× 10^8 years. This is "inexhaustible" enough for me.

References

1. Richard F. Post, PHYSICS TODAY, page 30, April 1973; and John Nuckolls *et al*, PHYSICS TODAY, page 46, August 1973.
2. Chauncey Starr, *Scientific American*, page 42, September 1971.

JOHN I. SHONLE
University of Colorado at Denver
Denver, Colorado

Professional responsibility

We who opposed passage of the Professional Responsibility Amendment have apparently prevailed, and now is no time to reopen the debate. However, the petulant, sour-grapes letter by Charles Schwartz in your June issue (page 9) requires a response.

The points he attempts to make are easily summarized. He says that the Amendment will be voted down. (Probably true.) He points out that several physicists have publicly stated it would be impossible to decide which activities are harmful to mankind's welfare. (Also true, see the November 1972 issue). Then he asserts that these physicists are incorrect, that it really *is* possible to judge which activities are harmful, as long as you don't have to be right all the time. (Dear Sir: Apologies for ruining your research, career and reputation five years ago. Our mistake. Sincerely, APS.) He concludes from this that there must be another reason for opposing the Amendment, and graciously tells us what it is—that evil projects are the bread and butter of scientific funding, and to oppose them would be an economic disaster for individual physicists. Finally, he draws from this new data the conclusion that the Amendment will be voted down because physicists are interested only in themselves, in the worst connotation of the phrase. Sour grapes.

And PHYSICS TODAY published the letter, demonstrating that one need not be scientific to publish in a scientific magazine. However, even more interesting than this is a quick analysis of Schwartz's letter. First, he considers only the "difficulty-of-implementation" objection to the Amendment, grandly ignoring all the other, equally valid arguments against it (such as the consequence of controversial, yet binding, moral judgments being made in the name of all APS members.) This alone is enough to invalidate all his conclusions. But Schwartz is just getting started. His refutation of the difficulty-of-implementation argument ("We never said the judgments hafta be right!") is a classic that should be included in every freshman logic course text—under the heading "Begging the Question." His next logical step, in an argument already elegantly meaningless, is to explain how individual physicists have a vested interest in the continuation of harmful physics projects; an explanation in undefined terms and without proof.

From these arguments, Schwartz is entitled to draw any conclusion he chooses—all would have equal validity. However, instead of declaring that therefore, the sun shuts off at night, he declares that therefore, the majority of physicists are pikers if they didn't vote for passage of the Amendment. This in itself, we learned as freshmen, commits the logical fallacy of composition (false generalization).

Interestingly, his conclusion that the majority of physicists are interested more in themselves than in the welfare of mankind (whatever that is) would be most refreshing, could it be adequately proved in the proper context. But this touches on philosophy and is best left to other discussions.

KEN PORTS
Purdue University
West Lafayette, Indiana

THE AUTHOR COMMENTS: I can only recommend that anyone trying to make sense out of Ports's letter should reread my original letter in the June issue.

CHARLES SCHWARTZ
University of California
Berkeley, California

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Juxtaposition of two letters in the June issue (page 9) is instructive. In one of the two, it is claimed that whoever does not share the political opinions of the writer (Charles Schwartz) is "dedicated to the enhancement of the quality of life" for himself and has little concern for the welfare of mankind. The other letter was written by a Czechoslovakian physicist dismissed because his political views were different from those of his superiors. Such dismissals are bound to happen whenever people of the Charles Schwartz mentality achieve power. I hope that American physicists will be on their guard.

J. J. BIKERMAN
Shaker Heights, Ohio

Radioactive wastes

The discussion by Jere Nichols, John Blomeke and William McClain of storage of nuclear wastes in the August issue (page 36) omits some hazards and comparisons that I find rather alarming. For example, Table 1 on page 38, giving the inhalation hazard and ingestion hazard for the wastes ac-

