 (1970).

Title and abstract not available.

T33 Weidenbaum, B., Coplin, D.H., and Lyons, M.F. Gen. Electr. REP. GEAP-5100-7 (1967).

Title and abstract not available.

T34 BORON DETECTION IN METALS BY ALPHA-PARTICLE TRACKING. Armijo, J.S., and Rosenbaum, H.S. J. Appl. Phys., 38, p2064 (1967).

Abstract not available.

T35 FOSSIL PARTICLE TRACKS AND URANIUM DISTRIBUTION IN MINERALS OF THE VACA MUERTA METEORITE. Fleischer, R.L., Naeser, C.W., Price, P.B., Walker, R.M., and Marvin, U.B. Science, 148, p629 (1965).

Abstract not available.

T36 Carpenter. Nat. Bur. Stand. Tech. Note 548, 88-94 (1970).

Title and abstract not available.

T37 DETERMINATION OF TRACE CONCENTRATIONS OF BORON AND URANIUM IN GLASS BY THE NUCLEAR TRACK TECHNIQUE. Carpenter, B.S. Anal. Chem., 44, p600 (1972).

Abstract not available.

T38 Carpenter, B.S., and LaFleur, P.B. Nat. Bur. Stand. Tech. Note 588 (1971).

Title and abstract not available.

T39 URANIUM DISTRIBUTION IN STONE METEORITES BY THE FISSION TRACK TECHNIQUE. Fleischer, R.L. Geochim. Acta, 32, p989 (1968).

Abstract not available.

T40 Fisher, D.E. Earth Planet. Sci., Lett., 7, p278 (1969).

Title and abstract not available.

T41 HOMOGENIZED TRACK ANALYSIS OF URANIUM IN SOME ULTRAMAFIC ROCKS OF KNOWN POTASSIUM CONTENT. Fisher, D.E. Geochim. Cosmochim. Acta, 34, p630 (1970).

Abstract not available.

T42 HOMOGENIZED FISSION TRACK DETERMINATION OF URANIUM IN WHOLE ROCK GEOLOGIC SAMPLES. Fisher, D.E. *Anal. Chem.*, 42, p414 (1970).

Abstract not available.

T43 URANIUM CONTENT AND RADIOGENIC AGES OF HYPERSTHENE, BRONZITE AMPHIBOLITE AND CARBONACEOUS CHONDRITES. Fisher, D.E. *Geochim. Cosmochim. Acta*, 36, p15 (1972).

Abstract not available.

T44 LA FISSIOGRAPHIE: DIFFUSION DE L'URANIUM EN DILUTION QUASI INFINIE DANS LE TOTANE ET LE FER. DeKeroulas, F., Mory, J., and Quere, Y. *J. Nucl. Mater.*, 22, p276 (1967).

Abstract not available.

T45 APPLICATION OF THE FISSION TRACK REGISTRATION TECHNIQUE IN THE ESTIMATION OF THE FISSIONABLE MATERIALS: ^{235}U .

CONTENT IN NATURAL AND DEPLETED URANIUM SAMPLES IN SOLUTIONS. Iyer, R.H.; Sagu, M.L.; Sampathkumar, R.; Chaudhuri, N.K. (Bhabha Atomic Research Centre, Trombay, India). *Nucl. Instrum. Methods*, 109: No. 3, 453-459(1973).

The results of an investigation on the estimation of the ^{235}U content in natural and depleted uranium samples and total uranium in solutions including highly active fuel reprocessing waste streams using the solid state track registration technique are described. Two different methods were used: the "dry" method in which the detector (Lexan strip) was in contact with the fissile material in a 2π geometry and the "wet" method in which the Lexan detector strips were kept immersed in the solution of the fissile material. The relative merits and demerits and also the accuracy and precision attainable by the two methods are discussed. The feasibility of using a portable neutron source for the estimation of the ^{235}U content was demonstrated and some of the practical problems encountered and the way in which they were overcome are discussed.

U. STUDY OF NUCLEAR REACTIONS

U1 DIFFRACTION PHENOMENA IN NUCLEAR REACTIONS RECORDED ON ORGANIC FILMS. Von Oertzen, W.; Horn, P. (Max-Planck-Inst. Kernphys., Heidelberg, Ger.). *Naturwissenschaften* 55(7), 324-8 1968.(Ger).

U2 SHORT LIFETIME MEASUREMENTS. Simms (P.C.), Kuhlman (H.) [*Nucl. Phys. Lab., Purdue Univ., Lafayette, Ind.*]. COO-1420-139 (Microfiche), mars 1968, pp. 52-4. (Res. nucl. Phys., final Rep., October 1, 1964-September 30, 1967).

U3 APPLICATION OF SOLID-STATE TRACK DETECTORS FOR MEASURING ANGULAR DISTRIBUTIONS OF ALPHA-PARTICLE GROUPS FROM NUCLEAR REACTIONS. Somogyi, G.; Schlenk, B.; Varnagy, M.; Mesko, L.; Valek, A. (Inst. of Nuclear Research, Debrecen, Hungary). *Nucl. Instrum. Methods*, 63: 189-94(Aug. 1968).

For α -particle tracks in cellulose nitrate and cellulose acetate detectors there is a correlation between the diameters of the track holes and the particle energies. On this basis there is a possibility to distinguish α -groups of different energy produced by nuclear reactions and to measure their angular distributions. The usefulness of the cellulose acetate (T-cellul) track

detectors was investigated for determining angular distributions of $\alpha_0, \alpha_1, \alpha_2$, and α_3 groups from the reaction $^{19}\text{F}/d, \alpha/^{17}\text{O}$. To check the results obtained by solid-state track detector the angular distributions were determined also by using a semiconductor detector. The relative angular distributions measured by these two different methods after normalizing were in good agreement with each other within the limit of the statistical accuracy. It is concluded that the cellulose acetate track detectors can be used successfully for studying the angular distributions of α -particles from nuclear reactions.

