INIS-mf--14780



RESEARCH AGREEMENT No. 6654/CF

Final report

TITLE

"RISK ASSESSMENT OF HOT BETA-PARTICLES FROM THE CHERNOBYL FALLOUT IN BULGARIA"

Part of the IAEA coordinated programme THE RADIOLOGICAL IMPACT OF HOT BETA PARTICLES FROM THE CHERNOBYL FALLOUT: RISK ASSESSMENT.

RESEARCH INSTITUTION

Laboratory of Dosimetry and Radiation Protection, Dep. of Atomic Physics, Faculty of Physics, Sofia University, Boulevard James Baucher 5, BG-1126 Sofia, Bulgaria

CHIEF SCIENTIFIC INVESTIGATOR

Prof. Ivan Uzunov, D.Sc.

TIME PERIOD COVERED

15 June 1991 - 10 September 1993

INTRODUCTION AND HISTORICAL BACKGROUND

One day after the author has discovered the relative high radioactive contamination of the streets in Sofia, together with Dr. Bonchev the first hot particles were registred.

The same day (3. May 1986) the author formulated 13 radiation protection rules for the population, part of which Dr. Bonchev transmitted to the Civil Defence (which resulted in the start of washing the streets). The next day the rules were discussed with the other members of the Department of Atomic Physics and on the 5. May after approval by the governmental experts group (appointed for coordination of measurements and radiation protection measures), the author presented them to the Deputy Minister-President, the Chief Sanitary Inspector and the responsible general of the Civil Defence (Board of the Permanent Emergency Commission) for immediate information of the population. The Chief Sanitary Inspector (Deputy Minister of Health) argued, that the rules are good but need to be recommended after a nuclear bomb explosion. The author expected such a reaction after so many years of intended minimization of the radiation danger from nuclear power reactors. Therefore he showed the curves calculated by Dr. Tsipis from MIT and argued that the Chernobyl incident could be worse, mainly because of the thousandfold higher concentration of hot particles measured.

In spite of these efforts the rules were not published. Only some of them were mentioned by the Deputy Minister of Health in a very unclear manner on the TV, and the President of the Committee on the Use of Atomic Energy for Peaceful Purposes claimed that the contamination is 1000 times less than during the weapons tests. All this desinformed the population and therefore according to the 1988-UNSCEAR Report Bulgaria is on the first place of the committed first-year dose, also because many of the recommendations of the experts group were not realized.

As it is known, the Deputy Minister-President and the Chief Sanitary Inspector were sentenced to 3 and 2 years prison (according to the paragraphs formulated by the author*) in the 1985-Atomic Energy Law) despite the efforts of the IAEA to help them.

Among other factors, the text in ICRP-Publications 14, § 41, 1969 and No.26, § 33, 1977 claiming that "... the absorption of a given quantity of radiation energy is ordinarily likely to be less effective when due to a series of "hot spots" than when uniformly distributed...", was the main argument for some "experts" not to inform the bulgarian population about the hazard of hot particles. Perhaps therefore the western authorities did

*) One of them together with Dr. Mladenova from the Ministry of Justice.

not recommend radiation protection measures especially against hot particles. This situation forced the author to suggest to the Deputy President of the Bulgarian Academy of Sciences to ask the Scientific Secretary of the Sovjet Academy of Sciences (who leaded the scientific rescue team in Chernobyl) about their attitude towards the hot particles. He answerd sometimes later, that the radiobiologists has claimed, that a hot particle deposited in the lung is encapsulated by killed cells and therefore is not harmful (perhaps also because of § 33 of ICRP 26).

Obviously the misinterpretation was due to the transfer of findings valid for alpha-emitting hot particles to the quite different situation - beta hot particles. (Sometimes perhaps intended).