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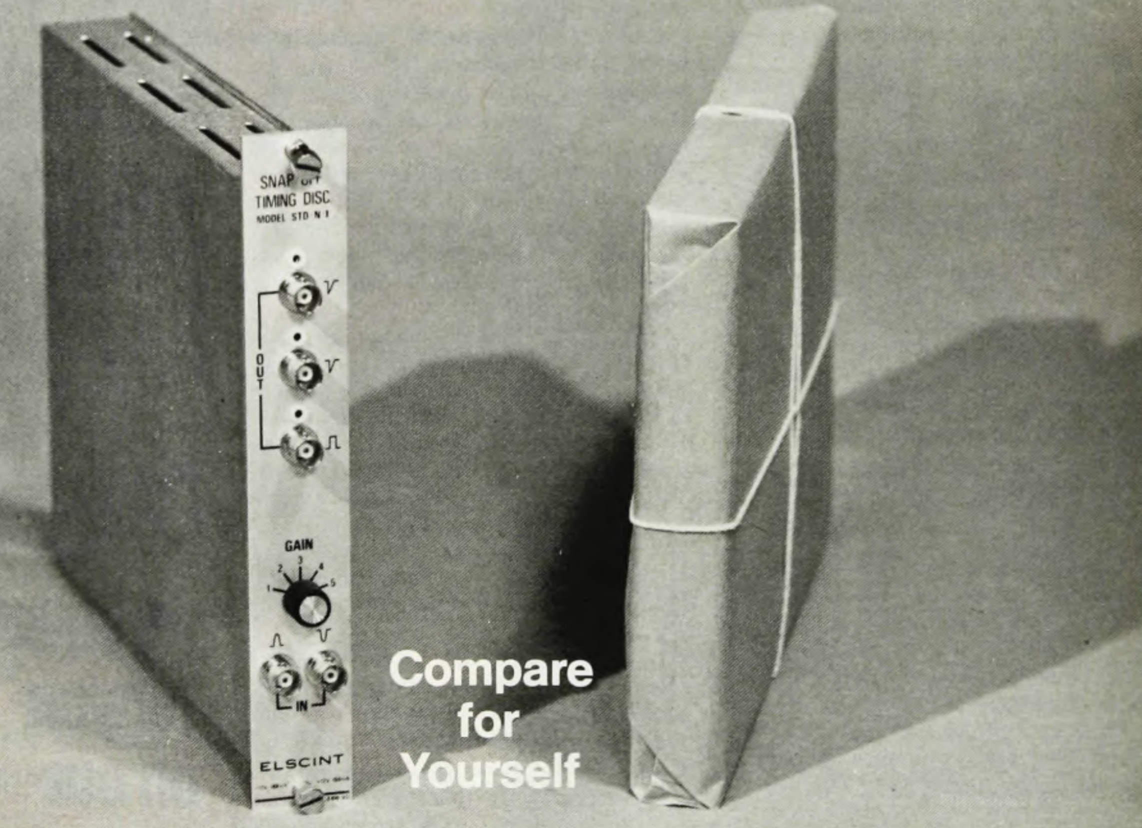

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cumulated by the year 2000, should be compared to the total available volumes of air and water on Earth. These are a few times 10^{18} cubic meters of air, and a few times 10^{17} cubic meters of water. The accumulated fission products expected by the year 2000 would require at least two orders of magnitude more air than the entire atmosphere of the Earth to dilute them to an acceptable level; the atmosphere will remain inadequate for at least a century. The actinides present an even worse situation: they require three orders of magnitude more air for dilution in the year 2000, and require more than one planetary atmosphere for at least a million years. The accumulated fission products are within a factor of ten of exceeding the acceptable level if diluted in the Earth's oceans; as these wastes will accumulate much more rapidly in the future, we can expect enough material to exceed the acceptable level, even if diluted with all the water on Earth, some time within the next century.

When we consider amounts of radioactive waste several orders of magnitude greater than would suffice to raise the oceans or the entire atmosphere above the level currently regarded as "acceptable," we are dealing with enough dangerous material to cause our rapid extinction, if not the extinction of all life on our planet. Then even *very* unlikely events must be taken into account, because a single accident would be our last.

An example of such an unlikely event is the disruption of underground storage sites by large meteor impacts. The frequency of such events is not well known, but one is known to have occurred in Arizona (not far from the proposed New Mexico salt mine) within the past 104 years or so, and several larger craters, with ages on the order of 10^5 or 10^6 years, are known in various parts of the Earth. Any of these impacts would disperse a considerable fraction of an underground respository into the atmosphere. Smaller impacts, comparable in energy to a nuclear weapon and certainly sufficient to disperse the contents of any kind of above-ground facility, are known to have occurred within the past century in Siberia.

One may claim that the probability of a direct hit by a large meteor is very small. However, it only takes *one* such coincidence to be truly catastrophic, in every sense of the word. Even if we decide that we want to live with the probability of such an event (which Murphy's Law would put close to unity!), it would be prudent to avoid accumulating more than 10^{-3} of the actinide waste expected by the year 2000 in any above-ground site, or as much as one percent of the fission-product waste expected by 2000 in any underground site. If one wanted to be able to withstand several such events, the numbers should be still smaller. Such widespread dispersal of storage sites may be required that one soon runs out of salt mines.

A. J. Young
Studio City, California

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John Blomeke, Jere Nichols, and William McClain, in an otherwise thoughtful article about nuclear waste disposal, have dismissed the concept of polar-cap disposal rather too cavalierly. Their principal objection is based on an erroneous but all-too-prevalent assumption about the longevity of polar ice caps. Ice caps are very stable geological features. They are quite insensitive to climatic changes, even on a global scale. The age of the Antarctic ice cap is at least 20×10^6 years, the most recent 5×10^6 years of which has been in nearly its present form. At least four major Northern Hemisphere glaciations during this time occurred without material effect on the Antarctic ice cap.

