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DEVELOPMENT OF CALCULATION METHODS AND CODES AND THEIR APPLICATION TO SPACE REACTOR SHIELDING

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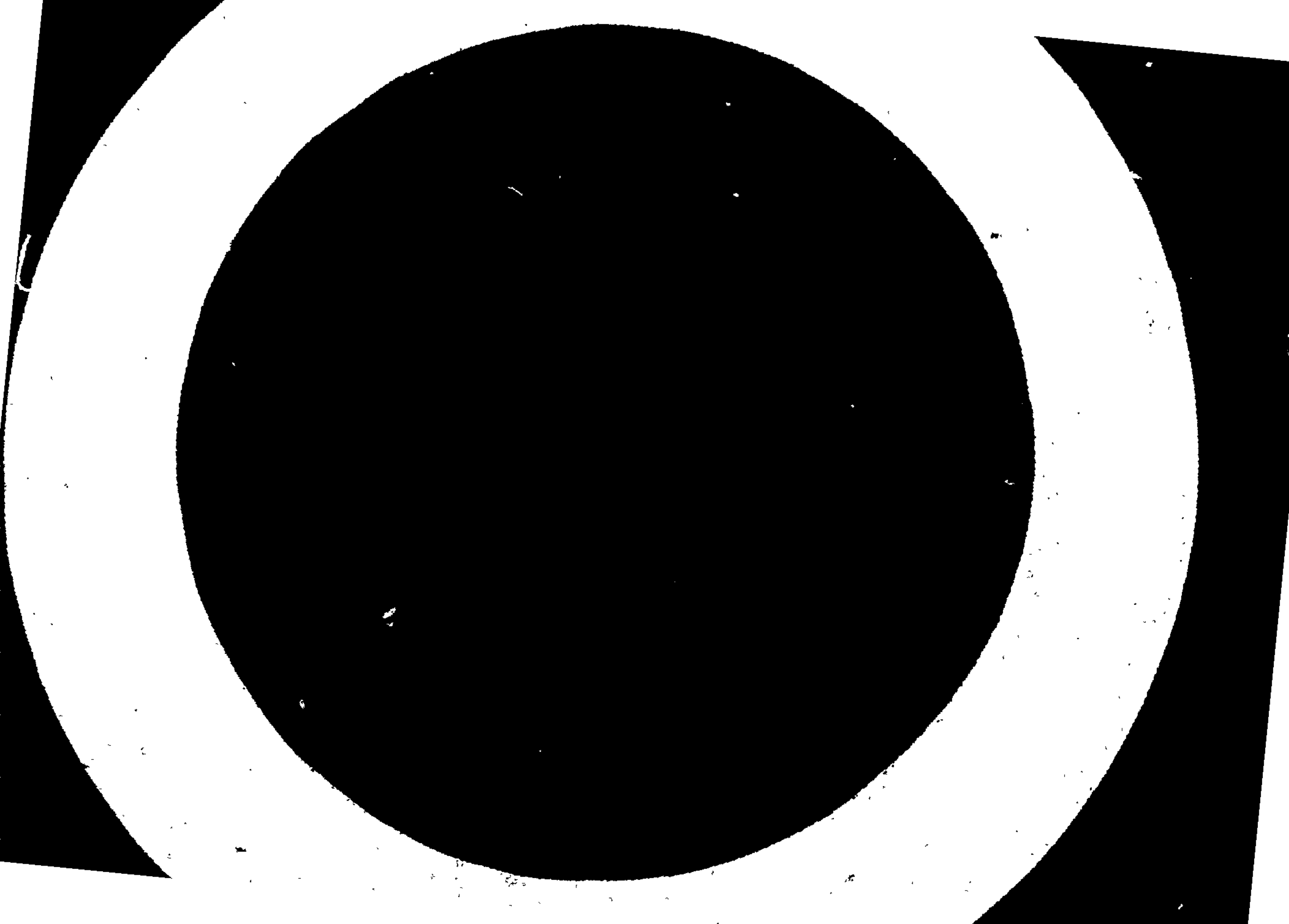
Abstract

For simplifying the handling of different reactor and shielding programs with large data input and output the modular program system RSYST has been developed which works with a central data pool from which the individual module gets all data and writes the results back. For two-dimensional deep penetration problems a special S_N-procedure is recommended which overcomes the ray effect by applying first collision correction together with local separation technique. An optimization method using dynamic programming was developed for space reactor shielding.