U4 INVESTIGATION OF THE REACTION $^{19}\text{F}/d, \alpha/^{17}\text{O}$ WITH PLASTIC TRACK DETECTOR IN THE ENERGY REGION FROM 450 TO 300 keV. Mesko, L.; Schlenk, B.; Somogyi, Gy.; Valek, A. *ATOMKI (At. Kut. Intez.) Közlem.*, 11: 9-14(May 1969). (In Hungarian).

Angular distributions for $\alpha_0, \alpha_1, \alpha_2$, and α_3 groups from the reaction $^{19}\text{F}/d, \alpha/^{17}\text{O}$ have been measured by plastic track detectors in the deuteron energy range 459-303 keV. Present work can be considered as a completion of previous measurements carried out by semiconductor detectors in the energy range 645-459

keV. It appears from the comparison of the two independent measurements at 459 keV that the plastic track detector can be used not only for determining relative angular distribution but also for measuring absolute cross section.

U5 APPLICATION OF SOLID-STATE TRACK DETECTORS FOR MEASURING ALPHA-PARTICLE ANGULAR DISTRIBUTIONS IN NUCLEAR REACTIONS. Somogyi, G.; Schlenk, B. (Inst. of Nuclear Research, Debrecen, Hungary). *Radiat. Eff.*; 5: 61-8 (Aug 1970).

The track diameter of particles entering the track detectors at right angles shows a strong dependence on the energy and type of particles. Some general features of this effect are discussed. It is shown that, even in glass, different heavy nuclei can be distinguished according to their track diameters. New data are presented for α particles registered in Makrofol E. Using the correlation between α -particle energy and track diameter, detailed investigations have been carried out to measure angular distributions of α -groups from nuclear reactions. Preliminary experimental reactions obtained for reactions $^{19}\text{F}(\text{d},\alpha)$ and $^{27}\text{Al}(\text{d},\alpha)$ at very low bombarding energies are presented.

U6 USE OF SOLID-STATE TRACK DETECTORS IN NUCLEAR REACTIONS STUDIES. Zoran, V.; Popescu, Gh. (Inst. of Atomic Physics, Bucharest). *Stud. Cercet. Fiz.*; 23: No. 9, 1127-30 (1971). (In Romanian).

The detection of α particles using cellulose acetate solid state track detectors was investigated. The application of this detection method for measuring angular distributions of α -particle groups from nuclear reactions was checked for the reaction $^{27}\text{Al}(\text{p},\alpha)^{24}\text{Mg}$ at $E_p = 7.40$ MeV. The agreement of the angular distributions measured by using plastic detectors with those obtained by semiconductor detectors is good.

U7 INVESTIGATION OF $^{27}\text{Al}(\text{d},\alpha)^{25}\text{Mg}$ NUCLEAR REACTION IN THE ENERGY RANGE 650 TO 540 keV USING A PLASTICS TRACK DETECTOR. Hunyadi, L.; Schlenk, B.; Somogyi, G.; Srivastava, D.S. (Inst. of Nuclear Research, Debrecen, Hungary). *Acta Phys. Acad. Sci. Hung.*; 30: No. 1, 73-9 (1971).

The angular distributions of the α_1 and A_1 groups

from the $^{27}\text{Al}(\text{d},\alpha)^{25}\text{Mg}$ nuclear reaction were measured at deuteron energies $E_d = 650, 585$, and 540 keV by using plastic track detector techniques. The angular distributions, which are nearly isotropic, are analysed in terms of the Legendre polynomials. For an assumed statistical compound reaction mechanism the relative-intensity ratio of the two measured alpha groups can be reproduced by a simple calculation giving the statistical weight factors for the alpha transitions concerned.

U8 DETECTION EFFICIENCY OF ANNULAR GEOMETRY USED IN FISSION ISOMER STUDIES. Namboodiri, M.N.; Ruddy, F.H.; Alexander, J.M. (State Univ. of New York, Stony Brook). *Nucl. Instrum. Methods*; 108: No. 1, 1-9 (1973).

The calculation of the detection efficiency for annular geometry employed in several recent studies of fission isomers is described. The calculations cover both thin target and thick target recoil experiments. A method is presented for determining the half life of a fission isomer from the radial distribution of fission fragments observed in the annular detector. The overall efficiency of the detector is calculated for use in cross section measurements. These overall efficiencies are applicable in both track detector and semiconductor experiments that employ annular geometry.

U9 ANGULAR DISTRIBUTION OF ^{238}U PHOTO-FISSION FRAGMENTS. Dowdy, E.J., and Kryszinski, T.L. *Nucl. Phys. A* 175, p501 (1971).

Abstract not available.

U10 PHOTOFISSION OF ^{232}Th NEAR THRESHOLD: ANGULAR DISTRIBUTION. Manfredini, A., Fiore, L., Ramorino, C., and Wolfi, W. *Nuovo Cim. A4*, p421 (1971).

Abstract not available.

U11 HIGH-ENERGY PHOTOFISSION OF HEAVY AND MEDIUM HEAVY ELEMENTS. Emma, V., LoNigro, S., and Milone, C. *Nuovo Cim. (Lett.)*, 2, p117 (1971).

