The concept of radiation safety, based on which the parameters of the radiation shielding for various schemes of a flight to Mars were calculated, is presented. The concept combines modern approaches to the regulation of radiation safety with experience in design investigations, performed by the present authors, in the field of radiation protection for cosmonauts. The general conceptual assumptions and assumptions with respect to separate aspects of the development of a radiation-safety system for a manned expedition to Mars are examined. Probabilistic approaches are absolutely necessary. Limitations on the mass of the material in the radiation shielding and taking account of other forms of the flight risk make it necessary to accept higher levels of irradiation for cosmonauts during a 1–2 yr flight than the levels established for people working with radiation sources under ground-based conditions over the same period of time. Acceptibility from the standpoint of the flight organizers and the cosmonauts is considered. In contrast to previous assessments made by the present authors, the protective role of equipment and structures in the manned module is taken into account.

It is well known that manned flight to Mars was the subject of a design concept even during the period when preparations were being made for the first manned flight in space. In the design studies that were performed under the direction of S. P. Korolev, it was supposed that such flight will occur in the 1970s. The range of scientific investigations on medical-biological support for manned flights and, specifically, radiation safety was determined, beginning in the 1960s, precisely with such a perspective [1]. It was already clear at that time that the problem of ensuring radiation safety during interplanetary flight is to develop shielding with a substantial mass. On the basis of studies performed in the 1970s–1980s, we estimated the required thickness and mass of the radiation shielding of the crew [2]. These studies were then made more precise [3] in connection with the adoption of a system of standards in the 1980s [4]. Attention was devoted to radiation shielding because with respect to its mass it competes with other systems of the spaceship and can even influence the choice of the flight scheme. Thus, a low-thrust motor is advantageous because of the economical consumption of the working body. But a flight using a low-thrust motor lasts for a longer period of time and, correspondingly, the shielding is heavier. If such a motor is used for gather speed near the earth, which must occur precisely in the Earth’s radiation belts for 1–2 months [5], then very heavy shielding is required. There arises the question: what kind of motor and what kind of flight scheme are best?

Advances in studies of Mars using automatic stations have stimulated a new wave of interest in manned flight. However, the beginning of this wave, in our view, must be considered to be the Moscow Science and Technology Center project No. 1172 [6], which was performed in 2000 at the M. V. Keldysh Center by specialists in design and research organizations. The main conclusion from these design investigations is that such a flight is possible even with the modern level of cos-

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1 Scientific-Technical Center for Radiation-Chemical Safety and Hygiene.
2 M. V. Keldysh Center.

monautics. It would cost approximately 30 billion dollars, and consequently it can and should be international in economic, technical, and scientific respects.

The above-mentioned estimates of the shielding characteristics were made even before the ICRP Publication No. 60 [7], where the radiation risk coefficient was increased by a factor of 2.5. In contrast to these estimates, by the time project No. 1172 was completed new radiation safety norms, which met the ICRP recommendations, were already put into practice [8]. However, new norms, which would replace GOST 25645.215-85 [9], for long-term (more than one year) space flights still do not exist. The methodological instructions for orbital flights with durations up to 1 yr were adopted only in 2004 [10]. In this connection, several variants of numerical criteria of radiation shielding were used in project No. 1172 to estimate the shielding for specific dimensions and mass of the manned module of the ship in a manned interplanetary expedition.

In the present paper, attention is focused on radiation safety in manned flight to Mars not only because the required norms are not available and must still be developed but also because at the present time our radiation-safety laws are still, as a whole, being updated [11]. Updating is needed because of the enactment in 2003 of the Federal Law On Technical Regulations and for other reasons also [12]. The desirability of using this law to regulate radiation safety is under active discussion and is raising serious doubts [13–17]. In addition, the design of the ICRP recommendations, which were to be adopted in 2005, replacing the above-mentioned publication No. 60, is now well known and is under discussion [18–20]. Consequently, the system of standards mentioned above also is to be updated [4].

Conceptual Assumptions. The concept of radiation safety of the crew of a manned expedition to Mars formulated in project No. 1172 is largely based on domestic scientific-research work on radiation safety of space flights, design studies of interplanetary expeditions, and experience in ensuring, in practice, the safety of orbital flights, i.e., on the results of work started in this country in 1960 [1]. It must be acknowledged that the experience gained in orbital flights is inadequate for direct application for designing and implementing a manned expedition to Mars – the radiation environment is different, the level of danger is different, and the measures required to decrease the danger to the required level are somewhat different.

The initial assumption of the concept is that ionizing radiation is one factor of space and space flight which has a negative effect on the crew of the spaceship, apparatus, and materials. The degree of danger of this effect depends on the adopted and reserve measures of protection, which, taken together, comprise the system of radiation safety for the crew.

The use of nuclear-technical systems in the expedition makes the problem much more complicated, because it is necessary to consider additional sources of radiation danger for the crew and the possibility of radioactive contamination of Earth and Mars, including the surface, atmosphere, and surrounding space. The latter presents a definite danger for Earth’s population and possibly for living organisms on Mars, and a long-term information obstacle for investigations.

Ensuring ground-based radiation safety when developing space nuclear-technical systems is, of course, of no concern for the safety of the crew. Although, with respect to a nuclear motor, if the goal is to use such a motor, then this is a big independent problem, whose solution for ground-based conditions is also important for developing safety systems for cosmonauts.

The main methodological assumption of the concept is the acknowledgment of the fact that, on the one hand, deterministic and stochastic sources of radiation which act nonuniformly in time are present. On the other hand, in an organism, different deterministic and stochastic effects can appear as a result of irradiation. Consequently, with respect to radiation safety of the crew the terms and methods of the theory of probability must be used.

The concept of radiation safety includes radiation safety of the manned expedition as a whole, the content, composition, development and operation of the radiation safety system for the crew. In the overall concept of radiation safety the answer to the question of what is to be considered dangerous is most important, since this answer is not identical for various decisions with respect to a manned expedition to Mars and consists in the following:

• for the members of the crew the concept consists in an acceptable probability and the degree of harm which radiation can have on the organism, i.e., in acceptability which is the result of a comparison (according to subjective criteria) of the radiation danger and harm from other factors of the space flight with positive motivations for participating in the expedition;

• for the individuals responsible for the preparation for and executing the expedition, the concept consists in the acceptability for their professional work on the fact that the completeness or quality of the execution of the program of the expedition can decrease as a result of degradation of the crew’s health during flight, which is actually caused by irradiation and/or will be attributed to (although unjustifiably) the inadequacy of radiation protection measures;