In order to clarify the problem of the Chernobyl hot particles, after so many years since the 1959-Bad Schwalbach Symposium, with Dr. Steinhäusler, Dr. Philipsborn and others interested in this subject we proposed to organize a workshop, which took place in the Bergbau- und Industriemuseum of the University of Regensburg on 28/29 October 1987. Also at the IAEA-Advisory Group meeting on Environmental Monitoring Data Base for Use in Assessing the Radiological Impact of a Severe Accident (30. November - 4 Dezember 1987) the author distributed a statement in which he claims that the most dangerous factor after an accident like that in Chernobyl could be the hot particles in combination with the still unknown, strong irritating substance contained in the radioactive cloud, and that caesium is not so important as claimed by the IAEA and other international organizations.

The author submitted this statement to Dr. Benett of UNSCEAR with the available publications on the Chernobyl hot particles, but the Committee voted against including the hot particles problem in the 1988-Report.

These historical details are described in order to make clear, that if an international authority as ICRP, WHO or IAEA was not precise enough, as in the case of the possible carcinogenic effect of hot particles, then the responsible authorities, the decision makers could be desinformed and, as in our case - even be sentenced.

RESEARCH CARRIED OUT

In this report the work performed mainly at the Laboratory of Dosimetry and Radiation Protection will be described. (The research at the Department of Atomic Physics as a whole will be reported by Dr. Bonchev and the work up to the end of 1987 can be seen from ref.1)

Measurements of hot particles

Since many years before Chernobyl for alpha/beta field measurements we use as basic detector the Geiger-counter SBT-10 (made in the former USSR). The detector has 10 electrodes, a 35 $cm^2$ window of 5 $mg/cm^2$ thickness. The body is extremely flat, made of plastics, so that the counter is very insensitive for gamma-radiation and detects almost only alpha and beta radiation. The detector was connected to different radiometers and attached to a handlebar of about 80 cm lenght for an easy scanning of hot particles deposited on the ground, streets, walls, trees, clothes, shoes, skin etc.

Perhaps because of this detector the early discovery and the direct measurement on the ground of the hot particles was possible (the author remembers how difficult it was for him to detect hot particles in Salzburg and Homburg because of unsuitable field detectors). Perhaps therefore also in this country the Institute of Nuclear Physics and Nuclear Energy as well as the

Institute of Radiobiology and Radiation Hygene for a long time claimed, that according their measurements hot particles does not exsist.

The calibration of the detector for the energy distribution of most of the hot particles showed an efficiency of about 0,25 imp/s/Bq for about 1 cm distance from the hot particle. In determining the density of deposited hot particles on the ground or other surfaces (number of hot particles/$m^2$) the uniformly distributed activity poses the detection limit. We determined that the counting rate over the hot particle has to be practically 2 - 3 times higher than over the uniformly distributed activity and besides appropriate visual display, the use of earphones is needed during scanning. Our experience showed that for example for an uniform contamination of 10 000 Bq/$m^2$, hot particles can be easily detected if their activity is about 40 Bq.

If a laboratory analysis of a detected hot particle was planned, a diaphragm was put on the SBT-10 counter or a common end-window counter (SBT-7) was used in order to localize the particle. The hot particle was removed from the surface by means of wet filter paper or adhesive tape. At the laboratory the precise localization was done by means of the G-M counter SBT-9 with a very small end window of 0,2 $cm^2$.

The beta-activity was measured with the counter SBT-13 with an end-window of 3 $mg/cm^2$, mounted in an anticoincidence shield of zylindrical G-M counters and appropriate Pb and Cu shielding, so that activities down to 0,05 Bq could be measured (in order to follow the desintegration of the particles down to negligible activities).

The alpha-activity was measured by means of the scintillation detector of the uranium mine radiometer RV-4, which was choosen because of the low background counts of 1 - 2 per hour and practically no sensitivity for beta-gamma and about 30 % efficiency for alpha particles.

The gamma-activity of the hot particles and their nuclide composition was determined by a 75 $cm^3$ Ge(Li) detector in a Pb, Cu, Cd and polystirol shield.

More details of all these devices, calibration procedures, the transfer of the hot particles to the countig equipment etc. are described in several papers presented at the symposium "Radiation Injuries and Radiation Studies", Dezember 1987 in Sofia (in Bulgarian)[2].

