September 22, 1994

TO: JACK GIBBONS

THROUGH: JANE WALES

FROM: FRANK VON HIPPEL

CC: M.R.C. GREENWOOD [OSTP Associate Director for Science]

THE POSSIBILITY OF REDESIGNING THE PU-238 CONTAINING GENERAL-PURPOSE HEAT SOURCES TO BE USED IN THE CASSINI MISSION TO INCREASE CONFIDENCE OF SURVIVAL OF REENTRY FROM AN EARTH FLYBY
(4 pages of text plus figures)

You will have to authorized the launch of Cassini (currently scheduled for Oct. 1997, see figure 1). [Cassini is of concern] principally because it will be carrying 3 radioisotope thermoelectric generators RTGs, containing a total of about 23 kg of Pu-238 (Fig. 2)

The multilayered General Purpose Heat Units (GPHU) in which the plutonium is packaged are designed so that [the plutonium] is unlikely to be dispersed by a launch accident or by reentry from an earth-escape orbit.   However, the design predates missions involving earth gravity assists. Galileo, launched in late 1989, was the first such mission and Cassini would be the second. The earth flyby speed of Galileo was higher than earth-escape velocity (14 vs. 11 km/sec) and Cassini's speed will be much higher still (19 km/sec).

When your predecessor authorized the launch of Galileo, he was put into a less than totally comfortable position. DoE, working in collaboration with NASA, issued a Final Safety Analysis report in December 1988 that concluded that the cylindrical graphite impact shells (GISs) surrounding the Pu-238 would survive reentry intact (Figs. 3). However, five months later – and less than six months before launch – the Interagency Nuclear Safety Review Panel (INSRP) found that this conclusion was based on the uncertain assumption that the GISs would be spinning [averaging the heating over the their surfaces] and concluded that, if they did not, they could burn through and the plutonium could be fully released and vaporized in the upper atmosphere. The Science Advisor’s decision that launch was still possible without undue risk therefore depended entirely on his (and INSRP's) the Bush Administration's confidence in the very low estimate for the probability of reentry from earth flyby.

Your situation for Cassini might be even less comfortable. DoE's space nuclear-power program has commissioned the development of a more advanced reentry model by Martin-Marietta that includes shielding of the outer aeroshells from the heat of the shock by the ablating carbon and concludes that [the aeroshells] would survive intact at Cassini flyby reentry velocities. However, the model is both complex and untestable and the INSRP reentry panel, which reviewed it in June, was reportedly skeptical that it could be relied on.

With regard to probabilities, Cassini's designer, the Jet Propulsion Laboratory (JPL) has adopted – as with Galileo – the requirement that the calculated probability of reentry from earth flyby be kept below 10^{-6}. JPL's   probabilistic risk analysts are confident that the probability of reentry as a result of an internal failure, such as is believed to have occurred with the Mars Observer, has been reduced below that level. They believe that the reentry probability is now dominated by a meteorite-induced puncture of one of the fuel tanks during the last 10 days before flyby when the impulse from such a failure could be large enough to cause reentry and the collateral damage could make corrective maneuvers impossible.

This time, however, INSRP's reentry panel, at its June meeting, after being briefed on the JPL's Cassini reentry probability calculations, was more skeptical than it had been for Galileo.

Given the history of catastrophic failures in complex systems, such low probabilities are difficult to defend. An upper bound on the reentry probability of 10^{-4} is probably defensible, however, and one might judge such a probability as adequately small. On an actuarial basis, the occurrence of one catastrophic failure (Mars Observer) among planetary spacecraft during an orbital maneuver with a 10-percent probability of subsequent reentry would lead to an estimate of failure on the order of 10^{-3}. Given the special care that is being devoted to the design of the Cassini hardware and flyby maneuvers, it would be reasonable to reduce this estimate by another order of magnitude to 10^{-4}.

