World War II Nuclear Bomb Projects

The letter by F. H. Schmidt (24 Mar., p. 1286) correctly points out the importance of the electromagnetic method in the separation of uranium-235 for the World War II Manhattan Project and for the subsequent separation of stable isotopes of many elements for research purposes. A characteristic of the electromagnetic method which contributed to its wartime success, and also its adaptability to the isotopic separation of various elements, is that it intrinsically offers a high enrichment per stage. The gaseous diffusion process for uranium-235 separation was more difficult to put into production, as it required a cascade of many stages with very low enrichment per stage.

Schmidt also discusses the key issue in the success of the electromagnetic method—the requirement for adequate space-charge neutralization within the ion beams. It is interesting that both the Japanese and German physicists were discouraged from attempting the electromagnetic separation of the uranium isotopes because of the difficulty presented by this problem. The U.S. effort to produce the Hiroshima bomb could not have succeeded without overcoming the space-charge–imposed limitation in mass spectrographic resolution when intense ion beams were employed. The solution used was space-charge neutralization by automatic trapping of electrons that were produced by ionization of residual gas in the vacuum tank by the ion beams themselves.

While this solution to the space-charge problem was used by E. O. Lawrence's Radiation Laboratory in designing the Oak Ridge electromagnetic separations plant, it was discovered before the Radiation Laboratory effort. In earlier work at Cornell University with lithium ion beams, Smith *et al.* (*1*) observed and explained the trapped electron neutralization resulting from residual gas. To quote from this reference (*1*, p. 1002):

> The fact that partial space charge neutralization takes place even when no effort was made to accomplish it indicates that neutralization could be made very much more effective by introducing electrons by any of a number of special ways.
>
> It must then be concluded that there is at present no indication the space charge is limiting the current that can be collected by this method.

The article by Smith *et al.* was received by the *Physical Review* on 18 February 1942, but for reasons of secrecy was voluntarily withheld from publication until the end of the war.

The electromagnetic separation device

in which we demonstrated space-charge neutralization was basically the Dempster-type mass spectrograph. The so-called "Calutron" used in the Oak Ridge electromagnetic separations plant was also basically a Dempster-type mass spectrograph. It lends itself to electron neutralization of the ion beam space charge because the geometric separation of the ions of different isotopes takes place in a region free from applied electric fields.

A little-known aspect of the Manhattan Project was another effort to carry out quantity separation of uranium-235 by electromagnetic means. This work was performed early in the war at Princeton University with a concept referred to as the "Isotron." It was based on velocity modulation of an ion beam with time-variant electrical fields applied between drift spaces. This method did not lend itself to effective space-charge neutralization by electrons, a limitation also observed in the earlier work at Cornell and discussed in (*1*). The Isotron project was discontinued in 1943, and the wartime electromagnetic separations work was concentrated on the Dempster-type mass spectrographic approach being developed at the University of California Radiation Laboratory at Berkeley.

Those of us who were involved in that frenzied effort frequently speculated on what the counterparts of our apparatus looked like in Japan and Germany. As it turned out, there were none. Even if the scientists of those countries had solved the space-charge problem of the electromagnetic method, it is unlikely plants could have been constructed and operated to carry out the necessary quantity of uranium-235 separation. The bombing attacks during the later phase of the war would have been too disruptive.

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References

1. L. P. Smith, W. E. Parkins, A. T. Forrester, "On the separation of isotopes in quantity by electromagnetic means," *Phys. Rev.* **72**, 989 (1947).

While my own research corroborates nearly all of what Deborah Shapley reports on Japan's attempts to build an atomic bomb (News and Comment, 13 Jan., p.152), the fact is that Japan lacked adequate long-range aircraft like the B-29 and by 1943 had inadequate capabilities to even launch a second attack on Hawaii. A much more likely scenario would have been for Japan to resort to using its bomb in China, Okinawa, or even the Soviet Union.

Some Japanese newspapers have chosen to give the *Science* article front-page coverage, perhaps because it comes at a time when Japan has a near-capability of building weapons using fuel reprocessed at its pilot reprocessing plant.

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Science, Media, and Worst-Case Limits

How can one discourage misuse of worst-case limits in the public domain? One approach is to widely publicize the fact that such misuse is unprofessional, unethical, and results in slanted information. When worst-case limits are misused, the transgressors should be taken to task.

The news media often report the results of criminal trials. In those cases where a defendant is found guilty on multiple counts, before sentencing it is standard procedure to describe the limit of possible sentences by assuming that each count will result in the maximum punishment and that prison time for each count will be served sequentially. Thus, a 60-year-old man found guilty on six counts, each with a 20-year maximum penalty, is described as being subject to a possible sentence of 120 years, notwithstanding the impossibility of such a sentence being carried out. It should be noted that the 120-year sentence even has a legal connotation, namely, that parole would not be possible for 60 years (in many jurisdictions) should the maximum sentence be implemented.

Regardless of the impossibility and meaninglessness of such a sentence, there has been no apparent public confusion or concern about the use of such numbers by the media. This lack of concern may be explained by the fact that there are criteria understood by the public that allow them to evaluate the statement with proper perspective. The limited life-span of individuals and the rarity of such sentences ever being completed are self-evident, and this may prevent misinterpretations.

I call this tendency of the media, the public, scientists, and others to make an estimate of the worst-case limit in the case above and in other situations the "penal syndrome." Just as an average is a central measure of a range of possible measures, the upper (or lower) limit of the range of possible measures is also a valid, but often inferior, way of describing quantifiable conditions. However, the use of such upper limits in many situations is made without the criteria neces-