Abstract not available.

U12 Methasiri, T., and Johansson, S.A.E. *Nucl. Phys. A* 167, p97 (1971).

Title and abstract not available.

V. NUCLEAR CROSS SECTION MEASUREMENTS

V1 THORIUM FISSION CROSS SECTION FOR NEUTRONS BETWEEN 12.5 AND 18 MeV USING FISSION FRAGMENT DAMAGE TRACKS IN LEXAN. P.F. Rago, N. Goldstein, *Health Physics* Vol. 13, 654 (1967).

V2 HIGH-ENERGY-PROTON FISSION CROSS SECTIONS OF U, Bi, Au, AND Ag MEASURED WITH MICA TRACK DETECTORS. Hudis, J.; Katcoff, S. (Brookhaven National Lab., Upton, N.Y.). *Phys. Rev.*, 180: 1122-30 (Apr. 20, 1969).

This interaction of 0.6-29-GeV protons with U, Bi, Au, and Ag was studied with mica track detectors. Binary fission events were identified as correlated pairs of tracks. A fragment registered an acceptable track if its mass was ≥ 30 and its kinetic energy $> 6-8$ MeV. The results show: The U fission cross section $\sigma_f(U)$ is 1400 mb up to 1.0 GeV and decreases monotonically to 670 mb at 29 GeV; $\sigma_f(Bi)$ increases from 125 mb at 150 MeV to a broad maximum of 215 mb at ~ 600 MeV, and then decreases to 105 mb at 29 GeV; $\sigma_f(Au)$ varies little, 59-76 mb, in the energy region 0.6-29 GeV (The highest values appear at 2 and 3 GeV); no binary events were observed from Ag targets: upper limits are 0.3 mb at 0.6 GeV, 2 mb at 1.0 GeV, 5 mb at 2-13 GeV, and 6 mb at 29 GeV. Effects of secondary particles were shown to be negligible; the experimental uncertainty varies from ± 10 to $\pm 20\%$. Ternary fission events (140) were seen for U starting at 1.0 GeV, and for Bi and Au starting at 2.0 GeV. The yields are about 1-2 per 1000 binaries. Many single unpaired tracks were also observed, and their yield increases with beam energy. From U, most of these seem to be from a small fraction of asymmetric fissions where one of the partners is below recording threshold. From Bi and Au, most of the single tracks are high-energy spallation residues.

V3 MEASUREMENTS OF THE CROSS SECTIONS FOR FORMATION OF COMPOUND NUCLEI IN HEAVY-ION REACTIONS. Kowalsky, L.; Miller, J.M.; D'Auria, J.; Jodogne, J.C. (Columbia Univ., New York). Ref. J18 pp VIII.41-6.

Mica detectors afford a possible method of measuring the compound-nucleus part of the reaction cross section in some of the nuclear reactions induced by heavy ions. The $^{20}\text{Ne} + ^{27}\text{Al}$ and $^{16}\text{O} + ^{27}\text{Al}$ reactions were studied with incident energies (lab.) of 50 to 200

MeV. The cross section decreases when the energy increases beyond 100 MeV. This behavior seems to put an upper limit to the angular momentum above which the compound-nucleus is not formed.

V4 SOLID STATE TRACK DETECTOR AND ITS APPLICATION (FISSION CROSS SECTION MEASUREMENTS). Sakanoue, Masanobu; Nakanishi, Takashi (Kanazawa Univ., Japan). *Proc. Jap. Conf. Radioisotop.*, 9th, Tokyo, 1969; 220-2 (1969). (In Japanese).

Techniques and performance of dielectric track detectors for fast-neutron fission cross section measurements are discussed.

V5 ORNL-4437: THERMAL FISSION CROSS SECTION AND RESONANCE INTEGRAL OF Cf 249. Oliver, J.H., Halperin, J. *Chemistry Division Annual Progress Report for Period Ending May 20, 1969* p22 (1969).

V6 FACTORS AFFECTING TOTAL FISSION CROSS SECTION MEASUREMENTS USING SOLID STATE TRACK DETECTORS. Iyer, R.H.; Sampathkumar, R. (Bhabha Atomic Research Centre, Trombay, India). pp 301-9 of *Proceedings of the Chemistry Symposium, 1970. Vol. II. Bombay; Dept. of Atomic Energy* (1970).

The powerful technique of fission fragment track registration on insulating materials like mica, lexan etc., and subsequent counting of these tracks under an optical microscope is being used increasingly for a variety of studies in nuclear fission. In an attempt to extend the usefulness of previous successful work on 14 MeV neutron fission cross section measurements using this technique for a number of isotopes from ^{232}Th through ^{241}Am , a systematic study of the factors affecting the accuracy of the measurements has been made. It is shown that the results depend critically on the target thickness, uniformity, the optical magnification used for the observations of both the reference and the unknown. Optimum conditions for accurate cross section measurements are discussed in the light of these experiments.

V7 USE OF A SOLID DETECTOR TO MEASURE THE THORIUM-232 EFFECTIVE FISSION CROSS SECTION BY NEUTRONS. Valle, J.; Casanova, Jose (Dep. Fis. Fund., Univ. Valladolid, Valladolid, Spain). *An. Fis.* 66(5-6), 195-200 1970, (Span).

