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DETERMINATION OF FISSION FRAGMENT COUNTING LOSSES FROM THE FISSION CHAMBER SPECTRUM

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Part II: Scratched targets

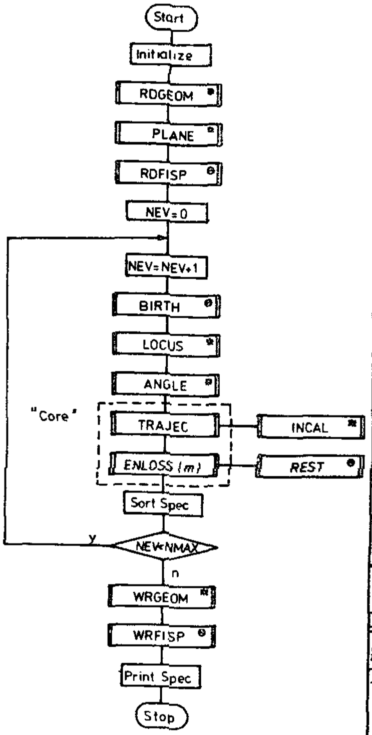
4. SIMULATION OF DISTURBED TARGET LAYERS

The relations obtained for a plane target layer suggest to investigate how the plateau height reflects additional counting losses caused by a disturbed - e.g. scratched - surface of the backing or the target layer. In this case, analytic calculations are involved, and a more efficient way is to simulate such effects by Monte-Carlo calculations.

4.1. Monte-Carlo code ROBER

In practice, various microscopic and macroscopic deviations from the plane layer model are imaginable which influence the detection efficiency in a different degree. It seems to be not advantageous to implement an algorithm restricted to a given surface type. On the other hand, the algorithm should be as simple as possible. Therefore, a procedure was choosen which allows to treat a broad variety of problems in a standardized manner (Fig. 8,9):

The geometry of the problem is assumed to be described by planes. (This is, in fact, no strong restriction, because a necessary improvement of the model can be realized by introducing additional planes.) For each emitted particle an origin P_0 inside the target layer T and an emission direction ϑ, φ are fixed by the subroutines LOCUS and ANGLE, respectively. The straight line given by P_o, ϑ, φ crosses the planes p_i describing the geometry; the distance a_i from P_o and a material index m_i are determined for each point of intersection P_i lying in "forward" (i.e. emission) direction. After that, points P_i with a material index m_i=0 (no transition into another medium) are erased, and the remaining P_i representing transitions into other media are arranged to rising distance a_i. The obtained in this way "coordinates" of material transitions ($[a_j, m_j]$; $j=1,2,\ldots,j_{max}$) are used to calculate the energy E_j of the particle at each P_j and subsequently the total energy loss in an egligible medium m. The described algorithm represents the "core" of the Monte-Carlo code ROBER ("Rauhe Oberflächen") and is implemented in the subroutines TRAJEC and ENLOSS (Fig. 8). To calculate fission chamber spectra, the obtained energy loss in the fission chamber gas (medium D in Fig. 9)



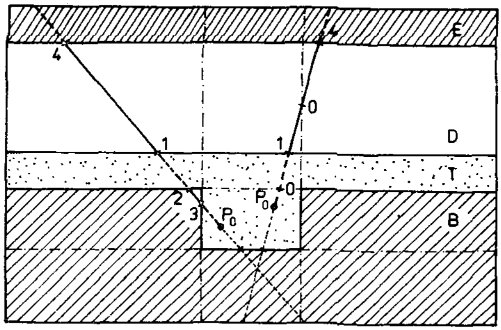


Fig.9: Illustration of the algorithm implemented in TRAJEC: Two trajectories are shown, points of intersection with the planes describing the geometrical model and the corresponding material indizes are indicated.

Fig.8:

Structure of the Monte-Carlo code ROBER (Rauhe Oberflächen)

* Library "Geometrical Model"

⊗ Library "Stopping-Power Model"

for each considered event is stored in a spectrum.

