Executive Summary

This Report was prepared to evaluate the potential impact of individual genetic susceptibility and previous radiation exposures on radiation associated health risks for astronauts during their lifetimes following space missions.[1] The Report also evaluates whether either of these factors needs to be included in the radiation protection program for astronauts.

With the development of techniques to sequence the human genome, the science of genetics has advanced rapidly over the past few years. Using these sequencing techniques, it may become possible in the future to determine the genetic background of individuals and thus to better understand individual risk and the mechanisms involved in radiation-related cancer. With current genetic techniques, it is possible to define many different mutations involving numerous known genes that may alter an individual's lifetime risk for radiation-induced cancer. Linking research on genetic background to radiation sensitivity may pave the way to predicting an individual's radiation-related risks and thus improve radiation protection guidance. Currently, this is not possible as all risk estimates are derived from large populations. The information available on the impact of genetic background on risk and its future potential is one of the major subjects addressed in this Report.

Another major purpose of this Report is to determine whether the risk associated with past radiation exposures from medical therapy or diagnostic procedures is altered by radiation exposure during space exploration. Whether to include nonoccupational exposure in evaluating total lifetime risk limits set by the National Aeronautics and Space Administration (NASA) is discussed. It was determined that such exposures should not be added to occupational exposures. It should be recognized that in population studies, risk estimates incorporate all sources of radiation that the population receives, whether natural background or medical, as part of the background exposure, albeit the magnitude is not known. Thus, the risk estimates that are derived are those that are above the normal population exposures to these other sources. This

[1]In the context of this Report the term "space missions" includes low-Earth orbit, lunar and interplanetary missions.

Report includes an evaluation of the regulatory, legal and ethical issues associated with using information on radiation-related genetic background and previous radiation exposures to predict an individual's lifetime radiation risk.

The following is a summary of the primary conclusions reached in this Report:

- Evaluation of genetic susceptibility to radiation-induced cancer and the influence of prior radiation exposure (*e.g.*, from medical therapy) should be given consideration as factors that could influence the long-term risk of cancer and other health effects in astronauts resulting from exposure to radiation received during space missions. However, at this time it is not possible to make accurate predictions of future risks associated with genetic susceptibility.
- NASA focus on health risk-based criteria for evaluating the safety of astronauts is consistent with the need to better understand the role of other factors such as genetic susceptibility and prior radiation exposures in evaluating the health risk to astronauts from estimated radiation exposures that may occur during planned space missions. The radiation risk level should not exceed a 3 % increase in lifetime risk of fatal cancer.
- There have been extensive laboratory studies on the role of genetic susceptibility in radiation sensitivity of cellular and tissue model systems. However, with the exception of a relatively small fraction of the human population that is known to have innate genetic susceptibility to cancer from radiation exposure, it is difficult if not impossible at this time to use the available information to make predictions on the role of genetic factors for the small corps of astronauts participating in space exploration.
- In addition to an increasing amount of laboratory data that are being obtained on carcinogenic effects from acute and chronic exposure to both low and high linear-energy transfer (LET) radiations, extensive data also are available from atomic-bomb survivors, medical patients and workers exposed primarily to low-LET radiation. However, because of the unique space radiation environment that involves low- and high-LET radiations, there is nonetheless a limited body of information on which to make precise predictions of astronauts' long-term risks of cancer and noncancer diseases resulting from radiation exposures in space missions.
- Important factors in analyzing the risk to astronauts from exposure to radiation, for which current knowledge is

inadequate, are the biological effects and cancer risk associated with exposure to energetic high atomic number (Z) cosmic radiation (HZE). A number of laboratory-based studies have indicated that exposure to protons and other high-LET particulate radiations such as those present in galactic cosmic radiation (GCR) may change the risk to astronauts of cancer and other late health effects. Similar concerns exist for astronauts' exposure to protons from intense solar particle events (SPEs). NASA should set a high priority on continued support of research on biological markers of radiation interactions at the cellular and tissue levels. Until further information is available, NASA should continue to use current estimates of health risks associated with radiation exposures in future space missions.

- There are legal and ethical issues associated with astronauts' space missions that must be addressed by NASA in a manner beneficial to astronaut health protection. These include maintaining up-to-date policies and practices that provide acceptable limitations on radiation exposure and continued effective communication with astronauts to facilitate shared decision making on acceptable levels of risk from radiation exposures in the space environment. There also is a need to implement practices in evaluating the radiation risks of individual astronauts that are consistent with laws that protect personal information on genetic susceptibility and prior radiation exposures for medical or other purposes.

The following is a summary of recommendations based on the evaluation of genetic susceptibility and prior radiation exposures as risk factors that may contribute to overall astronaut health risks from exposure to radiation in the space environment:

- It is recommended that radiation exposure data for previous astronaut space missions be normalized to a mean daily rate (*i.e.*, mSv d^{-1}) to facilitate risk communications for future NASA space missions. Missions of different types [*e.g.*, low-Earth orbit (LEO) or deep space] and different durations (*e.g.*, days or months) should be placed into a radiation-risk perspective using these data.
- It is recommended that no genetic testing of astronauts be carried out at this time. The probability of individual astronauts having genetic susceptibility factors for radiation-induced cancer or other radiation-induced diseases is low. Furthermore, there are only a limited number of genetic

characteristics that are known today to affect the risk of radiation-induced cancers or noncancer health effects in humans.

- There is little evidence at this time that an astronaut's prior exposure to radiation, including that from medical procedures, would significantly alter the risk per unit dose associated with subsequent exposures during space exploration. It is therefore recommended that previous medical or other nonoccupational radiation exposures not be taken into account in the occupational radiation protection limitations for astronauts.
- It is recommended that NASA continue to maintain regulatory occupational dose limitations for astronauts in all types of space missions of varying durations (Tables 6.1 and 6.2). NASA should continue to use regulatory dose limits based on mainstream consensus science recommended by radiation health protection organizations, such as the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP). NASA also should follow practices recommended by recognized standard-setting bodies such as the International Organization for Standardization (ISO) and the American National Standards Institute (ANSI), to establish the most defensible position from a legal perspective. NASA policies, procedures and exposure limitations used to minimize radiation risks for astronauts should consider those promulgated by various federal agencies for workers in other occupations involving radiation exposures.
- It is recommended that NASA continue to use a shared decision making model in reaching conclusions regarding appropriate levels of early and late radiation health risks associated with astronaut exposures during future space missions. NASA also should continue to provide training and maintain active discussions on radiation risk considerations with astronauts. It also is recommended that NASA maintain policies and practices that ensure the privacy of astronauts' information related to their genetic background and prior radiation exposures from medical or other sources.