V8 MEASUREMENT OF LOW REACTION CROSS-SECTIONS WITH DIELECTRIC TRACK DETECTORS. Srivastava, D.S. (Aligarh Muslim Univ., India); Somogyi, G.; Schlenk, B.; Hunyadi, I. pp 533-8 of *Proceedings of the Nuclear Physics and Solid State Physics Symposium. Vol. II. Bombay; Department of Atomic Energy (1970).*

V9 LOW-ENERGY DEUTERON FISSION CROSS SECTIONS OF ^{231}Pa MEASURED WITH MICA TRACK DETECTOR. T. Nakanishi and M. Sakanoue. *Radiochemistry Acta*, 16, 24 (1971).

V10 BNL-13124, HIGH ENERGY FISSION CROSS SECTIONS OF U, Bi, Au, AND Ag MEASURED WITH MICA TRACK DETECTORS. Hudia, J., and Katcoff, S. *Brookhaven Nat. Lab., Upton, New York (1969).*

Abstract not available.

V11 LOW-ENERGY CROSS SECTIONS FOR $^{10}\text{B}(\text{p},\alpha)^7\text{Be}$. Szabo, J., Csikai, J. and Varnagy, M. *Nuclear Physics A195*, 527-533 (1972).

Abstract not available.

V. MISCELLANEOUS SPECIFIC APPLICATIONS

W1 ETCH PIT STUDIES OF DISLOCATIONS IN COPPER CRYSTALS DEFORMED BY BENDING. I. ANNEALED CRYSTALS. II. IRRADIATED CRYSTALS. F.W. Young, Jr. (Oak Ridge National Lab., Tenn.). *J. Appl. Phys.*, 33: 3553-64 (Dec. 1962).

Annealed and irradiated copper crystals of low initial dislocation density were deformed by bending, and dislocation multiplication and motion were studied using an etch pit technique for observing the dislocations. For the annealed crystals, dislocation motion and multiplication was observed prior to macroscopic yielding, and the percentage of grown-in dislocations moved by the stress increased with the stress. The dislocations were hindered in the motion by subboundaries and by interaction with other dislocations. Relaxation effects were observed and were much greater for stresses less than the yield stress than for higher stresses. For neutron-irradiated crystals there was no motion or multiplication of dislocations prior to yielding. The slip traces were long, with dislocations closely spaced in the trace. Although not conclusive, the evidence was shown to be interpretable in terms of source hardening. A cube-root dependence of the yield stress on neutron dose was observed. No hardening resulted from irradiation with $10^{18}/\text{cm}^2$ cobalt γ rays.

W2 DETECTION OF NUCLEAR DISINTEGRATIONS PRODUCED BY 1.55-BeV PROTONS IN SILVER CHLORIDE SINGLE CRYSTALS. Charles B. Childs and Lawrence Slikin (Univ. of North Carolina, Chapel Hill). *Phys. Rev. Letters*, 9: 354-5 (Oct. 15, 1962).

A technique that makes tracks of heavy primary cosmic rays visible in transparent silver chloride single

crystals is shown to be applicable to the study of nuclear disintegrations produced by particles accelerated in high-energy machines. Tracks of events produced by a 1.55 BeV proton beam are presented and discussed. Events observed include hammer tracks, collision-produced particles with ranges greater than 1800 microns, and events thought to be decays of Be^8 into two alpha particles.

W3 AEROSOL FILTRATION BY NUCLEAR PORE FILTERS. Spurny, K., and Lodge, J.P., Staub, 28, 179-186, (May 1968). (In German).

Nuclear pore filters (NPF) are prepared in a nuclear reactor. Their plastic is drilled by fission fragments and then to enlarge the pore size, sent to an etching bath. This filter has properties very similar to membranes. The structure and filtration properties of NPF were studied by aerosol filtration. The pressure drop of NPF was approximately the same as membranes. The theory of a pore filter was extended and applied to NPF. Agreement with experiment was good. Filtration kinetics were also studied. The use of NPF for measurement of aerosol concentration, particle size, aerosol particle morphology and chemical analysis, was examined.

W4 SPONTANEOUS FISSION OF LEAD: SEARCH FOR VERY FAR TRANSURANIUM ELEMENTS. Flerov, G.N.; Perehygin, V.P. (Joint Inst. for Nuclear Research, Moscow). *Ref. J18*, pp VIII.20-26 (1969).

Tracks of nuclear fission fragments in Pb and its compounds were recorded with dielectric trace detectors. For the lead glass this effect corresponds to the spontaneous fission half-life of Pb (2 to 3) $\times 10^{20}$ years. Various possible sources of the effect are

analyzed. The existence of a long-lived spontaneously fissionable transuranic nuclid is a possible interpretation of the activity studied.

W5 (CERN-70-27) METHOD OF MEASUREMENT OF THE BEAM PROFILE FOR HIGH-INTENSITY PARTICLES ($10^{12}/\text{cm}^2$). Annoni, H.; Cordaillat, A.; Herz, A.J.; Mendola, O.; Oppel, R. (European Organization for Nuclear Research, Geneva (Switzerland). 13 Oct 1970. 12p. (In French).

This method allows a rapid and precise determination of the beam profile, the position of the maximum of the intensity and the absolute intensity (with an error of about 10%). At present, it can be used for intensities between 10^{11} and 2×10^{12} particles/cm². Thin plastic detector foils (cellulose nitrate) are exposed normal to the beam under study and the measurements are carried out with a microdensitometer. Nuclear-research emulsions have been used as a comparison standard. The first measurements were carried out in a proton beam of energy 600 MeV; the method can, of course, be applied to any other kind of high-intensity, high-energy beam.

W6 DETERMINATION PAR CANALIGRAPHIE DE L'ORIENTATION DE MICROCRISTAUX. Delsarte, G., Desormont, G., and Mory, J. *Phys. Status Solidi* 5A, p683 (1971).