<u>Estimation of the carcinogenic risk</u>

The basic problem in assessing the carcinogenic risk after incorporation of hot particles is the lack of past experience at such high concentrations which occured after the Chernobyl accident. The 7 years elapsed since then are not enough even for the minimal latent period of lung cancer.

The small number of humans who inhaled high concentrations of hot particles (almost only alpha emitters) during laboratory or factory accidents and the low concentration of beta-emitting hot particles during the period of nuclear weapons tests in the atmosphere did not provide sufficient data to estimate the carcinogenic effect by means of epidemiological studies.

Therefore risk estimation for cancer induction can only be done by modelling. The single appropriate model available to the author in May 1986 was developed by Mayneord and Clarke [3,4].

In his report of 17.June 1986[5] to the Deputy President of the Academy of Sciences the author used this model for estimating the carcinogenic risk of hot particles to "critical" groups of the population in order to justify his 13 radiation protection rules.

The author was forced to do this fast (even without the desired precision), because the government declared on the 24. May 1986, that all restrictions in connection with the contamination from Chernobyl are withdrawn. Later he planned to improve the initial estimations (as stated in the Research Agreement Proposal) but meanwhile Dr. Hofmann et al.(6) have analysed in several papers excellently the dosimetry of inhaled hot particles and assessed the coresponding carcinogenic risk, so that the author had nothing more to do. Therefore he will limit this description to the mentioned initial estimations from June 1986, published in ref.(7), trying to explain the higher risk values obtained, which he feels are still more realistic for the "critical" groups of the Bulgarian population.

As first it must be mentioned, that Hofmann et al.(6) also emphasize the important role of cell proliferation stimuli, caused by killed cells in the carcinogenic process initiated by the hot particles, but do not mention that in addition a strong irritating effect was registred from a hitherto unknown substance contained in the radioactive cloud, which affected the tracheobronchial tract of people in many european countries (skin lesions, inflammation of lymphe nodes and diarrhea were observed as well). Its impact was probably strong proliferative stimuli.

The importance of cell proliferation stimuli as promoters in the carcinogenic process initiated by the radiation the author emphasizes since more than 25 years, when in comparing the radiation risks in uranium mines with the risks in radon spas he developed a working hypothesis based on a statement of Curtis from Brookhaven and the computer experiments of Tsanev and Sendov(8), who at this time also used the work of Curtis.

Because the synergistic effect of nonradiation factors which stimulate cell proliferation are not always taken into account in assessing the carcinogenic risk, a brief description of the main points of our semiquantitative model must be done in order to understand our philosophy in estimating the cancer risk from hot particles (especially having in mind the very strange fact that the irritating substance in the Chernobyl cloud has not been identified during this 7 years).*)

The model is based on the simplifying assumption that the only carcinogenic factor is radiation (initiator) and all other factors such as dust, fumes, smoking, chronical bronchitis etc. (in this case also the unknown irritating substance and the necrohormones emitted by the killed cells) can be considered as unspecific stimulators for cell proliferation (promoters)[9].

Under this assumption the results of the computer experiments of Tsanev and Sendov[8] could be adapted to our case (ionizing radiation as initiator).

For example on fig.1 the number of cells is presented in function of the time elapsed after the irradiation, for 3 different radiation doses. The arrows lable the moment of action of the proliferation stimuli. The dotted intervals must be understood that the system remains unchanged until new cell divisions are provoked.For instance the lowest dose-curve (c) shows that in order to induce uncontrolled (cancer) growth more proliferation stimuli are needed than in the case of high dose (a).

Fig.2 shows that in the case of a low radiation dose (k=0,2) the probability for cancer is almost directly proportional to

---

*) As member of the governmental experts commission, the author insisted that the Institute of Hygiene should identify this substance, but someone has forbidden to do this. The author has some samples which still wait for identification. Perhaps because of this substance many early effects attributed to the radiation could be explained, but the WHO has also denied to do anything in this direction.

the number of cell divisions. It means that in this case the radiation acts almost only as a trigger for the cancer process and the "dose" of the promoters becomes more important in the induction process. If the radiation dose is high (k=2), the natural frequency of cell divisions is enough for promoting the malignancy initiated by the radiation.