Pour simplifier l'utilisage des différents programmes de calcul pour des réacteurs et des blindages qui exigent beaucoup de données input et output nous avons développé le programme modulaire RSYST. Le programme utilise une mémoire centrale dont les modules recoivent toutes les données et tous les résultats. Pour des problèmes de pénétrations profondes en deux dimensions une procédure S_N speciale, utilisant la technique de séparation locale, est recommandée, qui élimine le "ray effect" en appliquant le "first collision correction". Une méthode d'optimalisation, qui utilise des procédures dynamiques, a été développée. Elle peut être utilisée pour calculer des blindages pour des réacteurs à fusée.



1. INTRODUCTION

Our code development has been concentrated on the modular programming system RSYST in order to simplify the handling of different reactor and shielding codes with large data input and output. The modular system was made not only for an easy handling of transport codes. It proved even more in our second activity concerning nuclear data processing for shielding. We produce coupled neutron and gamma multi-group cross sections from point data paying special attention to proper treatment of resonances. Since the secondary gammas often depend very strong on the absorption of thermal neutrons we have devoted some work on proper thermal group data. Our third field of activities refers to shielding calculation in two-dimensional geometry. We had to choose between the S_N method and the group Monte Carlo and decided to use S_N primarily and leave Monte Carlo for checking. So we had to overcome the problem of two-dimensional S_N in deep penetration and in vacuum zones. For optimization of shields the method of try and error is one possibility but not the cheepest, especially in two-dimensional optimization. The method of dynamic programming was investigated and applied to minimizing the weight of the shadow shield of a space reactor. All the methods and programs developed had been primarily used for reactor shielding in spacecraft both to provide nuclear propulsion and to provide auxiliary electric power. But now they are going to be applied more and more for conventional reactor shielding problems.

2. MODULAR PROGRAMMING SYSTEM RSYST

For simplifying the handling of different reactor and shielding programs with large data input and output, the modular program system RSYST has been developed. All data are stored in data blocks with a flexible structure on a data pool. The data pool consists of a permanent part which resides on the disk, and a temporary part which exists only during a job. A sequential form of the datapool also exists for storage of large amounts of data on a tape.

Each data block can contain e.g. fluxes, group constants and also texts or input sequences. In addition to the data, it is characterized by a structure vector containing an identification number, a signifying text and a description of the data structure. In this way, each data block is individually interpretable.

Each operation, such as S_N-calculation, group condensation etc., is performed by a certain module which obtains all data required from the data pool and writes its results back into the pool. The transport of data is carried out by a special data management program. The module sequence is controlled by a monitor interpreting control words in the input sequence. In this way, any sequence of modules can be achieved with flexible assignment of data. External programs e.g. SUPERTOG or DOT-2 which because of their size or for other reasons are not involved in RSYST have access to data in the pool via special modules. Fig. 1 shows the part of RSYST including some external programs for group constant production. All group constants are produced from data in ENDF/B format. The module NGAMMA combines gamma data from GAMLEGX, gamma production data from POPOP-4 and neutron data to a n-γ-group constant block. In addition to these modules, Fig. 2 shows modules for group condensation, homogenisation, testing and manipulation.

Besides modules for reactor physics calculations there are a number of modules for data pool management as well as manipulation, print out, generation and plot of general data blocks. At this moment over 110 modules are avialable.

3. NUCLEAR DATA PROCESSING

An important part of the application of RSYST is the field of nuclear data processing. In shielding large data sets for neutrons and gammas must be handled. Starting from point data libraries for neutrons like ENDF/B III (April 72), KEDAK-Library (August 70), or UKAEA-ND-Library (April 70), the collections of gamma production cross section like POPOP-4-Library (September 70) or ENDF/B III-File $\geq$ 12 (April 72), and the gamma point data like GAMLEG-Library (August 68) or ENDF/B III-File 23 (April 72), we produce coupled standard multigroup sets with 98 neutron groups and 18 gamma groups in P_5-approximation. For neutron resonances the narrow resonance concept has been used, otherwise the weighting spectra is a 1/E spectra for fast neutrons and gammas as well. Below 0.416 eV one single thermal neutron group is used, which is condensed from a 123 group thermal library. This condensation is done for the two limits like moderation in pure material and moderation by hydrogen. A linear combination between these limits accounts for changes in the thermal neutron spectrum.

Kerma factors for heat sources and radiation damage calculation are produced from the same cross section point library data in the same multigroup structure. The multigroup condensation into few group sets is done by one-dimensional transport calculations or if necessary by a combination of one- and two-dimensional calculations.