Abstract not available.

W7 RADIOGRAPHY OF PLUTONIUM BY MEANS OF CHanneled ALPHA PARTICLES. Quere, Y., and Couve, H. *J. Appl. Phys.*, 39, p4012 (1968).

Abstract not available.

W8 METHOD FOR MEASURING THE BEAM PROFILES OF HIGH-INTENSITY PARTICLES ($10^{12}/\text{cm}^2$). Annoni, H. (CNRS, Strasbourg); Oppel, R.; Cordaillat, A.; Herz, A.J.; Mendola, O. Ref. J46 239-258, 1970. (In French).

This method allows a rapid and precise determination of the beam profile, the position of the maximum of the intensity and the absolute intensity (with an error of about 10%). At present, it can be used for intensities between 10^{11} and 2×10^{12} particles/cm². Thin plastic detector foils (cellulose nitrate) are exposed normal to the beam under study and the measurements are carried out with a microdensitometer. Nuclear-research emulsions have been used as a comparison standard. The first measurements were carried out in a proton beam of energy 600 MeV; the method can, of course, be applied to any other kind of high-intensity, high-energy beam.

W9 (IAE-2078) NEUTRONS SPATIAL MICRO-DISTRIBUTION MEASUREMENT BY FISSION FRAGMENT TRACKS DENSITY DISTRIBUTION IN POLYETHYLENETEREPTHALATE. Gulimov, V.N.; Zarubin, Yu.V.; Obukhov, V.K.; Ushakov, Yu. V. (Gosudarstvennyi Komitet po Ispol'zovaniyu Atomnoi Energii SSSR, Moscow. Institut Atomnoi Energii). 1971. 8p. (In Russian).

A method for the measurement of the three-dimensional microdistribution of neutrons by means of flexible sandwiches composed of polyethyleneterephthalate films and U-containing targets is described. Examples of the method are reported and the possibilities of the method are characterized. Recommendations on the application of the method are given.

TRACK REGISTRATION PATENTS

1 SHEET PERFORATION BY IRRADIATION. General Electric Co. Brit., 1,042,602 (Cl. C01b), Sept. 14, 1966; U.S. Appl. Feb. 28, 1962; 7 pp.

Thin sheets, esp. of mica, are subjected to radiation by heavy charged particles producing linear tracks therein, from which the material is removed by etching or leaching, leaving holes of 5-20,000 Å diam. which in many cases extend entirely through the sheet. By the use of proper screens and spacing, the holes are made parallel and perpendicular to the surface. O ions will produce parallel tracks, 5 Mev. being sufficient to drive them through mica 1 μ thick and 100-150 Mev.

through sheets 100 μ thick. Thus, a U sheet 2 μ thick and Al and mica sheets each 100 μ thick were superimposed and exposed for 1 min. to thermal neutrons from a reactor of the specifications for neutron flux of the Brookhaven reactor. Mica flakes ~2000 Å thick were split off and tracks 25 Å in diam. were observed in them by electron microscopy. There were ~ 10^{10} tracks/cm² of surface. The flakes were immersed in 20% aq. HF at 100°F. and removed at intervals, then rinsed in H₂O, leaving holes running completely through the sheet. The diam. of the holes can be controlled by the duration and type of

reagent used for etching. Such perforated sheets are useful as filters or mol. sieves, for H_2O purification, as calibrated leaks for vacuum systems, or as a collimator to produce point sources of radiations. The holes can be filled with superconducting material or with Fe particles to produce an oriented, single-domain ferromagnetic sheet, or for use as an imaging surface in TV cameras.

2 PROCESS AND DETECTOR FOR INDICATING THE TRACKS OF ALPHA PARTICLES USING STACKED LAYERS OF MATERIAL. Evans, Robley D. U.S. Patent 3,419, 472. Dec. 24, 1968. Filed Apr. 4, 1966.

Stacked layers of materials such as plastics are used for indicating the tracks of α particles. Each layer of material has the thickness comparable with the effective etching depth of the material. After irradiation, the layers may be separated and separately etched, enabling α tracks to be detected that would otherwise be undetectable in solid media of the same thickness as the stack of layers. Materials suitable for use include cellulose nitrate, cellulose acetate, and cellulose acetate butyrate.

3 TRACK REGISTRATION ALPHA AUTO-RADIOGRAPHY. Davies, John H.; Ruiz, Carl P.; Storms, Howard A. (to General Electric Co.). U.S. Patent 3,493,751. 3 Feb 1970. Filed 17 Jun 1966.

A process for producing autoradiographs of alpha-particle emitting objects is disclosed. Typically, a sheet of track-registration material is placed adjacent to an alpha emitting object, maintained there for suitable period, and then treated with an etchant. The etchant selectively dissolves damage tracks along the parts traversed in the material by alpha particles. The tracks produce a visible image corresponding to alpha-emitting portions of the objects.

4 METHOD AND APPARATUS FOR FISSION FRAGMENT IRRADIATION. Johnston, Robert B.; Porter, Charles R.; Wilson, Dennis W. (to General Electric Co.). U.S. Patent 3,529,157. 15 Sep 1970. Filed 11 Aug. 1966.

A method and apparatus are described for continuously irradiating a strip of dielectric material with fission fragments. In a typical embodiment, a tape of a dielectric material is passed adjacent a sheet of fissionable material which is bombarded with neutrons to cause the emission of fission fragments from the fissionable material. The fission fragments are collimated and impinge on the tape, forming damage tracks.