Therefore taking into account the possible high proliferative action of the unknown substance, the expected carcinogenic risk could be very high (also for hot particles with low activity) and exceed substantially the estimations based only on the pure radiation effect. Of course this should be valid also for the uniform distribution, but from the curves calculated by Mayneord and Clarke[3,4] it can be seen that for a low-level uniform contamination of the lung (as in the case of the Bulgarian population), the probability for cancer induction is lower by orders of magnitude as compared to the nonuniform irradiation by a hot particle of the same activity. (On the contrary, if the uniform contamination is high, it can be more carcinogenic than irradiation by a hot particle, because a major portion of the dose from such a particle is "wasted" in the production of necrotic tissue). The model of Hofmann et al.[6] developed after Chernobyl confirmed this basic predictions.

For estimating the total combined effect semiquantitatively, relations of the following type could be useful:

$D_{radiation} \oplus "D"_{prolif.f.} \Rightarrow$ B x radiat. effect = Total effect,

where the "built up" function B takes into account synergism and repair, as well as chronical bronchitis, the higher number of cell divisions for children etc.

Since cancer induction is probably a monoclonal process, the "old" concept of assessing the maximal doses to "critical" population groups, "critical" organs, cells and cell structures is more appropriate in estimating the carcinogenik risk than the "collective effective equivalent dose", because one can easily come to the absurdum of the UNSCEAR-1988 Report, where Bulgaria stays on the first place for the committed first-year effective dose equivalent and USSR - on the 11-th, but for everybody is clear, that not in Bulgaria but in Belorussia most of the cancers will occur.

Therefore the author estimated the carcinogenic risk only for critical groups of the Bulgarian population: farm workers engaged in dusty operations, construction workers and the youths and children who took part in the cross-country in the period of highest concentrations of hot particles in the air (in spite of the recommendation of our experts commission to stop it as well as all other outdoor sports activities).

The number of inhaled hot particles was also estimated for the worst conditions of the most contaminated areas (where meteorological stations with filteraspiration equipment were available).

Only the initial activity of the retained hot particles was not needed to be the highest measured, because the doses in the vicinity of the particles are so high, that a typical carcinogenic dose always exsists in a nearer or farer distance from the hot particle.

These are the main differences between the initial data choosen by the author and the average values used in almost all other studies on the carcinogenic risk of the Chernobyl hot particles. Therefore, as it will be seen from the next section, the estimated lung cancer risk for the mentioned critical population groups are much higher than the values reported in almost all other publications. The author thinks that his approach is justified, because mainly individuals from these critical groups will have a significant higher probability of developing lung cancer. The negative side of this approach is that the number of the individuals in these groups was not possible to be estimated.

In order to confirm or reject the initial estimation of the number of hot particles retained in the lungs, together with colleagues from the Military Medical Institute, lung ash of persons who died in accidents approximately one year after May 1986 was analysed. The ash was dispersed evenly and fixed between two X-ray films and screens (to discriminate artefacts). The exposure was choosen to be 40 days[10].(As it will be seen in the next paragraph, the initially estimated number of retained hot particles was confirmed).

The ingestion of hot particles, apart from the swallowing of the excreted particles from the lung, occurred via food uptake. The estimation of the retention of these particles at the folds of the small and large intestines is difficult to quantify. Though we detected many hot particles in faeces of domestic animals, we have not tried to detect their retention in human intestines. Therefore no attempt was made to estimate the carcinogenic risk. The author could state several arguments which could show that the carcinogenic risk in this case should be high as well, but obviously further research is needed.

At the end of this paragraph it must be said, that much of the planned work listed in the Research Agreement Proposal was not carried out, because our laboratory was not financed for this research and therefore no workforce was available.

RESULTS OBTAINED

The results of measurements of hot particles till September 1987 are summarized in ref. 1. Details and some results obtained later are given in several papers published in ref. 2 (in Bulgarian), so that only results which were relevant for the initial estimation of the carcinogenic risk will be briefly discussed.