4. SPECIAL S_N-PROCEDURE FOR TWO-DIMENSIONAL DEEP PENETRATION PROBLEMS

In the course of transport calculations a second kind of data like differential fluxes, integral fluxes, activities or heat sources can be easily transfered by RSYST from one program run to the other. Two-dimensional deep penetration problems require a series of S_N-calculations with the appropriate data transfer even on the largest machines. On the other side the possibility of local separation in fixed source problems has an advantage which we don't miss even in one-dimensional calculations. When inner parts of the radiation field remain unchanged and only the materials in the outer part will be varied, then the new calculation can be restricted to these outer parts. With the local separation technique we could do deep penetration calculations with the two-dimensional S_N-method if there were not the numerical difficulty called ray effect at deep penetrations as well as for large vacuum zones. The ray effect could not be overcome by a series of S_N calculations alone. Our recipe is to change the numerical procedure by application of the first collision correction within the local separation technique. The particles leaving the preceding S_N-calculation are forced to make a collision before they are going into the next S_N-calculation. We demonstrated this procedure in the extreme case of a nuclear rocket shielding where a series of six S_N-calculations following each other were used. Fig. 5 shows the results in the form of neutron and gamma heating of the liquid hydrogen along the axis of the propellant tank. In Fig. 6 the radiation heating of the tank wall consisting of an aluminum wall with a thermal isolation layer is given. In this case the nuclear rocket shielding was determined by the energy deposition in the propellant tank as well as in other structural materials, because the payload dose was small.

5. TWO-DIMENSIONAL OPTIMIZATION METHOD APPLYING DYNAMIC PROGRAMMING

A method for minimising the weight of the shadow shield of a space reactor has been developed. The method is a combination of two well established methods, which are connected in an iterative procedure. For shielding calculations the two-dimensional S_N-code DOT-II [2] and for the optimization the dynamic programming method is used. The method consists of the following steps.

1. DOT-II calculation of a preliminary shield configuration in cylindrical r-z-geometry, which is considered to be similar to the optimal configuration. Similar means that the dose behind the preliminary shield should not differ by a factor more than ca. 500 against the allowed dose limit and that the sequence of material layers is reasonable.
2. By the program DOSBE [3] various parameters of the neutron- and the gamma-flux-field in the shield are calculated. The parameters are needed in the optimization procedure.
3. Optimization by the code DYNOPT2 [4], which applies the method of dynamic programming. Therefore the shield is divided in tube-shaped zones parallel the z-axis; each zone represents an optimization step in the dynamic programming method. Result is a new shield configuration of less weight and a dose rate near the dose limit.
4. DOT-II shielding calculation of the new configuration.

The parts 2-4, called one optimization step, are repeated, until the change in the weight becomes negligibly small and the dose limit restriction is fullfilled. Fig. 3 shows the flow diagram of the method. The shadow shield may consist of several material layers of arbitrary shapes. The method searches for the optimal shape of each layer due to the dose restriction. It is possible to introduce further restrictions for instance limitations for the volume, total thickness or costs of the shield.

The method was proved by an example with two material layers consisting of LiH and U 238. Dose limit was $5 \cdot 10^{-8}$ Rad/h. (Radiation source was normalized to 1.0). 6 neutron and 4 coupled gamma groups are considered. The cross-sections are expanded until P3. The following table shows the results:

Step m	Dose D^m	Weight G^m(kg)	$\Delta G = G^{m-1} - G^m$	Calculation time (min) CDC 6600
0	1.092-8	243.46	-	17.8
1	4.577-8	161.62	71.84	17.9
2	4.418-8	155.50	6.12	16.6
3	4.684-8	150.10	5.46	16.6
4	4.965-8	146.35	3.75	16.8

In fig. 4 the shape of the preliminary and the optimal shield configuration are shown.

Conclusion:

1. The method shows the desired convergence.
2. By means of perturbation theory it was shown, that the method converges rapidly when the axial streaming of the radiation is much greater than the radial streaming, which is the case in many applications.
3. To obtain good results it is necessary to use asymmetric S_N-weights and directions.

References

[1] R. Rühle: Datenstruktur und Steuerung des Reaktorprogrammsystems RSYST, Reaktortagung des Dt. Atomforums/KTG in Bonn (1971)

[2] F.R. Mynatt: A User's Manual for DOT, USAEC Report K-1684 (1969)

[3] W. Klumpp: DOSBE Manual, IKE Report (1971)

[4] W. Klumpp: DYNOPT2 Manual, IKE Report (1971)

