ASSESSMENT OF RADIATION HAZARD FOR ISS CREWS BASED ON RADIATION MONITORING SYSTEM

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Introduction

The main goals of radiation monitoring system (RMS) of Russian Segment at the International Space Station are:

- radiation environment monitoring inside the station and on its trajectory;
- estimation of radiation exposure to cosmonaut's critical organs in units of dosimetric functionals used in the standards;
- forecasting of the crew exposure levels and development of recommendations directed at decreasing the radiation hazard level;
- providing the radiation safety service (RSS) with information necessary for estimating and forecasting the exposure dose to cosmonauts and developing optimal recommendations for their radiation safety.

The report contains the description of main approaches, used in RMS and information on its structure and functioning procedure.

Main criteria of radiation environment estimation

The radiation environment categories are defined by the values of mean-tissue radiation dose or the values of equivalent dose to a critical organ from the list established by the standards. The values are presented in Table 1. The dynamics of radiation situation and getting of the crew into one of the established categories should be forecasted for taking preventive measures, the fulfillment of which will result in intervention into the flight program. For establishing the criteria of this intervention it is expedient to add some conditions, characterizing reliability of the situation assessment and in this way, the intervention validity.

For probabilistic estimation of radiation category it is proposed to be guided by the two values establishing the boundaries of radiation categories: dose limits given in Table 1 and probabilities of their exceeding presented in Table 2.

Table 1. Boundary values (low values) of Radiation Environment Categories

Organ	Category of radiation environment			
	Normal, mSv/day	Disturbed, mSv (mSv/day)	Accident, Sv	Critical, Sv
All body	-	-	0,25/0,50*	1,00
BFO	0,3***	$10xD_{norm}$ $2.5xP_{max}$ SAA (δ=4g/cm^2)	0,25/0,50*	1,00
Skin	1,8	-" "-x 6**	1,5/3,0*	6,00
Ocular lens	0,6	-" "-x 2**	0,5/1,0*	2,00
Possible Actions	Flight according to the program. Routine Control of crew doses.	Intervention into flight program on the basis of ALARA principle	Operative intervention into the flight program, with the possibility of losing some parts of its elements	Advanced flight termination

- *Dose in the numerator is limitation for any month during the flight provided that the total dose will not exceed the annual limit presented in the denominator.
- **Factors are the transmitting coefficients from BFO dose limits to those for skin and ocular lens.
- ***Assessment was made on the basis of averaging the radiation monitoring data on board the MIR station during March 1986 – August 1997. The daily quality factor was taken equal to 2.

According to the accepted classification of the current and forecasted radiation situation it is possible to develop some general regulations of the crew actions directed at radiation safety ensuring. It should be noted that current estimation of radiation situation is realized on the basis of measured (and recalculated to areas of interest) values of adequate dosimetric functionals, and assessment of forecasted radiation situation is made on the basis of specific methods and models used in them.

The decision on using intervention should be made with taking into account the radiation situation category, the probability of its appearance and possible consequences of the intervention. The main information on measured values is given in Table 3.

Table 2. Confidential probabilities of estimation

Radiation Situation category	Normal	Disturbed	Accident	Critical
Probability of dose limit exceeding	Measured value (without probabilistic Estimations)	Probability of dose exceeding from column 3 of Table 1 >10%	Probability of dose exceeding from column 4 of table 1 >1%	Probability of dose exceeding from column 5 of table 1 >0.1%

Table 3. Measured dosimetric values and the ones calculated on their basis

Category of radiation situation	Dosimetric values		Range of measured values
	Measured	Estimated	
Critical or accidental	Absorbed dose rate in the given points of spacecraft, skin absorbed dose, LET spectrum inside the spacecraft.	Mean tissue equivalent dose, effective dose, equivalent dose in organs, risk of dose exceeding.	From 10^{-6} to 1 Gy/hour. Absorbed dose up to 10 Gy, LET spectrum from 0.3 up to 1500Kev/mkm.
Disturbed or normal	Absorbed dose rate in the given points of spacecraft, skin absorbed dose, LET spectrum inside the spacecraft.	Mean tissue equivalent dose, effective dose equivalent dose in BFO, equivalent dose rate in organs, BFO dose rate forecast	From 10^{-6} to 1 Gy/hour. Absorbed dose up to 10 Gy, LET spectrum from 0.3 up to 1500 Kev/mkm Forecast on 24 hours

Table 4 presents an example the calculated dose values for maximal solar proton event (October 19, 1989) during MIR-station flight.