The complete code consists of a "frame" organizing the course of the calculation, the "core" realizing the general section of the algorithm, and the libraries "Geometrical Model" and "Stopping-Power Model" containing all subroutines which must be specified regarding the implemented geometrical model, the used stopping-power data and the assumed mass and initial energy distribution of the fission fragments (Fig.8). The structure of the code ROBER (including common block structure and parameter lists of the subroutines) guarantees a maximum decoupling of the two libraries from the general algorithm. The implementation of different geometrical models or the application of various stopping-power and fission fragment data (empirical formulas or tables) then can be realized by a simple exchange of selected subroutines and functions and does not require any knowledge about the implementation of the general part of the algorithm. Introduced statement variables render possible to generate separate spectra containing selected events, i.e. particles originating in a fixed area of the target layer and/or having trajectories with selected emission directions. In the implemented versions of ROBER, such a separate spectrum is built-up only for particles emitted from an emphasized area of the target layer; but a refinement is possible and easy.

4.2. Implementation of simple surface and stopping-power models

If the influence of deviations from the plane layer model on the observed correlation between counting losses and the plateau height in a parallel plate ionization fission chamber is to analyze, one has at first to search for systematic trends, and various types of disturbances have to be investigated. Therefore, simple models reflecting the main attributes of the investigated effects are efficient even if no precise quantitative description of true counting losses can be expected - all the more as it should be impossible to construct a "realistic" geometry of target layers used in practice. The "Triangle" stopping-power model

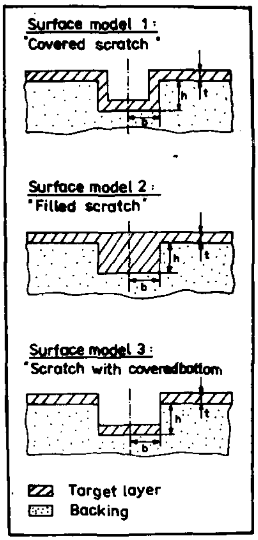


Fig.10 :

Implemented scratch models

(see Fig.4) was succesful in describing the main features of the plane layer model, and its application to investigate disturbed target layers is obvious. In a first version of the library "Stopping-Power Model" (STOPOWØ1) this model was implemented for a "mean" fission fragment, in analogy to the analytic calculations carried out for the plane layer model (see Fig.5). The range-energy data then are completely defined by the energy E_o of the "mean" fission fragment and its ranges R_{oi} in the various media. Photographies of fissile layers used in fission cross-section measurements of the TU Dresden/RI Leningrad cooperation, obtained by microscopy /5/, suggested to investigate the "scratch" as the dominating type of surface disturbances. Therefore, three different "scratch" models were constructed representing borderline cases of possible fillings (Fig.10). The geometrical models realized in the versions SURFACEØ1...Ø3 of the library "Geometrical Model" describe parallel plate fissions chambers, consisting of a backing covered by a target layer with periodic scratches corresponding to Fig.10, an electrode, and a gaseous agent filling the space between target surface and electrode; the dimensions of electrode and target arrangement are assumed to be great enough to neglect a fission fragment escape out of the active volume. The parameter defining the geometry are

- scratch distance (2a);
- scratch width (2b);
- scratch depth (h);
- thickness of the target layer (t);
- target-electrode distance (d);
- pressure of the gas filling (p).

The subroutines LOCUS and ANGLE are based on the conception of a homogeneous distribution of the origins of fission fragment trajectories and an isotropic distribution of the emission directions, i.e. spontaneous or thermal neutron induced fission within a homogeneous target material and a homogeneous neutron field. Because counting losses as well as pulses in the plateau region of the pulse height spectrum are produced by rare events with origins inside the scratch or "flat" trajectories (small angles relative to the target surface), a non-analogous Monte-Carlo method was applied. A distribution function F(x) was introduced which allows a simple and intuitive adjustment of the deviation from a "white" distribution by means of a parameter A (Fig.11): The subroutine RNDIST(A,X,WEIGHT) generates a random value X ($0 \leq X < 1$), and the probability of generating a value $X > A$ is nearly 0.5 for $A > 0.5$; WEIGHT = $(dF(X)/dx)^{-1}$ is the weight of a corresponding event and renormalizes the weigh-

