DISPOSAL OF HIGH-LEVEL NUCLEAR WASTE IN SPACE

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Abstract

This paper discusses the key technological and non-technological issues involved in disposing of high-level nuclear waste by launching it into space. Space disposal has two major benefits. First, it will permanently remove the burden and responsibility of high-level radioactive waste from future generations. Second, the guarantee of large payloads for decades will create a market for launch systems that could truly provide inexpensive access to space. Disposal in space consists of solidifying the wastes, embedding them in an explosion-proof vehicle, launching it into earth orbit, and then away from the earth. A wide range of technical choices exists for launch systems, including electromagnetic launchers, gas guns, laser propulsion, and solar sails. The range of possible destinations include solar orbits inside Venus, Earth-moon libration points, lunar landings, and outside the solar system. This project will not succeed until supporters and opponents are thoroughly convinced about its safety and efficiency. Key demonstrations, such as exploding a launch vehicle with a mock cargo and sending a test capsule to reenter the atmosphere, will be necessary to prove the project's safety.

Introduction

This paper proposes a common solution to two apparently separate issues: the high cost of space operations and the safe disposal of high-level radioactive waste. Forty-two years into the Space Age, access to space is still expensive and unreliable -- sending a satellite into space costs $2,000-10,000/pound and the insurance premium for that satellite from launch until reaching its final orbit is 12-20%. Until the cost of going into space drastically decreases, the large-scale exploitation of space will not occur.

Fifty-six years into the Atomic Age, no system to dispose safely of high-level radioactive waste has been fully accepted by the public or scientific community despite billions of dollars and decades of research on underground storage. The problem is not trivial: American civilian reactors will have produced a projected 42,300 metric tons of spent fuel rods by 2000 and 77,100 tons by 2020. In addition, the Department of Energy holds over 2600 metric tons of spent fuel from foreign, naval, and university reactors, and nuclear weapons programs have created over 380,000 cubic meters of high-level waste created by the American military. Nor do these numbers include the less radioactive, but long-lived transuranic wastes, and, the 1.5 billion cubic meters of water and 73 million cubic meters of soil at 9900 sites contaminated by nuclear weapons production.[1]

In the United States, the Nuclear Waste Policy Act of 1982 set a 1998 deadline for the initial permanent disposal of nuclear waste. The latest -- optimistic -- deadline is 2010, and the program may still not succeed.[2] The rest of world faces the same problems.[3]

The major problems of underground waste disposal are geological and political: as Yucca Mountain and the Waste Isolation Pilot Plant have demonstrated, researchers cannot guarantee completely environmental isolation for the thousands of years needed until these wastes cease to be a threat. Nor are local and state governments receptive to federal siting proposals. The "not in my backyard" (NIMBY) syndrome holds particularly true for nuclear waste.[4]

Despite decades of research and huge expenditures of money in the United States, a fully viable solution remains on the horizon.[5] The permanent elimination of high-level radioactive waste demands a reconceptualization of the problem. We need to look up, not down.

important criteria are safety, and technological and economic feasibility.

Disposal in Space

In the spirit of Jonathan Swift, let me offer a modest proposal: Let's put high-level radioactive waste where it belongs -- out in space where it cannot endanger anyone on earth. The idea is not new -- NASA's Lewis Research Center concluded it was technically feasible in 1974 and the Space Systems Technical Committee of the American Institute of Aeronautics and Astronautics endorsed it in 1981, to name only two of many studies, but space disposal has never received strong institutional support from government or the private sector.[6]

Space disposal has two major benefits. First, it will permanently remove the burden and responsibility of high-level radioactive waste from future generations. Second, the infrastructure needed to dispose of radioactive waste safely will greatly reduce the cost of exploiting space.

The tonnage currently launched into space is not that great. In 1998, rockets launched less than 200 tons of payloads into earth orbit and beyond (excluding the weight of the space shuttle).[7] The attraction for the aerospace community of waste disposal is the guarantee of large payloads for decades to come. What could engineers develop if asked to launch 10,000 tons annually? Space disposal will create the first market for launch systems that could truly provide the inexpensive access to space promised for decades.

Disposal in space consists of three steps:
- preparing and transporting the waste to the launch site
- launching into low earth orbit
- launching to a final destination

All three steps have been studied extensively over the last quarter century. I will focus on the last two steps, each of which offers a wide range of technological options. The

Launch into earth orbit

The most visible technological choice is the launch system -- or systems -- to provide a quantum increase in access to space. The two basic choices are conventional rockets carrying large cargoes or ground-based systems launching smaller vehicles. Most studies in the 1970s-80s assumed the use of the space shuttle, possible derivatives, other rockets like Ariane, and even surplus ICBMs.[8] The next generation of rockets, such as the EELV and even the proposed reusable launch vehicles (like the Kistler K-1) will reduce the cost of access by an order of magnitude at most and probably less. While these are major improvements on existing rockets, only more radical approaches may reduce costs by the one or two more orders of magnitude necessary to truly change the economic perceptions of space.