Table 4. Doses on board the MIR station in October, 1989

	Working compartment	Absorbed Dose, mGy
1	Adapter module	93,3
2	Central console	17,6
3	Small diameter bay	36,5
4	Big diameter bay, working table	9,2
5	Big diameter bay, stadium	5,4
6	Commander compartment	29,0
7	Engineer compartment	29,4
8	R-16 unit's place	27,4

Background dose rate level before the solar flare was 0,17-0,23 mGy/day.

Methodological basis of RMS functioning is the estimation of current absorbed depth-dose curve on the basis of the dose rate data measured by the set of detectors, located in the points with different shielding /2/. Processing and analyses of these measurements permits to calculate the values of the required dosimetric functionals practically in every point inside the station if the shielding function in this point is known. The calculations are carried out on the basis of the equation

$$P_j = \int_{x_{min}}^{x_{max}} f(x)\rho_j(x)dx \qquad (1)$$

where

j-number of the station point for which estimations are carried out;

P_j –absorbed dose rate in this point;

f(x) – absorbed depth-dose curve;

ρ_j (x) –probability density function of x- shielding mass around the point of interest;

x_{min} and x_{max} – minimal and maximal boundaries of defining the interval of sub-integral function.

The logic of dose estimation in any point is based on the following preconditions:

1. Depth–dose curves for various materials of the station equipment are close.
2. Secondaries aren't taken into account.

3. All depth-dose curves in practically important for calculation range of thickness are continuos.
4. The superposition of shielding mass spatial distribution and angular distribution of radiation outside the station permits to accept the distribution of the dose rate inside the station compartment as isotropic and to use the equation (1) for absorbed dose calculation.

The last precondition should be detailed analyzed, especially in the light of investigations of the radiation angular distribution in the near Earth space /3,4,5/. The estimation of the shielding conditions of the RS ISS is presented in Fig.1. The method of shielding function calculation is described in /6/ and analogous to one was used by Atwell at all /7/. It is seen the great shielding anisotropy in the ISS compartment, but the influence of this effect on the dose distribution in the body can be investigated experimentally only.

For dose estimation in the compartment the depth-dose curve must be calculated. For this goals 8 semiconductor detectors /8/ are used in RMS. The data from all detectors form the basis for calculation of this curve and consequently for the dose estimation inside the compartment.

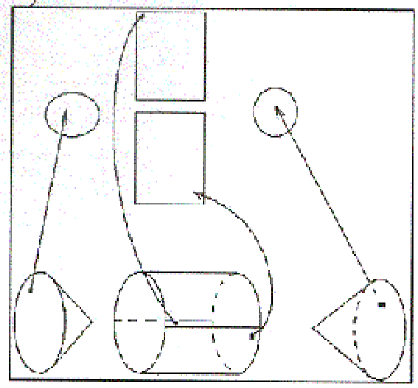
However the cosmonaut's moving in the station should be taken into account for individual dose estimation. For improving this situation the active units "Pille" and "Liulin-4" were included in RMS and the calculation method was expanded with taken into consideration the cosmonaut's standing probability in different compartments of the station (a cyclogram of cosmonaut's work).