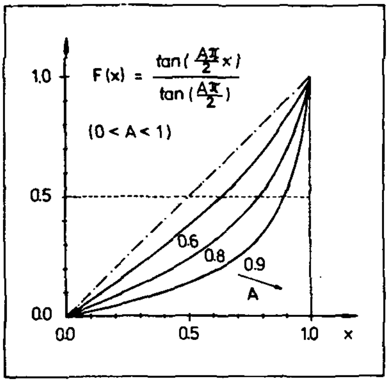


Fig.11:
Distribution function F(x) implemented in RNDIST

ted distribution to a "white". spectrum. RNDIST was used in both subroutines LOCUS and ANGLE to favour the interesting rare events. Two additional geometrical parameters DL and DTHETA are requested from RDGEOM: About 50 % of the total number of generated fission events then have trajectories with an origin inside a localized area, characterized by a maximum distance from the middle of the scratch of DL+b ($-b < DL < a-b$), and with an angle relative to the electrode plane smaller than DTHETA ($0 < DTHETA < 90^{\circ}$), respectively. By choosing optimum parameters, the statistical uncertainty of the calculated plateau height was reduced significantly (see for example Fig.12,13).

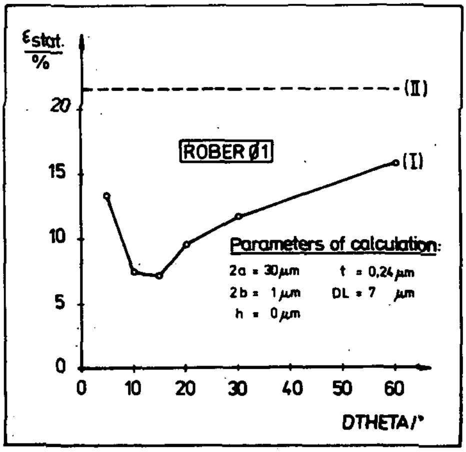


Fig.12:
Influence of the parameter DTHETA on the statistical uncertainty ε_{stat} of the calculated plateau height:

(I) obtained with ROBERØ1 (5000 events; geometry: plane layer; $t/R_o = 0.0267$; analyzed plateau region: 6...14 MeV);

(II) estimated statistical uncertainty of a corresponding analogous Monte-Carlo calculation.

Using the libraries STOPOWØ1 and SURFACEØ1...Ø3, the versions ROBERØ1...Ø3 of the code ROBER were generated and installed at the CDC-6500 computer of the JINR Dubna. To verify the correct work of the complete codes, the subroutines and functions were tested separately following a bottom-up strategy; selected sets of input data guaranteed that each order was addressed. As an additional test, the plateau height as well as the counting losses were simulated for a plane target layer, applying the codes ROBERØ1...Ø3 with specialized sets of geometrical parameters. Fig.14 shows the results, compared with the plateau height, the counting losses and the plateau height / counting loss relation obtained by analytic calculations using the formulas (6,10-12); details of the analysis and error estimates agree with the cal-