The scanning of different aerias in Bulgaria carried by our laboratory, other members of the Dept. of Atomic Physics and the Military Medical Institute, have shown that the hot particles were unevenly distributed. Even within the Sofia area, where most detailed studies were performed, hot particles varied from 0 to 3 - 4 per square meter.

It can be assumed that the rainfall on the 30. April and 1. May contributed considerably to the deposition of both, total radioactivity and hot particles. On the other hand, the torrential rains during May 10 - 11 led to a fast reduction of hot particles on various surfaces, tree leaves, etc.

The results from the scannings are given in ref.2, p.212-215. The minimum density of hot particles (o,5 particles/$m^2$) was measured in the aeria of the Jakoruda Lakes and the maximum - in the village Jelesnik near Sliven (18 particles/$m^2$).

The minimal uniform contamination was measured in the town Michurin on the 25. May (9200 Bq/$m^2$) and the maximum -in the kurort Borovetz on the 20.May (124 000 Bq/$m^2$). These values were of course much higher at the beginning of May, but a reasonable correction is practically impossible to be made.

The best possibility to estimate the number of inhaled hot partcles were the routinely exposed filters at the metereological stations (in spite of the protecting cap of the filterholders which retained the larger hot particles, but which at the same time could be regarded as simulators of the nasal region). Therefore the number of inhaled hot particles was estimated from the autoradiographs of such filters of the most contaminated regions.(Dr. Bonchev, who made the autoradiographs will report his findings in detail, but it must be said here, that the highest concentrations of hot particles in the air were in the period May 2 - 8 1986).

It was estimated, for instance, for a farmer staying 8 hours dayly on the field during the period May 2 - 8, that he could inhale about 50 hot particles, and after one month about 8 hot particles may have been retained in the lungs. The same could happen to a construction worker, engaged outdoors in dusty operations, or a sportsman, etc.

In spite of the statement on p. 10, that the exact activity of the particles is not so relevant, (because the doses in the vicinity of the hot particles are so high, that a typical carcinogenic dose always exists in a nearer or farer distance from the particle) in order to use directly or by interpolation the curves (fig.3) and tables of Maynaord and Clarke[3,4], it was assumed that the retained hot particles had an average activity of 50 Bq/particle.

An activity of 260 Bq/particle was also considered, because at that time we determined it as a mean value of the measured hot particles on the ground. Therefore in ref.7 the dose rate of such a particle of 2 micrometer diameter was calculated from the results obtained by Sommermeyer[11] in 1959. For the lung cells adjacent to the particle surface: 9000 Gy per hour; at 10 micrometer distance - 60 Gy/h; at 50 micrometer - 1,5 Gy/h. (Later, in Oktober 1986, the mean activity diminished to 66 Bq in the range of 7,3 - 298 Bq/particle. The alpha-activity was not more than 0,6 Bq/particle (in the particles containing probably $^{242}Cm$).

Taking into account also the considerations described on p. 7 - 11 (especially the unknown irritating substance), the carcinogenic risk was estimated as high as 0,1 - 1 % for critical groups of the Bulgarian population, e.g. persons having been exposed to high levels of dust in the most contaminated areas.

CONCLUSIONS

1. For measurements of hot particles on the ground, on different surfaces, tree leafs, clothing, skin etc. the most suitable detector was the flat G-M counter SBT-10.

2. The best possibility to estimate the number of inhaled hot particles were the routinely exposed filters at the metereological stations. These filters showed that the highest concentrations of hot particles in the air were in the period 2 - 8 May 1986.

3. During the first days after the radioactive cloud from Chernobyl reached Bulgaria, the most dangerous factor of intake through inhalation, besides iodine, were the hot particles. For some critical groups of the population, engaged in dusty operations during the highest concentrations of hot particles in the most contaminated areas, the carcinogenic risk could be very high and could reach 0,1 - 1 %.