The next goal of the RMS is the estimation and forecast of cosmonauts doses during the radiation disturbances. The one of main sources of such disturbances are solar proton events (SPE). Earlier during the MIR-station flight the SPE forecast and adequate information for crew was provided by the ground Radiation Safety Service (RSS) at IBMP. Now, on board of ISS there is the automatic channel of direct informing crew about the radiation environment disturbance determined on the basis of the RMS data.

The form of this information permits crew to make the solution about the work cyclogram changing if the recommendation from the RSS does not come in time. Estimation of the radiation environment category and recommendation development is carried out by the comparison of the current parameters of radiation environment with criteria described above.

Structure and method of RMS performance

Block diagram of the RMS hardware on the Russian Segment of the ISS is given in Fig. 2. The following instruments are used within the RMS. The R-16, DB-8, DCU, and UU were developed and produced at the Nuclear Research Institute of MSU, these instruments were reported several times at previous meetings / 1, 2 /. Liulin-4 and Pille instruments are also well known / 3, 4 /. Besides the above а)



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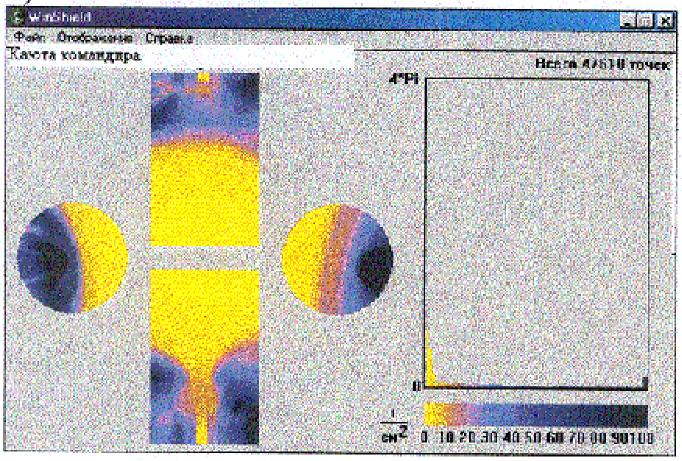

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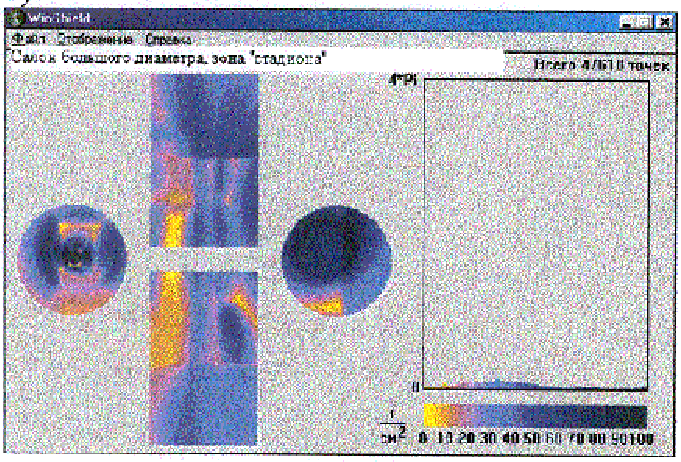
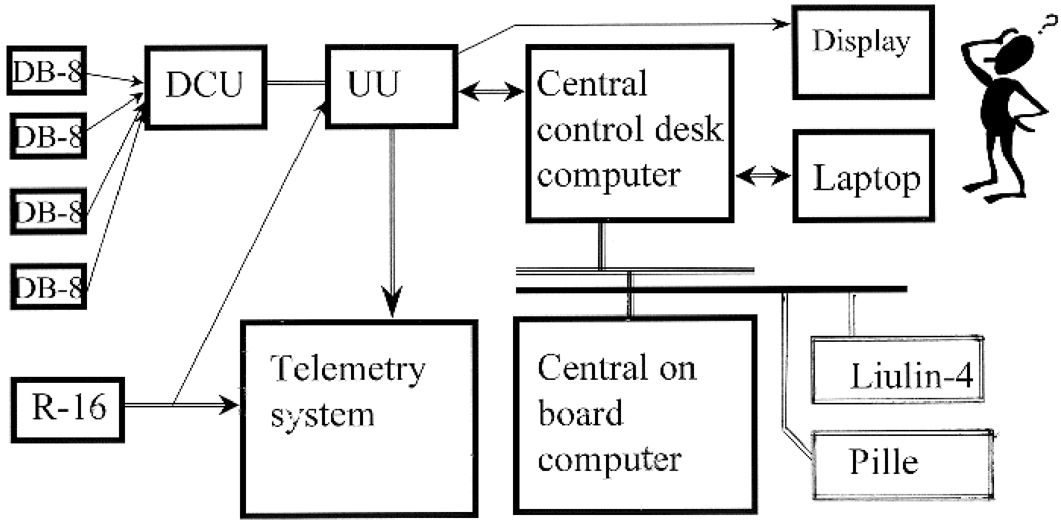


