T O F F L E R A S S O C I A T E S ®

May 31, 2002

Dr. Maurice Averner
NASA Ames Research Center
MS 19-20, Building: 19, Room 1067A
Moffett Field, CA 94035-1000

Dear Dr. Averner:

We are providing this memo to summarize the results of our recent independent assessment of the societal value of several R&D activities associated with NASA's *Generations* initiative. As we describe below, it is our assessment that the activities we looked at in our "case studies" already provide or have provided significant societal value, and/or are highly likely to provide significant societal value in the future. While it is difficult to quantify this value in some cases, we believe the qualitative arguments for the value are strong, and that the value ultimately is quantifiable.

In selecting our cases, we considered a number of activities in and related to Generations specifically, the R&D portfolio of NASA's Office of Biological and Physical Research, and the broader NASA R&D portfolio. We eventually settled on three cases:

- Generations Space-Based Research on Bacterial Infectivity
- Generations Next Step in NASA's Legacy of Kidney Health Contributions
- Generations Technology Advances for Space-Based Research and Earth Applications

A synopsis of our assessment of each case is provided below. Following the synopses is a summary of the background behind our effort.

Case 1 – Generations Space-Based Research on Bacterial Infectivity

The first flight experiment scheduled under the Generations initiative will study patterns of gene expression and infectivity in salmonella and three other organisms. The experiment advances earlier work done in conditions of simulated microgravity (in the NASA-developed bioreactor) in which salmonella became twelve times more infectious. Researchers conducting this experiment believe they can learn from the organism's gene expression in space what turns on and off the particular genes that control infectivity. Ultimately we may learn to control these genes on Earth and identify novel targets for vaccines to deal with salmonella-related illnesses. The returns from just this one Generations experiment are potentially many times greater than the investment when we consider the following.

New insights from Generations space-based experiments may teach us about infectivity of other organisms that also pose threats, including ones that may be of interest to officials responsible for bio-terrorist threats in the context of homeland security. Ultimately the Generations experimentation on salmonella and other bacteria in space may help to save billions of dollars and millions of lives on Earth. Estimates on the costs to the U.S. economy from more than 1 million

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reported annual cases of salmonella-related illnesses range between $2-4 billion. Should the viability of the food supply be undermined as antibiotic resistance emerges in the salmonella bacterium, these health and industry impacts could rise sharply (the U.S. poultry industry alone is $22 billion per year).

Moreover, salmonella isn't just a U.S. issue. In developing nations it is a major killer with severe impacts on economic growth. New insights into salmonella infectivity, unobtainable in any other laboratory or experimental environment, could help reduce the economic and human toll in these lesser-developed countries as well as in the U.S. At the same time, the Generations experiments also can help advance research on other diseases. Researchers are investigating the use of genetically-modified salmonella and other organisms to deliver experimental preventive vaccines effective against a range of diseases. New ways of manipulating salmonella gene expression, learned in space experiments, could help them modify the vaccine transmission medium, allowing customized vaccines for different disease strains.

Case 2 – Generations Next Step in NASA's Legacy of Kidney Health Contributions

Few know of NASA's contributions to the battle against kidney disease. These include inventing a chemical process that led to the invention of a new kidney dialysis machine; inventing the bioreactor and conducting other R&D that has enabled new advances in tissue engineering useful for repairing damaged organs; and conducting genetic research in space that showed kidney cells producing greater quantities more quickly of hormones important to treatments for kidney disease. The *Generations* initiative continues this heritage of breakthroughs.

The societal benefits from NASA's past contributions to kidney health are significant. Kidney disease remains one of top ten causes of death in the U.S. About 41 million in the U.S. have decreased kidney function, including 90,000 end-state renal disease cases annually. The kidney dialysis machine, an unanticipated outcome of NASA engineers' and scientists' work, each year extends the life of 230,000 of these patients by an average of 5-10 years. The only other treatment for kidney disease is organ transplantation, but there is a worsening shortage of donors, and organ repair is not yet in reach. However, advances in tissue engineering are moving us in that direction, including advances made possible by the bioreactor. The bioreactor was designed by NASA to understand how human tissue might be affected by prolonged spaceflight, but it has become the "industry standard" for culturing a number of medically important types of cells on earth.

Beginning in the late 1980s, NASA-sponsored research on kidney cells in space has moved us closer to the next breakthrough in kidney disease treatment. This work has shown that the genes in kidney cells in space express differently and produce hormones valuable for kidney disease treatment in greater quantities than is possible in any laboratory or experimental environment on earth. As part of the *Generations* initiative, NASA-funded researchers will study why and how kidney cell genes express (i.e., turn on and off) differently in space. Understanding this may allow us to turn the genes on and off on earth, which may enable us to create novel treatments or cures for kidney disease.