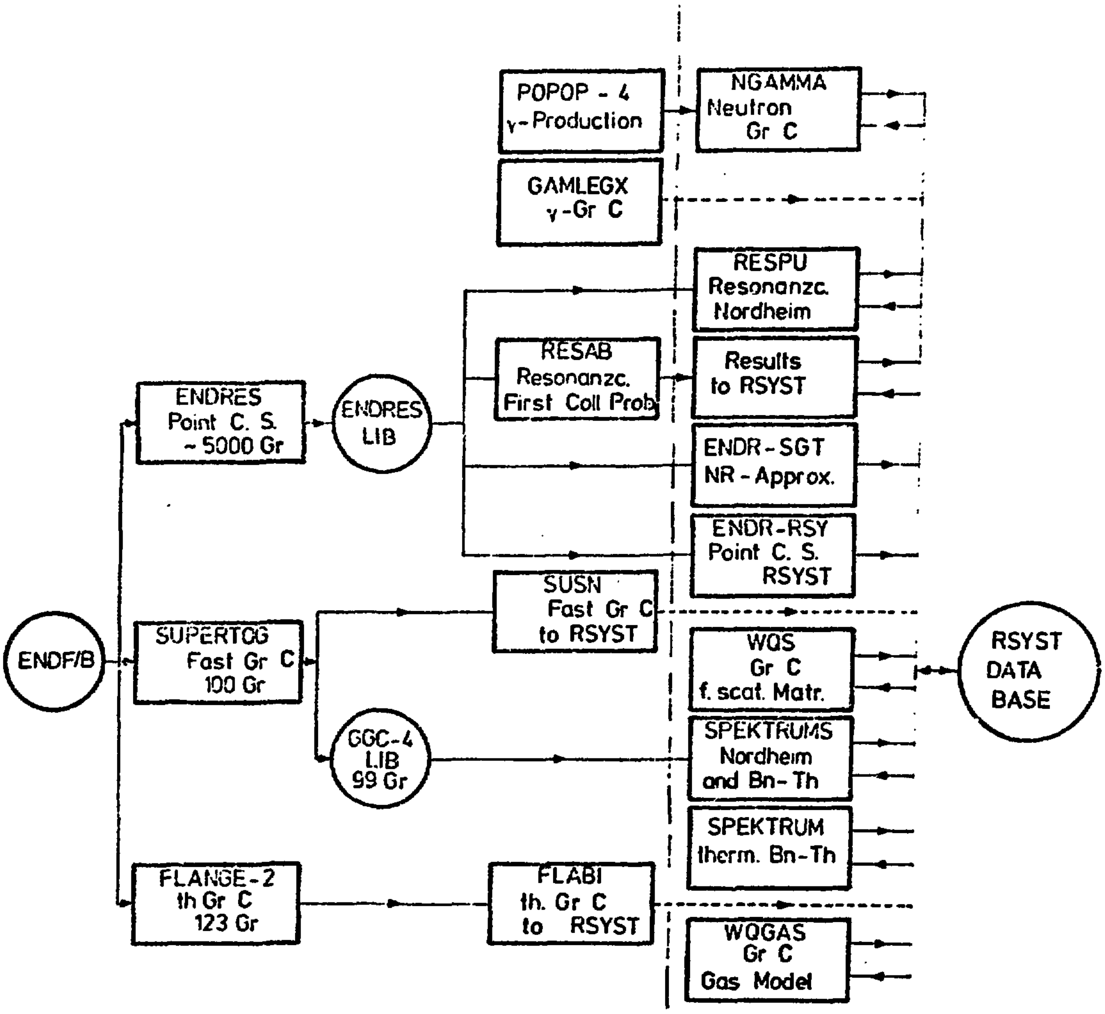


Fig.1 Production of Group Constants in RSYST

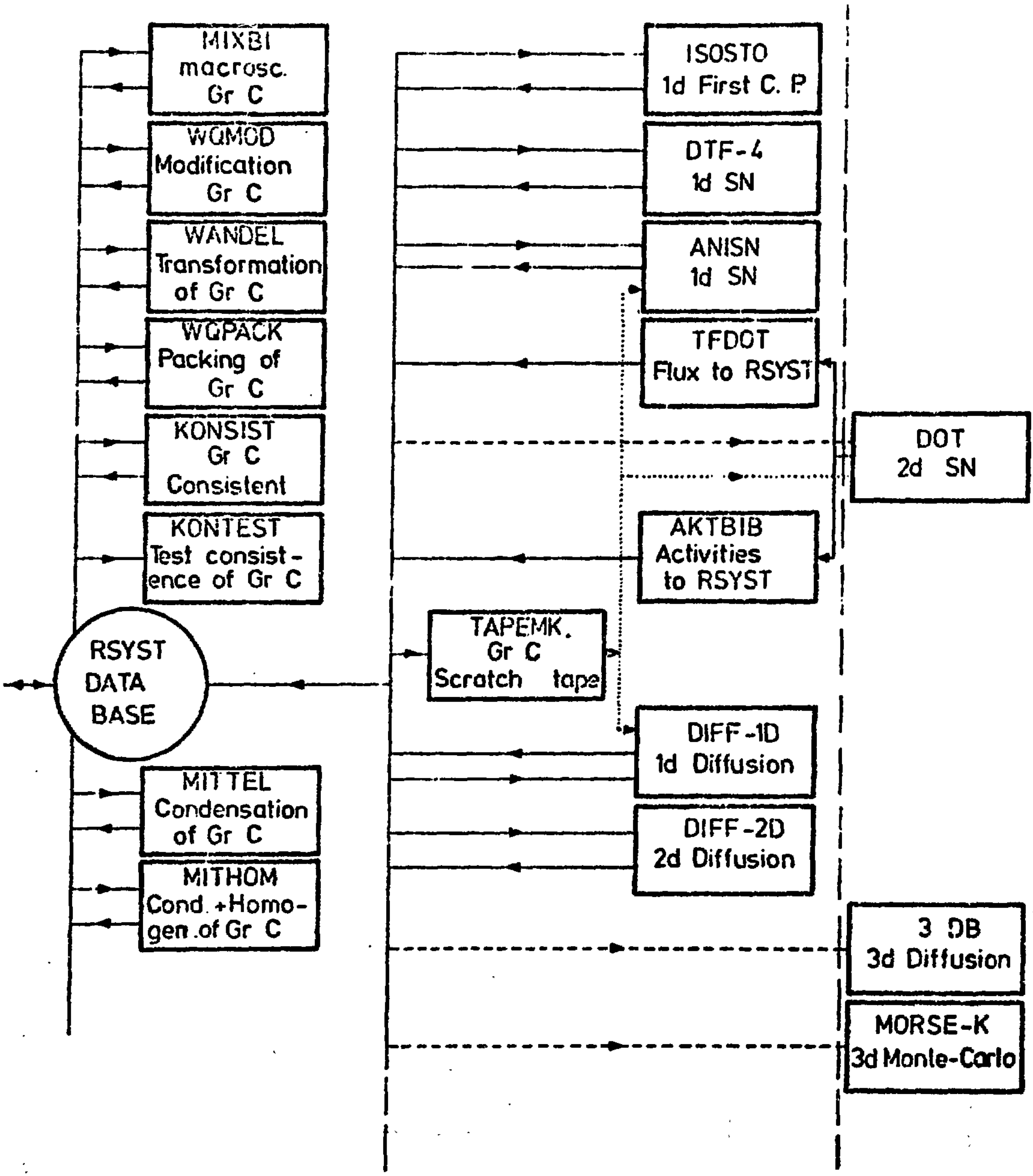