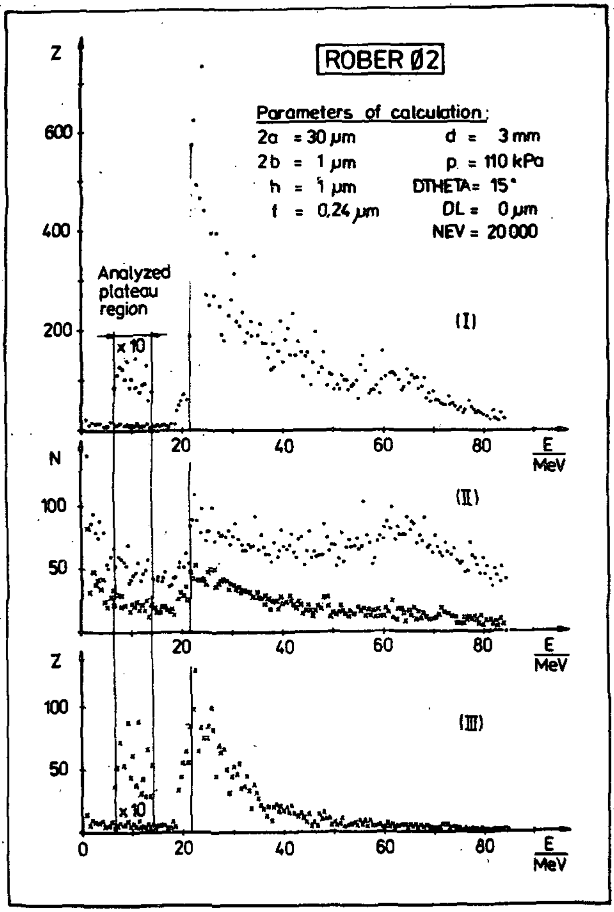


Fig.13:

Example of calculated fission chamber spectra - surface type "Filled scratch"

(I) Weighted total spectrum

(II) Unweighted total spectrum (.) and unweighted spectrum of the fragments generated inside the scratch (x)

(III) Weighted spectrum of the fragments generated inside the scratch

A comparison of the weighted and unweighted spectra shows the preference of the rare events in the plateau region.

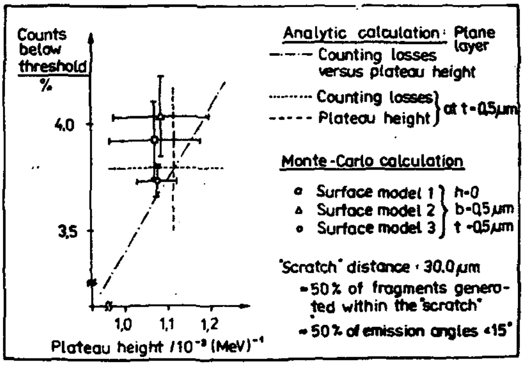


Fig.14:

Test of the codes ROBER Ø1...Ø3 - simulation of a plane layer and comparison with analytic results. Parameters: DL=0, DTHETA=15°; t/R_o = 0.0555; counting threshold E_{thr} = 6 MeV; 20000 events in each case.

culations described below. The CP time need of $\lesssim$ 2 min for 20000 events and the statistical uncertainty reached by means of the non-analogous Monte-Carlo method allow to carry out systematic investigations without any restriction due to the CP time consume.

4.3. Results of calculations

The codes ROBERØ1...Ø3 were applied to perform first investigations concerning the influence of microscopic scratches on the detection efficiency and the pulse height spectrum of parallel plate fission chambers. To obtain systematic trends of detection efficiency and plateau height for the implemented scratch models (Fig.10), fission chamber spectra and absorption losses were calculated at fixed dimensions of the scratch, but varying the target thickness t. The parameters used in this first series of calculations are summarized in Tab.1. A realistic scratch distance was estimated from photographies of U-235 target layers produced in the Khlopin Radium Institute of Leningrad /5/: About 2...10 scratches /100 μm were observed, and therefore a mean distance of 20...30 μm should be a good approach. Due to the procedure of polishing the backings, scratches with a depth in the $\lesssim 1$ μm range are expected /23/; this is in good agreement with the estimate from a photography taken by means of an electron microscope /5/. A methane-filled fission chamber and a KOVAR backing covered by an U_3O_8 layer were assumed; mean ranges of fission fragments in these materials were estimated from an empirical formula /24/, the stopping-power data of ZIEGLER /18/, and the value of R_0=7.5 mg/cm^2 for U_3O_8 /25/, using a density value of 8,3 g/cm^3 for KOVAR as well as for U_3O_8. The target thickness t was varied in the (0.001 - 0.5) μm range, corresponding to averaged areal densities $\leq$ 375 μgU/cm^2 which are typical for precise fission cross-section measurements. A total number of 20000 events in each case was sufficient to obtain the correlations searched for.