These values are likely to be realistic because:

- the analysis of lung ash of persons who died in accidents about one year after May 1986 showed that hot particles are contained in three of the five lungs investigated. Dr. Bossevski will probably report more details, but we can mention, that 11 particles were detected in the lung ash of a construction worker, 5 in a truck driver and none in a hospital patient who stayed only indoors. (Of course it is possible that the retained particles were less, but broken into fragments during grinding of the lung ash). Nevertheless the number is of the same order of magnitude estimated by the author and about 100 times more than the 0,03 hot particles per person estimated in ref.6 and almost all other publications (because the average for the whole population was calculated) ;

- the choosen activity for the retained particles of 50 Bq per particle was not too high, because the mean activity of the hot particles measured during the first days of May was about 260 Bq/particle and in Oktober was still 66 Bq/particle;

- the findings in Finland (and partly in Salzburg), which will be reported by Dr. Rytömaa, show".that Chernobyl-type hot particles are extremely effective in producing malignant transformations in vitro, and possibly also in vivo".[12] Dr. Rytömaa will comment the obtained pictures probably in details, but such strong impact can not lead to a risk of the order of the fluctuations of the estimated radon induced cancer in dwellings per year, which is claimed in almost all other publications (known to the author).

The critical groups in Bulgaria are larger than they could be, because as described in the introduction, the population was not adequately informed and most of the recomended (by our experts group) radiation protection measures were not realized. One of the main causes not to accept protection measures against hot particles was the desinforming text of § 33 of ICRP 26 and the lack of any information and recommendations from UNSCEAR, WHO, IAEA, etc. in the case of emission of large quantities of ß - hot particles during severe accidents of nuclear power reactors or spent fuel.

Therefore we hope that this final meeting of the IAEA-CRP will inform the scientists, the health physicists, the responsible authorities and the public of the research carried out since the 1959-Bad Schwalbach Symposium, taking into account not only the Chernobyl accident, but also the hot particles problem during normal operation of nuclear power reactors.

ICRP and IAEA should also formulate as soon as possible appropriate radiation protection recommendations for ß-hot particles.

REFERENCES

(1) Antonov,A. et al., Studies on micro-uniformity of the radioactive contaminations, hot particles and homogeneous radioactivity,"Hot particles"(Proc.Workshop, Theuern, 1987), Vol.12, Bergbau- u. Industriemuseum (1988) 131-140.

(2) Proc.Symp."Radiation injuries and radiation studies",Sofia (1987). (In Bulgarian).

(3) Mayneord,W.V. and Clarke,R.H.,Carcinogonesis and radiation risk: A biomathematical reconnaissance. Brit.J.Radiol.Suppl. 12(1975).

(4) Mayneord,W.V. and Clarke,R.H., Quantitative assessment of carcinogenic risks associated with "hot particles". Nature 259 (1976) 535-539.

(5) Uzunov, I., Unpublished report to the Bulgarian Academy of Sciences, 17 June (1986). (In Bulgarian).

(6) Hofmann,W., Crawford-Brown,D.J.,Martonen,T.B., The radiological significance of beta emitting hot particles released from the Chernobyl Nuclear Power Plant. Radiat.Prot.Dosimetry, Vol.22 No.3 (1988) 149-157.

(7) Uzunov,I., Measurements of hot particles in Bulgaria and carcinogenic risk assessment, "Hot particles" (Proc.Workshop, Theuern, 1987), Bergbau - u. Industriemuseum, Vol.12,(1988)141 - 142.

(8) Tsanev,R, Sendov,B, An epigenetic mechanism for carcinogenesis, Z.Krebsforsch. 76 (1971) 299.

(9) Uzunov,I., Das Risiko/Nutzen-Verhältnis bei der Radontherapie, Z. angew. Bäder- und Klimaheilkunde 4 (1979)425.

(10) Belokonski,I. et al., Radiobiological studies and risk estimation in the event of incorporation of hot particles. Proc.Symp. "Environmental contamination following a major nuclear acci-

dert", IAEA, Vienna, Vol.1 (1990) 168-170.

(11) Sommermeyer, K.,Die Dosisverteilung in der Umgebung der heißen Partikel. Proc. Colloq. Bad Schwalbach (1959).

(12) Servomaa,K., Lang, S., Kosma, V.-M,, Rytömaa,T., Transformation of cells irradiated with Chernobyl-released and artificial hot particles, (1992), Unpublished paper submitted to the IAEA.