Fig. 2 Solution of Transport Equation and Related Moduls in RSYST

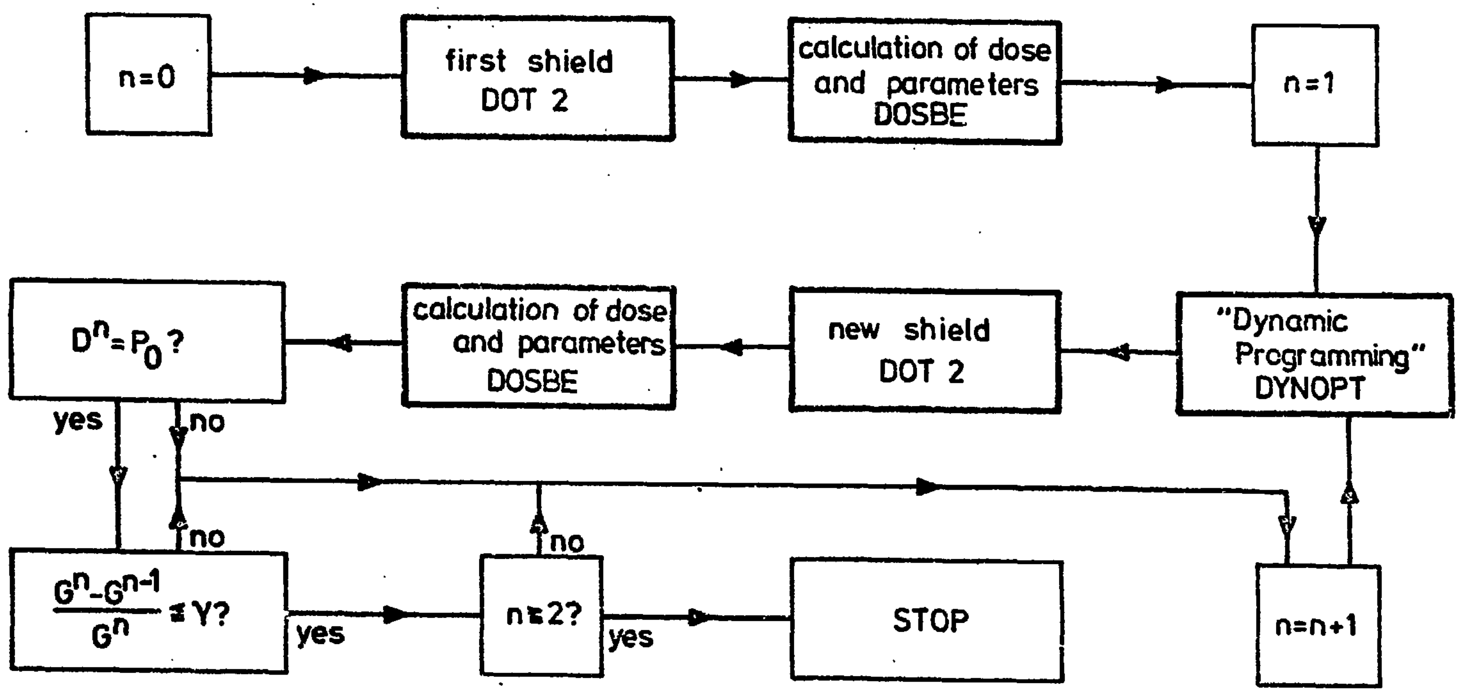


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Fig.3 