The spectra resulting from the calculations were analyzed as follows: A counting threshold of 6 MeV was introduced. Fission events with a total energy release in the chamber gas below the threshold energy were regarded as counting losses; the absorption

Parameter	Value
Scratch distance	30 µm
Scratch width	1 µm
Scratch depth	1 µm
Target–electrode distance	3 mm
Methane pressure	110 kPa
Fission fragment energy	84 MeV
Fission fragment range	
- in methane at normal pressure	23.5 mm
- in the target material	9.0 µm
- in the backing material	5.8 µm

Tab. 1: Parameters used in the described calculations

losses stored in the first channel of the spectrum were included. The energy range from 6 MeV to 14 MeV (channels 13–28) was defined as the plateau region; it is characterized by a nearly plane spectrum (see Fig.5,13). The plateau height then is given by

$$\varphi_p = \frac{Z_p}{Z}\,\frac{1}{8\ \mathrm{MeV}}$$

$Z_p = \sum_{i=13}^{28} z_i$ ... sum of channel contents in the plateau region;

Z .... total number of events (sum of all weights).

To estimate the statistical uncertainty of φ_p, the Central Limit Theoreme was applied:

$$\left|\frac{\Delta\varphi_p}{\varphi_p}\right| = \left|\frac{\Delta Z_p}{Z_p}\right| = \frac{\sqrt{k_p}\cdot\sigma_z}{Z_p}$$

$k_p = 16$ ... number of channels in the plateau region

σ_z .... dispersion of the channel contents in the plateau region.

In a similar way, the uncertainty of the counting inefficiency K_{tot} was estimated: The number Z_{loss} of not counted fissions was thought to be divided into separate "portions" corresponding to the mean channel contents z_i in the plateau region. Assuming a dispersion of these portions which is equivalent to σ_z, one obtains

$$\left|\frac{\Delta K_{tot}}{K_{tot}}\right| = \left|\frac{\Delta Z_{loss}}{Z_{loss}}\right| = \frac{\sqrt{k_{loss}}\cdot\sigma_z}{Z_{loss}} = \left|\frac{\Delta \mathcal{g}_p}{\mathcal{g}_p}\right| \cdot \sqrt{\frac{Z_p}{Z_{loss}}}$$

$$k_{loss} = \frac{Z_{loss}}{z_i} \quad \text{... number of "portions".}$$

The results of the calculations are shown in Fig.15–16. The simple stopping-power model allows a direct comparison with analytic calculations for a plane target layer of an equivalent effective (i.e. averaged over a period of the surface profile) thickness (6,10–12). As expected, an additional counting loss occurs, depending on the surface profile (Fig.15). The strong rise of the curve belonging to the "filled scratch" at $t \to 0$ is due to the fact that at last all the fissionable material is concentrated inside the scratches. A serious conclusion can be drawn from Fig.15: The argument that the counting inefficiency of a fission chamber (including the corresponding error contribution) can be made as small as wanted by reducing the target thickness – which is often used in evalutions of the uncertainties in fission cross-section measurements /2,26/ – is invalid in practice. Counting losses up to some percent, caused by microscopic surface disturbances, cannot be excluded even for a negligible areal density of the target layer; but the usual correction procedure does not consider such effects. This fact might be a cause of the unsatisfactory situation in experimental fission cross-section data, where the scatter of results is much larger than the quoted error estimates (see e.g. /1/).

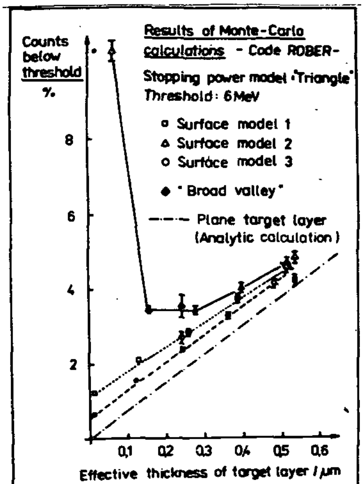


Fig.15: Obtained counting loss/ target thickness relation

On the other hand, Fig.16 shows no significant violation of the counting loss/plateau height relation which was deduced for an idealized