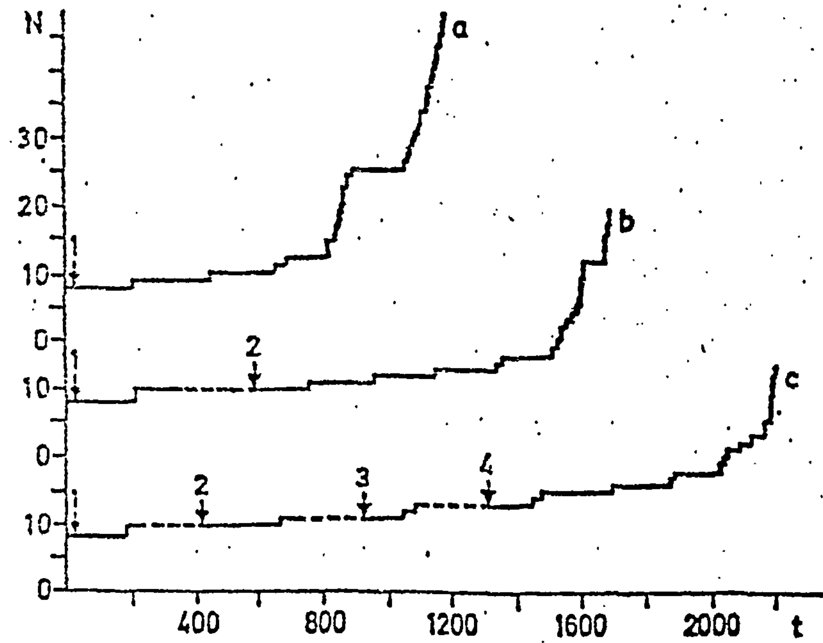


Abb. 1: Zahl der Zellen als Funktion der Zeit bei drei verschieden hohen Strahlendosen. Die Pfeile markieren zusätzliche Proliferationsstimuli.

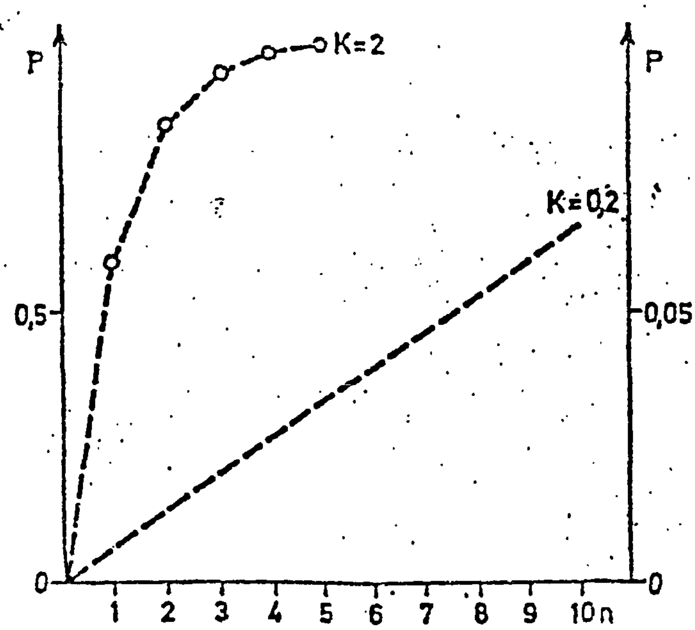


Abb. 2: Wahrscheinlichkeit eines bösartigen Prozesses als Funktion der Zahl der Zellteilungen bei zwei verschieden hohen Dosen. Hohe Dosis (K = 2): linke Wahrscheinlichkeits-Skala, niedrige Dosis (K = 0,2): rechte Wahrscheinlichkeits-Skala.