Flow diagram for optimization method

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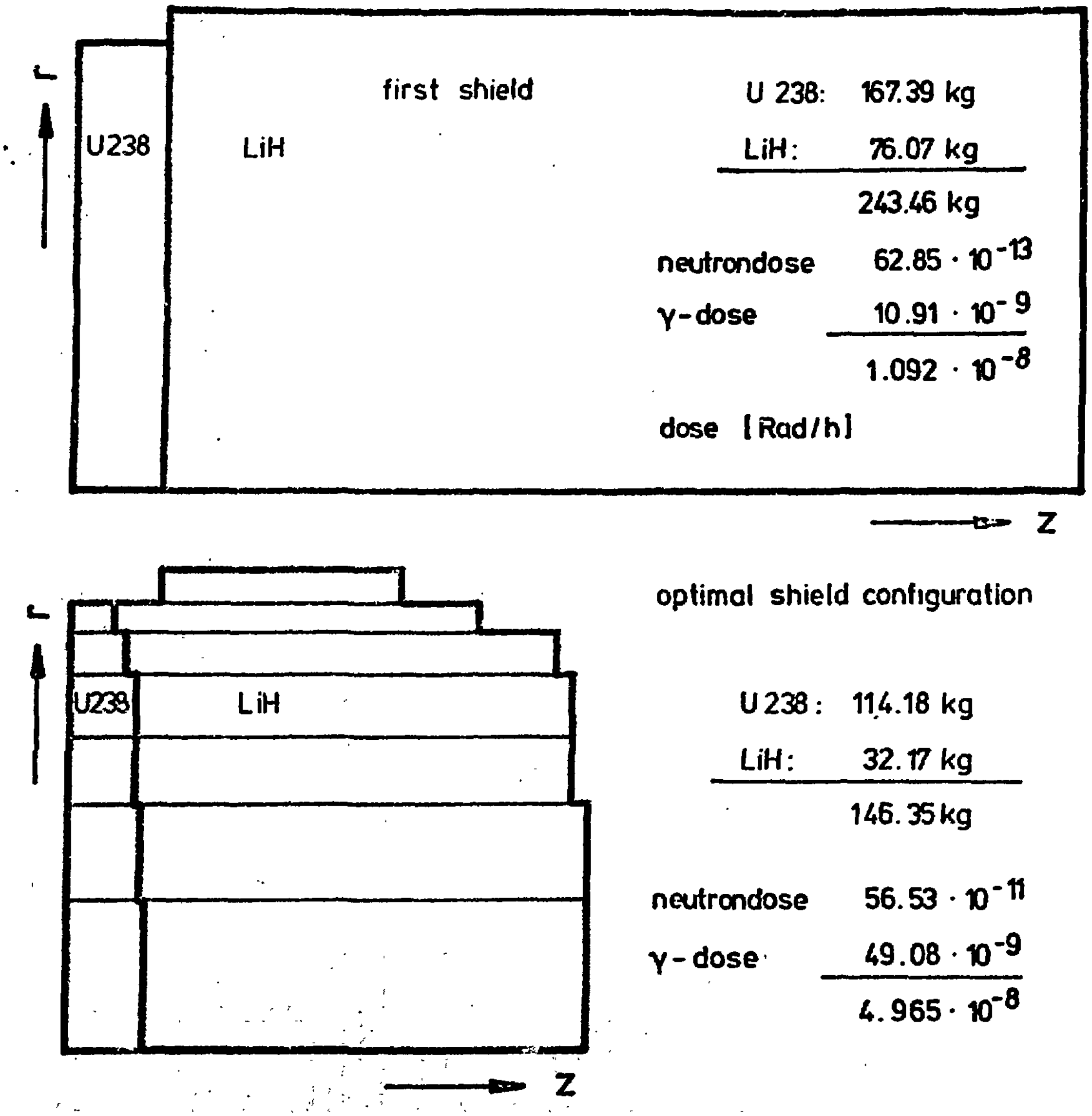