The irradiated strip is suitable for treatment in an etchant which removes material along the damage tracks formed by the fission fragments. These strips are then ready for use as membrane filters.

5 VISUAL IMAGING OF TRACK-ETCHED PATTERNS. Alter, Henry Ward (to General Electric Co.). British Patent 1,152,032. May 14, 1969. Priority date Oct. 20, 1966, United States.

A method of producing a visual image of a pattern of holes through a sheet of track-etched material, comprising the steps of positioning a sheet of receptor material in face-to-face contact with the track-etched sheet; applying a marking fluid to the track-etched sheet to flow through the holes into contact with the receptor sheet, whereby the marking fluid is deposited in a pattern of dots on the receptor sheet to produce a visual image of the hole pattern.

6 VISUAL IMAGING OF TRACK-ETCHED PATTERNS. Henry W. Alter (to General Electric Co.). U.S. 3,373,683 (Cl. 101-129), March 19, 1968, Appl. Oct. 20, 1966; 3 pp.

The damage tracks produced by irradiation in a thin (<0.0005 in.) solid-state detector material (e.g., mica, inorg. glass, or a polymeric plastic) are etched in a conventional manner. The detector material is then positioned in face-to-face contact with a slightly porous receptor material (e.g., paper). A marking fluid, such as a low viscosity ink, is then applied to the surface of the track-etched sheet so that the fluid is forced through the holes to produce dots on the receptor sheet, which dots are large and intense enough to be visible without the need of optical magnification. Multiple copies of the hole patterns can also be produced by repeating the marking process with additional sheets of receptor material. Another approach is to use a receptor sheet which includes an indicator dye which changes color on contact with a reagent contained in the marking solution. This inexpensive process increases the speed with which the presence and depth of etched holes can be detected and should increase the application of the track-etching process to such fields as dosimetry and radiography.

7 RADIATION SENSITIVE MATERIALS. Sherwood, Harold Frank (to Eastman Kodak Co.). British Patent 1,208,024. 7 Oct 1970. Priority date 9 Nov 1966, United States.

A thin color-change layer is coated with a thin polymer film. After exposure to charged particles, the polymer film is etched and then the color-change

layer is selectively developed (only the portions exposed by the etched tracks in the polymer film). In the preferred embodiment, the color-change layer is a photographic film.

8 ENHANCING RADIATION DAMAGE FOR NUCLEAR PARTICLE DETECTION. Sherwood, Harold Frank (to Eastman Kodak Co.). U.S. Patent 3,501,636. 17 Mar 1970. Filed 9 Nov 1966.

A solid-state nuclear particle detector is composed of two layers, an overcoat sensitive to radiation damage and an underlying material in which color changes occur when contacted by certain materials. The radiation-damageable material is exposed to the nuclear particles and then etched to produce fine channel in the material showing the particle paths. A modifier is then applied to the overcoat and passes through the etched paths in the overcoat to react with the color sensitive material in the underlying material. This provides a high-contrast image of the radiation damage caused by the particles. Various materials are suggested for both the overcoat and underlying material depending on the type radiation to be detected, and the type of indication of radiation damage desired.

9 TRACK-ETCH NEUTRON RADIOGRAPHY. Alter, Henry Ward (to General Electric Co.). U.S. Patent 3,457,408. Filed Dec 12, 1966.

A method and apparatus for neutron radiography using track-etch techniques are disclosed. Typically, in this system an object is placed between a neutron source and a composite consisting of a sheet of detector material and a conversion material. Neutrons passing through the object with variable attenuation, cause the emission of charged particles by the conversion material which impinge on and form damage tracks in the detector sheet. The damage tracks are enlarged by etching. Where neutron density is sufficient, a visible variable density, light scattering, radiographic image of the object results.

10 METHOD OF MEASURING FAST NEUTRONS BY OBSERVING MULTIPRONGED TRACKS OF CHARGED PARTICLES FORMED IN CELLULOSE NITRATE. Price, Paul B.; Walker, Robert M.; Fleischer, Robert L. (to General Electric Co.). U.S. Patent 3,564,250. 16 Feb 1971. Filed 3 Jan 1967.

A means for detection of fast neutrons by chemically drilling or etching out multipronged tracks of charged particles formed in cellulose nitrate test bodies by collisions of fast neutrons with nuclei including

those of carbon, nitrogen, oxygen, and boron is described.

11 VITREOUS COMPOSITION FOR MEASURING NEUTRON FLUX. Yokota, Ryosuke; Muto, Yuhei; Nakajima, Saburo; Fukuda, Kiyoshi (to Tokyo Shibaura Electric Co., Ltd.). British Patent 1,194,141. 10 Jun 1970. Priority date 17 Jan 1967, Japan.

A vitreous composition that essentially consists of an alkali metal metaphosphate throughout which there is uniformly distributed a fissile material in the form of an oxide is presented. The vitreous composition is particularly sensitive to fast neutrons.

12 APPARATUS FOR DETECTING α -PARTICLES. Alter, Henry V.; Price, Paul Bulford (General Electric Co.) Fr 1,578,275 (Cl. G 01t), 14 Aug 1969, US Appl. 19 Jul 1967; 16 pp.

13 DETERMINATION OF α -EMITTERS IN SOLUTION. Alter, Henry W. (General Electric Co.) Ger. Offen. 1,908,621 (Cl. G 01r), 18 Sep 1969, US Appl. 26 Feb 1968; 15 pp.