Fig.1. Shielding conditions estimation for the Service Module of the ISS.
A) – Diagram of 4π solid angle conversion into the plate surface
Б) – Calculation results for compartment No. 1
B) – Calculation results for the stadium zone.

Block scheme of the radiation monitoring equipment of the RMS development and accompanying on board devices



mentioned instruments, on board hardware of the Service module is used to provide the performance of the RMS and also to download the data to the ground, and to display the data to the crewmembers.

To display the data obtained to the crewmembers, the data are sent to the on board hardware after processing, namely, to the laptop connected to the CCDC, and in case of radiation accident, to the alarm display shown on the block diagram. The laptop software can generate special forms to demonstrate radiation data. The mode of the first form is presented in Fig.3.If we click with mouse the button "Working compartments", the next form appears (Fig. 4), this form demonstrates the silhouette of the Service Module and main crew working compartments, extra vehicular activity (EVA) included. In case of normal radiation environment all these compartments are colored blue, in case of disturbed environment part of these compartments can be colored yellow. Yellow color means a situation when a solar flare dose exceeds 10 times a mean daily dose but is still below the accident level. The red color corresponds to exceeding of the accident level. Yellow and red color imply to determine the duration of radiation contingency. If we click with mouse the compartment, a plot characterizing dose rate dynamics for this compartment appears on the screen. The dose rate dynamics is forecasted for the current and next day. The software methodic takes into account the heterogeneity of the dose field along the trajectory, the alarm signal is generated if the additional dose rate is measured in regions above Canada or southern part of Indian ocean. In this case RMS determines the category of radiation environment for every working compartment based on the comparison of predicted and boundary values of the radiation environment category. After the request of the crew RMS marks every compartment with corresponding color. Such diagnostics based on the forecasting estimations should allow to the crew members to undertake necessary protection actions (see Table 1) or determine themselves working procedures on board the station for radiation contingency periods..

Proposed RMS allows to increase essentially the reliability of implementation of the ISS crewmembers radiation safety. This system practically excludes the situation when crewmembers do not have information on radiation environment in working compartments. RMS gives an opportunity to adopt a decision corresponding to real radiation environment.

Such opportunity is extremely important for future space missions. That is why, at the current moment for manned ISS missions, maximum number of problems should be solved regarding radiation monitoring for future manned flights. To do this it is necessary to realize the following tasks during ISS flights:

- to verify experimentally within the ISS research program the algorithms of the analysis and processing of the RMS detectors signals, and the methods to extrapolate the dose rate values for habitable volume and future time periods;

- to study the interaction between the on board expert system, namely, RMS and on ground groups that analyse and process the data;
- to check the convenience for the crew to work with the proposed forms of radiation data presentation and modify these forms taking into account crew recommendations.

Conclusion

The radiation monitoring system of the Russian Segment of the ISS allows to increase essentially the volume of radiation measurements and to analyze the data directly on board the station. This system should essentially increase the accuracy of the ISS crewmembers radiation exposure measurements, and the reliability of implementation of their radiation safety.

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