first shield

U 238: 167.39 kg
LiH: 76.07 kg
243.46 kg

neutrondose $62.85 \cdot 10^{-13}$
γ-dose $10.91 \cdot 10^{-9}$
$1.092 \cdot 10^{-8}$

dose [Rad/h]

optimal shield configuration

U 238: 114.18 kg
LiH: 32.17 kg
146.35 kg

neutrondose $56.53 \cdot 10^{-11}$
γ-dose $49.08 \cdot 10^{-9}$
$4.965 \cdot 10^{-8}$

Fig.4 Shield configuration before and after optimization

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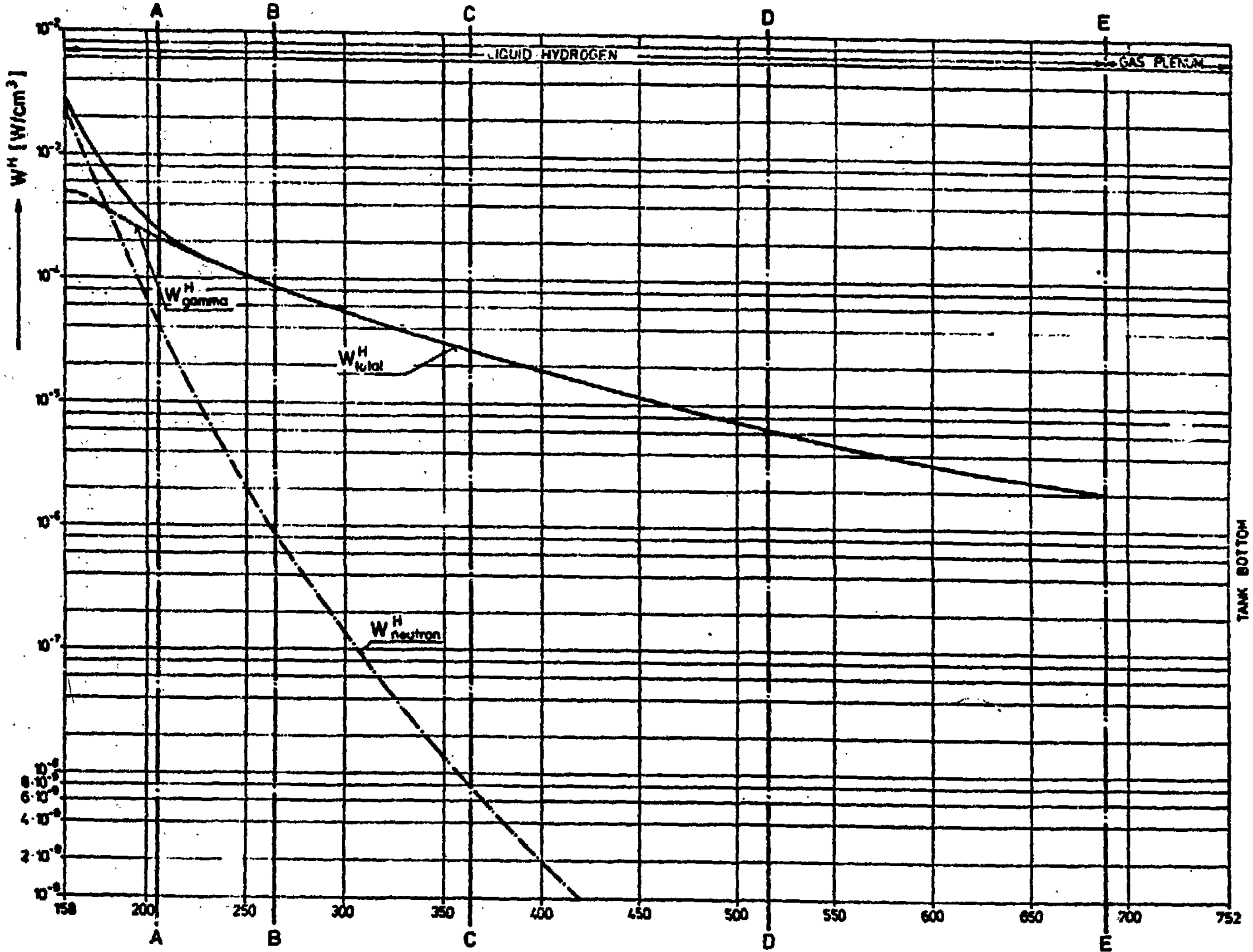