Advocates have proposed ground-based launch systems for decades: Arthur C. Clarke proposed the electromagnetic launcher in 1960 and Arthur R. Kantrowitz first proposed laser propulsion in 1972.[9] Among the possible systems are electromagnetic launchers, mass drivers, gas guns, laser propulsion, and the Scramaccelerator.[10] Laser propulsion is probably the most appealing option because of its ability to launch people as well as plutonium, if the Lightcraft Technology Demonstrator performs as promised.[11]

The major stumbling blocks of ground-based systems have been the low efficiencies of the technologies, which were in an early stage of development, the high development and construction costs (usually estimated at billions of dollars), and the absence of sufficient payloads to justify these high costs. A more subjective factor was their unconventional approach, compared with the existing rocket launchers.

The theoretical advantage of ground-based systems is that most of the weight of such a system remains on the ground so most of the spacecraft is payload. Although each launch would dispatch kilograms instead of tons, such systems might prove ideal because of their low operational costs. The large tonnages will offer, finally, the great demand and economic rationale needed to justify building a ground-based launching system.

Launch to a final destination

The key determinant in the final destination of the radioactive waste is the energy needed to transport it there. With the exception of proposals to expel charged particles of waste out of the solar system, all studies assume the physical movement of shielded capsules.[12] Some options, such as sending the capsules out of the solar system or into the sun, are very energy intensive, measured in terms of the velocity needed. Soft or hard landings on the moon are another possibility, as are very high earth orbits and the Earth-moon libration points.[13]

Possibly more appealing would be an solar orbit inside Venus.[14] This is because future generations might find our radioactive wastes valuable, just as old mine tailings are now a useful source of precious metals. If so, placing the waste in a retrievable location far out of possible human and harm's way, such as a solar orbit, would be wise.

Because time is not critical, propulsion systems with low speed -- and low cost -- will have the advantage over chemical rockets. Again, space disposal will offer opportunities for promising technologies like low-weight solar sails, electric rockets, mass drivers fueled by lunar material, or laser- or microwave-propelled systems.[15] Less likely is a nuclear-powered system.[16] A space tug might collect a number of capsules, bind them together, attach the propulsion system, and launch the new spacecraft gently into a orbit around the Sun.

Two major public concerns will dominate future discussions -- safety and cost. To succeed, space disposal must demonstrate lower risk than underground disposal. This project must be completely safe technically, but nonetheless will not succeed unless potential supporters and opponents are thoroughly convinced about its safety and efficiency. Researchers have worked on how to contain wastes in case of accidents, explosions, atmospheric re-entry, a concern explored for other missions.[17]

Computer simulations and controlled tests, however, will not be enough. Key demonstrations -- exploding a launch vehicle with a mock cargo and sending a test capsule to reenter the atmosphere -- will be necessary to calm fears and prove the veracity of safety calculations. Minimum danger must be demonstrated, not assumed.

An important but lesser consideration is the economics of space disposal. Space disposal will be cost billions of dollars -- but so have and will the existing plans for underground waste disposal. The difference is that the infrastructure for space disposal can be used for other purposes.

Space-based disposal demands not only technical but institutional and political developments. The United States can launch its own national program, but a cooperative international effort could prove the better organizational approach because of the worldwide problem of nuclear waste and the array of available technologies to harness. International consortia might best allow the exploration of different technological paths.

Conclusion

The history of engineering projects shows that good ideas and technology are necessary but not sufficient. The successful engineer-entrepreneur also has to generate political, economic and social support to obtain the resources and approval vital to overcome opposition and realize the project.[18] We have the opportunity to bring the different technical, scientific, political, and economic communities together to determine whether space disposal should succeed.

Space disposal may not appear the obvious solution to the high-level nuclear waste problem. Nor may disposing of nuclear waste appear the obvious answer to the question of how to reduce the space of exploiting space. The sheer magnitude of nuclear wastes provides the incentive to develop launch systems that will drastically cut the cost of space exploitation. The result will be lower costs, more infrastructure and more skilled personnel able to develop other areas of space.

An analogy may be the development of the computer. Government funding, mostly from the military and NASA, greatly accelerated research and development of computers since the 1940s. Not until the 1970s did the civilian market grow large enough to seize the technological initiative. Space disposal may provide a similar opportunity.

Both the technology and the need exist. What does not yet exist is the will and support of the engineering and political communities.

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