14 METHOD OF AMPLIFYING RADIATION DAMAGE IN A NUCLEAR DETECTOR. Goulin, Jean Paul Lucien (to Eastman Kodak Co.). British Patent 1,250,233. 20 Oct 1971. Priority date 5 Mar 1968, France.

An etching procedure for dielectric track detectors is described for amplifying the particle tracks. A basic aqueous solution containing a swelling agent for the sensitive material is used, and then another basic aqueous solution containing a solvent for the sensitive material is used.

15 TRACK REGISTRATION PROCESS. Crawford, Wayne Thomas; Humphrey, Joseph Stevenson Jr. (to General Electric Co.). British Patent 1,240,767. 28 Jul 1971. Priority date 28 June 1968, United States.

In the processing of dielectric track radiation detectors, the step is proposed of exposing the dielectric to ultraviolet light in the presence of oxygen after irradiation and before the tracks have been treated with etchant. This procedure results in greatly increased etching of the altered material along the tracks.

16 PERSONNEL RADON DOSIMETER. Becker, Klaus H. (to U.S. Atomic Energy Commission). U.S. Patent 3,505,523. 7 Apr 1970. Filed 2 Aug 1968.

An organic polymer foil, such as cellulose triacetate, mounted within a holder and worn on a person has been found to be an efficient and accurate dosim-

eter for radon and its daughter products. This material is insensitive to light and sufficiently insensitive to temperature and humidity such that it may be used in uranium mines and other environments where these injurious agents may be present. Simple etching of alpha particle tracks which are registered in the foil makes them visible at low power magnification, and radiation dose may then be estimated by conventional or automatic track counting techniques.

17 NEUTRON DETECTOR. Kozlov, Stanislav Fedorovich (to Fizichesky Institut Imeni PN Lebedeva Akademii Nauk Sssr). British Patent 1,246,372. 15 Sep 1971. Priority date 3 Oct 1968, Russia.

A neutron detector is described which employs a radiator foil and a diamond crystal detector. The radiator may consist of boron-10, lithium-6, or fission foils.

18 METHOD AND APPARATUS FOR DOSIMETRIC MEASUREMENT OF RADIATION. Price, P.B.; Walker, R.M. (to General Electric Co.). Canadian Patent 803,628. Jan 7, 1969.

A device is described which consists of a thin sheet of glass or mica containing a minute amount of fissionable material and a strip of cadmium foil for measuring radiation at extremely high levels such as nuclear explosions or operating reactors. After exposure, there is a process of dissolving and removing from the sheet fission fragment damage "track-defining" material and thereafter determining the number of recesses formed in the sheet by optical microscope counting. Fast and thermal neutron radiation can be detected up to a factor of 10^{15} and from room temperature to 600°C. An accurate readout is obtained from the fission product tracks.

19 PLASTIC TRACK-TYPE DETECTOR FOR SLOW NEUTRONS HAVING THE NEUTRON CONVERSION SUBSTANCE UNIFORMLY DISPERSED THEREIN. Schultz, Warner W.; Jones, Stanley L. (to United States Atomic Energy Commission). U.S. Patent 3,548,191. 15 Dec 1970. Filed 13 Mar 1969.

This invention is a track-type detector for slow neutrons (0.01 eV to 0.1 MeV) comprising a substrate on which a track detector plastic is deposited, the plastic containing a uniform dispersion of one of the following compounds: Tetraphenyl boron, hexamethyl borazine, lithium ricinoleate, or carborane.

20 METHOD FOR MAKING VISIBLE RADIATION DAMAGE TRACKS IN TRACK REGISTRA-

TION MATERIALS. Crawford, Wayne T.; Humphrey, James S. Jr.; De Sorbo, Warren (to General Electric Co.). U.S. Patent 3,612,871. 12 Oct 1971. Filed 1 Apr 1969.

An improved method for treating a plastic film to make tracks formed in the film visible is described. The film is subjected to irradiation with charged particles, then is exposed to radiation selected from the group consisting of electromagnetic radiation having wavelengths less than about 4,000 angstroms and electrons having energy levels above about 1.5×10^6 electron volts in the presence of oxygen. When treated with a solvent which preferentially attacks the material along the particle tracks, the tracks dissolve away rapidly, leaving substantially cylindrical holes in the film, with little degradation of the body of the film. This pre-etching treatment results in more rapid etching of the damage tracks, in tracks of more uniform cross section, in smaller initial pore sizes, and in greater thermal stability of the tracks.

21 NEUTRON DOSIMETER INCLUDING A STEP WEDGE FORMED OF AN ALPHA-ATTENUATING MATERIAL. Kastner, Jacob; Oltman, Billie G. (to United States Atomic Energy Commission). U.S. Patent 3,604,931. 14 Sep 1971. Filed 10 Dec 1969.

A neutron dosimeter includes a material which emits alpha particles when bombarded with neutrons, a plastic foil in position to intercept these alpha particles and a step wedge of a material, capable of attenuating the alpha particles disposed between the alpha-emitting material and the plastic foil. The step wedge varies from zero thickness to such a thickness as will attenuate the most energetic alpha particles formed in the dosimeter to particles having an energy such that the particles form tracks in the plastic foil. Following exposure to neutrons the plastic foil is etched to expose the alpha tracks in the plastic. The location of the tracks in the plastic indicates the energy of the neutrons and the total number of tracks in the plastic indicates the intensity of the neutron flux.

22 DETERMINING RADIATION TRACKS IN SHEET MATERIAL AND APPARATUS THEREFOR. Cross, W.G.; Tommasino, L. (to Atomic Energy of Canada Ltd.). Canadian Patent 859,262. 24 Dec 1970.