FIG.5: NEUTRON AND GAMMA HEATING OF LIQUID HYDROGEN

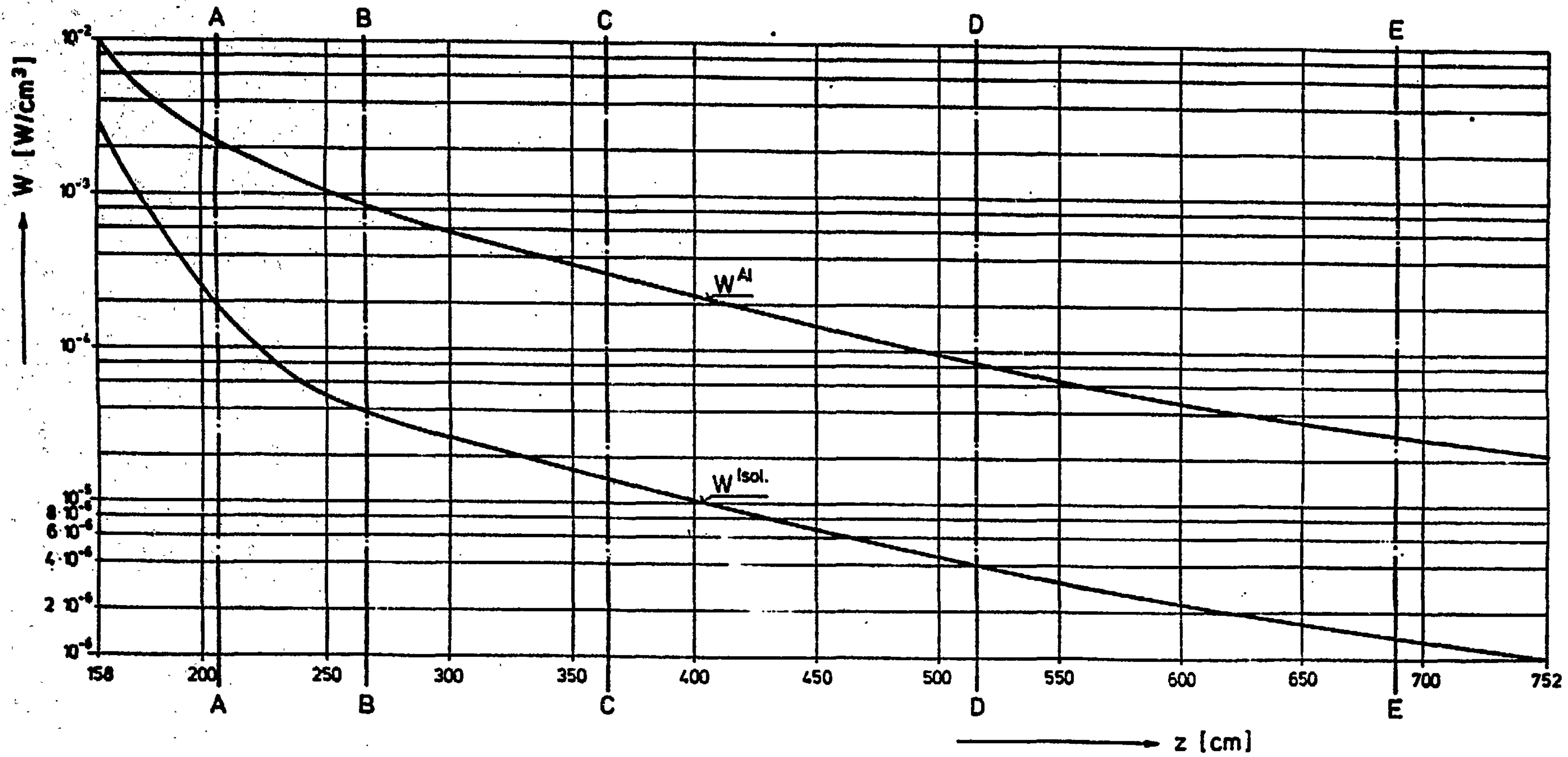

FIG.6: RADIATION HEATING OF THE TANK WALL