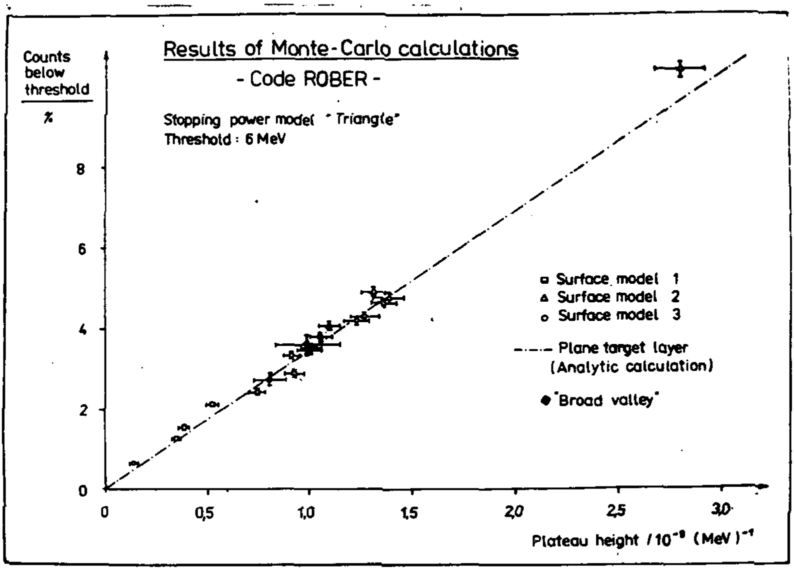


Fig.16: Counting loss / plateau height relation obtained for a 1 μm x 1 μm scratch cross-section

plane layer. The plateau height thus proves to be a realistic measure of the total counting inefficiency even for target layers which are disturbed by microscopic scratches of ~ 1 μm depth: Inspite of strong distortions of the counting loss / target thickness relation (6), the total counting loss can be deduced from the plateau height by using the relations derived in the plane layer model.

This fact was confirmed by a second series of calculations where the scratch cross-sections were varied from 0.5 x 0.5 μm^2 to 2 x 2 μm^2 at a given target thickness t = 0.24 μm (the other parameters correspond to Tab.1). Fig.17 illustrates the results: Only relatively small deviations (< 20 %) from the plane layer model were observed for the obtained counting loss / plateau height ratio, and no systematic trend was found within the estimated error limits. Against this, the calculated counting losses for the events produced inside the scratches are 3 - 20 times higher than the value K_{tot} = 1.82 % derived from (6,10) for a plane target layer (t = 0.24 μm) at the given counting threshold of 6 MeV.

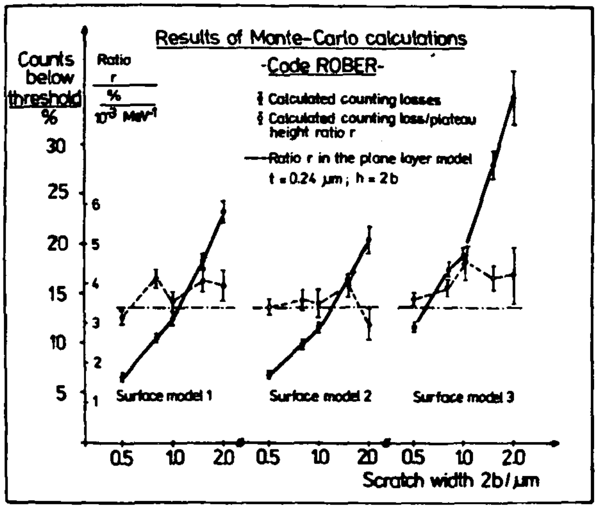


Fig.17: Influence of the scratch cross-section on the total counting inefficiency and the counting loss / plateau height ratio for fission fragments generated inside the scratches

The situation changes if larger surface disturbances are introduced. Fig. 18 shows the results of a third series of calculations where the scratch width was varied from 1 μm to 100 μm at a given scratch depth (h = 1 μm) and target thickness (t = 0.45 μm; the other parameters were taken from Tab. 1): If the scratch width comes close to the range parameter R_o (see Tab. 1), a rise of the counting loss / plateau height ratio up to about two times the value r_p of the plane layer model was stated. This means an additional counting loss which is not completely reflected in the plateau height. In this case, the proposed method of determining the FC counting inefficiency from the plateau height underestimates the true counting losses by the factor r/r_p; but one should bear in mind that the usual procedure gives at least no better result!