If reentry were to occur, the worst-case model used by INSRP to assess the consequences of reentry of the Galileo spacecraft would predict a release of up to all of the Pu-238 in the form of respirable-size particles in the upper atmosphere. In this case, the estimates of worldwide latent cancer fatalities by a DoE contractor (NUS) ranged from 15,000 to 65,000, depending upon the reentry latitude. The individual doses would be on the order of one month's radiation dose from natural background radiation or a lifetime cancer-death risk on the order of 10^{-5}. (These two perspectives recall the different perspectives of Sakharov and Teller on the risks of atmospheric testing. Using modern dose-risk coefficients, [their] numbers [would be] 5 million deaths [Sakharov] versus a maximum increased individual cancer death risk of 10^{-4} [Teller].)

Given the uncertainties in both the reentry probability and RTG survival of reentry from earth flyby, and given the worst-worst-case (probability)x(risk) estimate of 1-10 cancer deaths from the Cassini mission, I decided it might be worthwhile to investigate whether the RTG design could be made more robust to increase the probability of reentry survival without unacceptable weigh penalty.

In response to our interest, DoE had its contractors brief us on possible design improvements in the protective structure around the Pu-238 capsules. They indicated that a number of improvements would be possible. These included (Figs. 4):

1. Replacing the layer of insulation inside the GIS with ablation-resistant pyrolytic carbon. (The reduced insulation would, however, increase the temperature seen by the iridium clad around the Pu-238 during reentry resulting in more embrittlement at the time of impact.)
2. Machining the carbon-carbon aeroshell so that the GIS would not fall out until more of the aeroshell had ablated.
3. Increasing the thickness of the aeroshell. (This would result in a weight increase on the order of 100 kg and require resizing of the shell of thermo-electric converters surrounding the GPHUs.)

Overall, the contractors felt that all of these options were well worth exploring. Indeed, they regretted that no such effort had been funded. However, they also felt that none could be implemented within the three-year time span remaining before launch of Cassini (see Figs 5).

Indeed, the carbon-carbon aeroshells for the GPHUs have already been machined at a cost of $5 million. Delay of the Cassini mission would be quite costly because of all of the personnel involved at JPL and because of the longer flight times for the other trajectories available in the following few years.

Although we do not have the expertise to authoritatively challenge the judgement that it is too late to consider RTG redesign options such as those discussed above, we are not entirely convinced either. OSTP could ask for a timeline for such redesign, analysis and fabrication and see if independent reviews could suggest ways in which they could be fit into the available time. Since more risk would be involved, the existing design could be used as a fallback.

The effort would cost money – probably more than $10 million.

A weight penalty of up to 100 kg would have to be absorbed by the Cassini mission. (For comparison, in the current design, the weights of the fuel, structure, and payload are up to 3100 kg, 1760 kg and 690 kg.)

Since it is impossible to simulate on earth the conditions of reentry at 19 km/sec, there would not be full confidence in its reentry capabilities either.

If it were necessary to fall back on the existing design, challengers to the safety of the mission could seize on the redesign effort as evidence that the Administration considered the safety of the current design inadequate.

The current situation, in which no effort has been made to redesign the aeroshells for intact reentry at earth-flyby speeds, is hardly optimal. Even if the redesign is too late for Cassini, the work will have been done in case there is another mission requiring an earth flyby. Given NASA's new "smaller-faster-cheaper" policy, no future RTG earth-flyby is currently on the horizon. However, if no design effort is launched now, it is likely that advanced warning for the next mission would again be too short for improved designs to be seriously examined.

It seems that your choices at this point are:

1. Have us drop the matter because it might be impossible to implement a safety redesign for Cassini without delaying the mission, the increase in confidence of reentry would be still not be to 100 percent, and, with no future earth-flybys on the horizon, there might be no benefit for future missions.

   This decision might be accompanied by including in the space-nuclear policy document that we have drafted, the requirement that, if there is consideration of an RTG flyby in the future, a redesign for high-confidence intact reentry from earth flyby speeds would be required.

2. Explore with DoE and NASA their willingness to commission a quick study of the timeline for the design and fabrication of a new RTG that would, with higher confidence, survive reentry from earth-flyby speeds. The timeline should be such as to maximize the likelihood that the new design could be used on Cassini. NASA should in parallel undertake a study of the tradeoffs in mission payload or duration that would be required to accommodate any increased RTG weight.