Fission fragment tracks produced in sheet mica and other electrical insulating materials of radiation dosimeters are counted by leaching the tracks so that

they provide electrical discharge paths through the sheet. Aluminum foil is placed on top of the sheet and a voltage is applied between an electrode covering the underside of the sheet and the foil to sequentially puncture the foil by electrical discharges through the tracks. The discharges are then counted.

23 ARRANGEMENT FOR NEUTRON DOSIMETRY. Serge Pretre, Geroldswil, and Kurt Heusi. Swiss Patent number 508 887.

24 RADON DETECTION. Alter, Henry Ward; Price, Paul B. (to General Electric Co.). U.S. Patent 3,665,194. 23 May 1972. Filed 27 Dec 1968.

Method and apparatus for detecting and monitoring radon gas and its alpha-emitting daughter products are described. A sheet of track-registration material is exposed in an area to be monitored, the material having the property of forming damage tracks along paths traversed by alpha particles. After exposure, the material is etched with a reagent to enlarge the tracks, this process making them visible so they can be counted. The number of tracks formed during the exposure period is a measure of the amount of radon and radon daughters present in the monitored area. The invention is useful as a dosimeter to monitor mine atmospheres, and also has applications in uranium prospecting. (9 figures)

25 METHOD AND APPARATUS FOR COUNTING RADIATION DAMAGE TRACKS IN SHEET MATERIAL USING A CAPACITIVE DISCHARGE DEVICE. Cross, William Gunn; Tommasino, Luigi (to Atomic Energy of Canada Ltd.). U.S. Patent 3,663,815. 16 May 1972. Priority date 18 Feb 1969, Canada.

Fission fragment tracks produced in sheet mica and other electrical insulating materials of radiation dosimeters are counted by leaching the tracks so that they provide electrical discharge paths through the sheet, placing an aluminum foil on top of the sheet, applying a voltage between an electrode covering the underside of the sheet and the foil to sequentially puncture the foil by electrical discharges through the tracks and counting the discharges.

26 METHOD OF RECORDING THE TRACKS OF IONIZING PARTICLES. Audran, R.G.; Renard, G.G. (to Societe Kodak-Pathe). French Patent 2,092,829. 28 Jan 1972. Filed 23 Jun 1970. (In French).

A method of recording the tracks produced by ionizing particles in a plastic material is presented. The method enables photographic reproductions of the

tracks to be made by contact. A colored cellulose material is used. The thickness of this material is chosen in relation to the ionizing particles under consideration and the etching process envisaged, such that it exceeds the maximum length of the particle tracks. After irradiation, the material is treated with an alkaline reagent, such that the particle tracks are revealed in the colored material. In the case of the colored material considered, this density difference is sufficient to allow a photograph to be made by contact. In neutron radiography, the secondary α emission resulting from the conversion of a neutron flux is also recorded. The cellulose material is, in this case, covered with a conversion layer (lithium borate), which is dissolved away by treatment with warm water.

27 PRODUCT FOR NEUTRONOGRAPHY. Audran, Roger Gaston Louis; Renard, Guy Jean Alfred (to Kodak-Pathe). French Patent 2,092,830. 28 Jan 1972. Filed 23 Jun 1970. (In French).

A product for neutron radiography is presented. This product may be used for recording and counting tracks produced in solid media by the secondary emission of ionizing α particles resulting from the conversion of a neutron flux. This product consists of an inert, transparent, and uncolored polyester substrate provided with a substratum. The recording layer is made from colored cellulose nitrate. The product is also provided with an intermediate layer composed of a water-soluble hydrophile bonding material and a conversion layer consisting of a borate dispersed in lithium in a water-soluble bonding material.

28 GEOMETRY CONTROL OF ETCHED NUCLEAR PARTICLE TRACKS. Fleischer, R.L.; Price, P.B.; Bostick, E.E.; Holub, F.F. (to General Electric Co.). U.S. Patent 3,713,921. 30 Jan 1973. Filed date 1 Apr 1971. 6p.

A process is described for making holes of reduced taper in a solid containing tracks of radiation damaged material. The solid is contacted with an etchant containing a surfactant. The product is useful as a filter.

29 NEUTRON DETECTOR OF THE TRACK-DAMAGE TYPE. Bredoux, F.J.M.; Mercier, C.A.; Philpot, G.A. (To Eastman Kodak Co.). U.S. Patent 3,735,135. 22 May 1973. Priority date 4 Nov 1969, France. 8p.

A neutrographic product comprising a recorder layer capable of undergoing selective radiation-damage (dielectric track detector) and a converter layer comprising a composition dispersed in a binder, said

composition being capable of producing a nuclear (n,α) reaction, is described.

30 RADIATION DETECTION METHOD. Fleischer, R.L.; Walker, R.M. (to General Electric Co.). U.S. Patent 3,770,962. 6 Nov 1973. Filed date 1 Nov 1971. 8p.

A method for detecting and measuring charged particles is described. A thin sheet of a dielectric material is exposed to form tracks which pass through the thickness of the sheet. The sheet is then contacted

with an etchant which selectively dissolves and removes the tracks of radiation damaged material to form holes extending from one surface of the sheet through the opposite surface. The resulting holes are a measure of radiation damage and are detected by visual means by detecting the light which emerges from the holes on the one side of the etched sheet while the opposite side of the etched sheet is irradiated with light having a wavelength which is absorbed by the material in an amount sufficient to produce a significant contrast to the light passing through the holes.