A further calculation was performed simulating macroscopic deviations from the plane layer model. The "Broad valley" model was introduced by enlarging the dimensions of the "Scratch with cove-

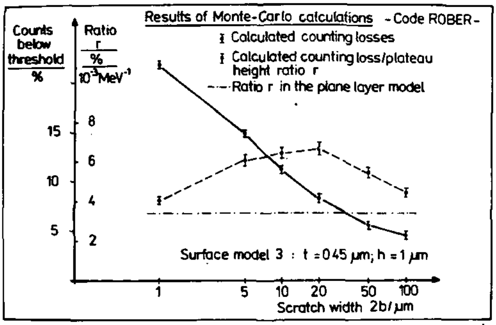


Fig.18:

Total counting inefficiency and counting loss / plateau height ratio for fission fragments generated inside the scratches at growing scratch width

red bottom" (Fig.10) from microscopic to macroscopic values: A scratch distance of 20 mm, a scratch width of 10 mm and a scratch depth of 0.1 mm were assumed; the target thickness of 0.24 µm corresponds to the calculations illustrated in Fig. 17, and the other parameters were taken from Tab. 1. This model describes in a coarse approximation a sample (backing covered by a target layer) which is not correctly mounted in the carrier ring (shifted edges!). Both spectra - the total (lower absorption) and the partial containing fission events with an origin inside the "valley" (higher absorption) - were analyzed, the results are shown in Fig. 15-16. In this case, the enlarged counting loss is followed by a corresponding rise of the plateau height.

Summarizing the results of the described calculations, two important trends can be derived:

- Scratches, which are typical for polished backings, have a noticable influence on the fission fragment detection efficiency; additional counting losses in the percent region are possible.
- If characteristic dimensions of the scratch cross-sections are significantly smaller than the fission fragment range, these additional counting losses are reflected in an approximatively proportional rise of the plateau region in the fission chamber spectrum. Therefore, the method of estimating the total counting inefficiency by analyzing the plateau height of the FC spectrum - which was proposed in consequence of the results obtained for the plane layer model - can be applied

even for realistic target layers, if surface disturbances with characteristic dimensions in the region of the fission fragment range can be excluded.

However, further systematic investigations should be carried out, especially to consider other possible types of surface disturbances.

5. SUMMARY AND CONCLUSIONS

The calculations described in this paper underline the doubts concerning the correctness of the usual procedure of estimating the detection inefficiency of parallel plate fission chanmbers: Not only chemical modifications or contaminations of the target material, but also the non-linear plateau shape in the fission chamber spectrum and the influence of microscopic scratches on the fission fragment absorption are possible sources of additional counting losses which are considered neither in the correction procedure nor in the error estimate.
However, the plateau height in the fission chamber spectrum was found to be a realistic measure of the counting losses including the effects mentioned above, if scratches with characteristic dimensions of the scratch cross-section in the region of the fission fragment range can be excluded. If the latter is guaranteed by the technology of target production, the ratio of the total fission fragment counting inefficiencies of different plane target arrangements in the case of spontaneous or thermal neutron induced fission is equivalent to the ratio of the corresponding plateau heights, which can be measured easily.
Moreover, individual range parameters of the examined fission foils, which reproduce the true counting loss with the usual procedure, can be obtained by comparing the measured plateau height with calculations in the plane layer model, if the energy scale of the FC spectrum is defined. A calibration becomes possible e.g. by calculating the fission fragment edge in a differential chamber.
Summarizing the results it can be stated that the analysis of fission chamber spectra should be a simple and promising way to improve the estimates of counting losses in ionization fission

chambers and to exclude coarse errors due to individual features of the target layers.

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