Antarctica is a continent, a land mass that separated from the other components of Gondwanaland on the order of 10^8 years ago and drifted to its present position, which happens to coincide approximately with the area bounded by the Antarctic Circle. The ice that subsequently accumulated is now in the form of a continental glacier, which resembles the more familiar mountain glaciers in most respects. The principal difference is the very much larger distances involved in the transport of ice (from inland snow accumulation) to the sea, and the correspondingly greater time scale required for that transport. The longevity of the Antarctic ice cap, therefore, is not of the order of the 10^4 to 10^5-year time scales of glaciations, but of the 10^8-year time scale of continental drift itself. This approaches or surpasses the age of bedded-salt deposits the authors favor, and has the additional advantage that the temperature precludes invasion of waste-capsule disposal sites by ground water, if the disposal sites are chosen judiciously.

As the authors correctly pointed out, there may be liquid water at the ice-rock interface at some locations. This was found to be the case at Byrd Station, Antarctica, at a depth of 2164 meters. However, at Camp Century, Greenland, where a similar test hole was drilled, the ice cap was found to be firmly frozen to the rock. Certainly test drillings should be made at each proposed disposal site, in order to measure the bottom temperature and de-

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termine the suitability of that site for nuclear waste disposal.

Finally, there is the possibility that the waste capsules can be initially prevented from melting their way to the bottom of the ice by a suitably constructed, non-mechanical heat removal system with a design life of some hundreds of years. This system would dissipate the heat given off during the years when the capsules are most intensely radioactive, cooling them and maintaining their retrievability against the event of the development of a better waste-disposal plan.

J. CURTIS SIREN
Stanford Electronics Laboratories
Stanford, California

THE AUTHORS COMMENT: We appreciate the interest shown by the authors of the above letters and welcome this chance to amplify our thoughts with respect to the dispersibility of deeply buried wastes and the suitability of the Antarctic ice cap for waste disposal.

In response to the argument by A. T. Young, we believe that it is misleading to compare the defined inhalation and ingestion hazards of accumulated wastes with the volumes of air and water that exist in the biosphere because of the impracticality of dispersing globally significant quantities and concentrations of deeply buried wastes. An event (such as meteoric impact or volcanic eruption) that has potential for ejecting large quantities of deeply buried solids into the atmosphere also would be characterized by (1) mixing of the wastes with other materials in the formation (such that the toxicity of the airborne particles would be determined more by their natural physical and chemical properties then by their waste content), and (2) rapid sedimentation of most of the ejected solids in the immediate vicinity. Events potentially leading to dispersion in water would be characterized by extremely long time frames and would tend to leave practically all of the waste materials in local solid deposits because of (1) the limited solubility of the waste materials in competition with other materials, (2) the removal of dissolved species by ion exchange and (3) the removal of suspended species by filtration and sedimentation. It should also be noted that there are many types of naturally occurring materials in the earth's crust that could theoretically foul our biosphere if it were not for such physical chemical effects that effectively limit their dispersibility and provide for self-purification of the atmosphere and oceans.

In response to the comments by J. Curtis Siren, we believe that the relevant issue concerning the stability of the Antarctic ice cap is not its longevity as a geologic feature but the residence time of a particular water molecule in the ice. It is well established that Antarctica has been mantled by a continental glacier for a period of the order of 10^7 years. However, regardless of how stable the glacier may be, the ice within it is quite dynamic; it accumulates in the central portions, is transported by plastic deformation, and is both oblated and discharged as icebergs around the edges. The length of time required for this cycling is quite variable in different parts of the glacier and, in general, is not accurately known. Even in a region of relatively stable ice it would be necessary to establish that stability would not be disturbed in the future, for example by climate-induced migration of the centers of ice accumulation.

There are several other similar objections to the use of the Antarctic ice cap for radioactive waste disposal but they all reduce to essentially one point: knowledge of the behavior, mechanics and dynamics of continental glaciers, and the effects that outside influences have upon them, is so incomplete that we feel they presently cannot be taken seriously as future repository sites.

J. O. BLOMEKE
J. P. NICHOLS
W. C. MCCLAIN
Oak Ridge National Laboratory
Oak Ridge, Tennessee

Realistic costs for hydrogen

Clarence Zener's article on solar sea power (January, page 48) considered various aspects of an ocean thermal-gradient electric power plant that would produce hydrogen.

We have considered the economics of selling this hydrogen to continental users as an intermediate for chemical products or as a fuel for clean electric power plants. The conclusions are that such hydrogen would cost from five to ten times what hydrogen from other sources of power plant fuel is likely to cost.

Zener states that the ocean-plant capital costs could be as low as those of land-based combustion power plant. If we take this at an optimistic value of about $200 per kW including the cost of the electrolyzing equipment, then the electric power output from his plant would cost about 4 mills per kWh (14% fixed charge rate and 0.8 operating factor). Assuming 67% efficiency for conversion to hydrogen by electrolysis, which is appropriate for current industrial practice, the hydrogen price is about 4 mills per kWh