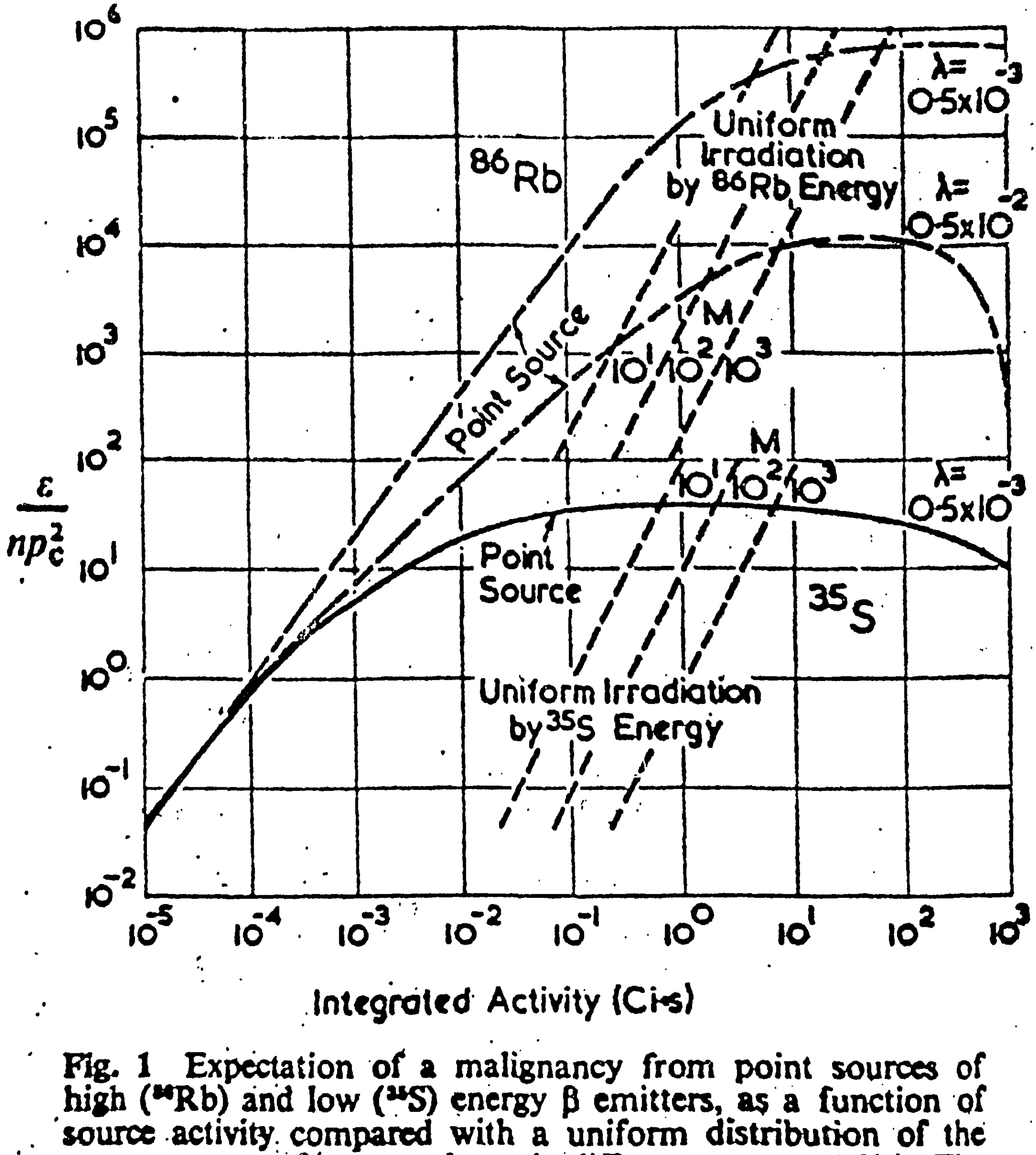


Fig. 1 Expectation of a malignancy from point sources of high ($^{86}$Rb) and low ($^{35}$S) energy β emitters, as a function of source activity compared with a uniform distribution of the same amount of energy through different masses *M*(g). The cellular response function was $\varphi(p_c D) = p_c^2 D^2 \exp(-\lambda D)$ for $\lambda = 5\times10^{-4}$ and $5\times10^{-3}$ rad $^{-1}$

Fig.3