Kidney research is important; the economic value of "solving" kidney disease would be significant. For example, estimates show the total costs associated treatment of End State Renal Disease were $17.87 billion in 1999. The social value of extending many millions of lives each year also would be significant.

Case 3 – Generations Technology Advances for Space-Based Research and Earth Applications

The *Generations* initiative is making it possible for private- and public-sector innovators to deliver life-saving and money-saving applications to the American people, and the world. Converging advances in miniaturization, automation, and remotely operable technologies, many enabled by NASA R&D, have for some time been revolutionizing medicine, bio-informatics, biosensors, nanotechnology, and more. The demanding environment of space flight has compelled us to push the limits of human science and engineering achievements, and conducting biological research in space in Generations and other programs is pushing technology further. Without the innovation that space flight demands, we would not have this technology to draw upon for accelerating needs in homeland defense, environmental monitoring, individual health, and other areas.

There are clear economic, social, and other benefits from NASA's past technology advances in areas like miniaturization, automation, and remote operability. For example, technologies to monitor astronaut health during space missions helped create implantable medical devices like the fetal heart monitor. In addition, NASA scientists and engineers helped make strides in the development of Microelectromechanical Systems (MEMS), an enabling technology whose current applications include accelerometers, pressure, chemical and flow sensors, micro-optics, optical scanners, and fluid pumps. The MEMS industry has a projected 10-20% annual growth rate, with the potential of a greater than $8 billion market by the year 2001. The societal benefits from advances in the fields enabled by MEMS are even greater.

As part of *Generations*, NASA is developing and funding a range of new micro- and autonomous biotechnologies. There are important potential earth applications of these technologies even just in three areas we examined: bio-defense and homeland security; environmental monitoring; and individual health. For example, new bio-warfare and bio-terror threats raise the importance of sensors that reflect the characteristics in which NASA is pushing the envelope, like micro-miniaturization and autonomous operation. Sensors being developed with *Generations* funding can be rapidly encoded with genetic information of any genetically sequenced pathogens to detect their presence even in tiny concentrations. Technologies to improve water quality monitoring are projected to emerge with *Generations* funding from already-demonstrated NASA-funded distributed monitoring systems developed under Fundamental Biology. The potential social value of such advances can be measured in terms of improved quality of and life expectancy not only for humans but also for other elements of our ecosystem. Finally, in the area of individual health, new technologies are being assessed that could build on previous NASA successes such as the minimally-invasive sensing technologies developed in collaboration with the National Cancer Institute as an element of disease intervention strategies.

Background

Toffler Associates was engaged in September 2001 by NASA Ames Research Center to conduct an independent, objective assessment of the societal value of the *Generations* initiative in multiple domains and develop frameworks for communicating this value to executives. Our approach was to identify and employ a wide range of social value assessment methods used by executive managers. The assessment and communications methods we used were culled from the best management practices across many fields, adapted as appropriate to the Generations case based on our experience with NASA, other Government agencies, and a wide range of commercial industries. We applied the selected impact assessment techniques to NASA space biology at a high level and developed an executive level assessment and communications "tool-kit."

In April 2002, senior leaders at Ames responsible for the *Generations* initiative asked Toffler Associates to take our work to the next level. Specifically, we were asked to look closely at several "cases" and assess the social value of the experiments, research programs, or technologies associated with those cases. As in our earlier macro-level assessment, our charge was to provide logical,

documentable qualitative arguments, using social value techniques familiar to executives. Through these arguments we would offer an independent and objective basis for evaluation of the *Generations* program by OMB and Congress, each of which use "value to society" as one key criterion.

In doing our cases, we drew on the portfolio of social value arguments we articulated last year, from which NASA can select depending upon the audience. We concentrated as we did last year on four primary domains of value – social, economic, scientific, and value to NASA as an organization. Where appropriate we also considered a fifth domain of great interest to NASA and the American society – security, especially homeland security.

To employ the value assessment methods to the selected cases, we gathered information and data from researchers and other executives in NASA, and from a range of external sources. We drew on the resources of our extensive network of experts, including retired executive managers at NASA, directors of other R&D intensive institutions, and directors of financial research institutions. As in our earlier effort, we adapted and applied management assessment techniques taught in leading business schools and used by executives worldwide. We made innovative use of methods utilized by leading R&D organizations in the public and private sectors. We applied the data conservatively and, where appropriate, we used our judgment in applying the methods to Generations. We tested and validated the models and the communications with others on our team and with senior leaders and scientists at Ames associated with the *Generations* initiative.

None of our analysis and assessment should be construed in "if / then" terms – that is, we believe the societal value we have described is possible stemming in part from scientific and engineering advances under the *Generations* initiative, but we would not suggest that specific outcomes are to be expected as a direct result of specific experiments. We do however believe that the Generations initiative is a worthy investment for American taxpayers for practical reasons beyond it's value as a new arena for fundamental scientific discovery.

Sincerely,

Steven H. Kenney