APPLICATIONS OF ACCELERATORS IN PHYSICS AND CHEMISTRY

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ABSTRACT

Accelerator beams are becoming increasingly used in a variety of applied fields, such as material testing, space simulation, radiodiagnostic and radiotherapeutic work, and elemental analysis. Criteria necessary to establish a viable program based upon such a technique are proposed. In light of these criteria, programs involving elemental analysis of environmental, medical and industrial samples are discussed, with special emphasis on methods for reducing the disadvantages associated with an accelerator-based technique.

The rapid increase in the number of applications based upon accelerator beams is well illustrated by the diversity of topics already presented at this conference. This paper will discuss yet another – that of the accelerator as an instrument for elemental analysis.

Before going into the details of the "analytical accelerator," a few words should be given as to why such a diversion of time and energy should be made into an applied field. One answer is that the pressures to be accountable for the utilization of public funds for public needs have increased at exactly the same time that funding for basic research has, at least in the United States, decreased. The development of a viable, self-supporting application that bears upon the problems of today thus both acts as a dividend to society for the funds that in the past developed the present expertise, and as a means of support for the facility derived from new, and perhaps more abundant, sources. In addition, a variety of other benefits can accrue to such a facility, including interesting job possibilities for graduate students, increased interaction with the scientific community, and even new directions for basic research uncovered during the development of the applied work. The greatest benefits seem to appear, however, when basic and applied programs are reasonably well balanced, and, in this condition, a very productive overall research effort can exist.

Once the desire for a program in accelerator-based applications has arisen (this can be done either internally or externally), a number of points should be satisfied or the program will never become self-sufficient. Perhaps the following criteria could be a guide:

1. An unsatisfied need,
2. Backed by sufficient funds,

3. A method for satisfying the need, and
4. Ways of reducing disadvantages associated with accelerator beams, such as cost, access, beam and vacuum damage, etc.

It might be noted that if the first three points are satisfied strongly enough, the fourth point becomes less important. The applications to be discussed in this paper, however, can all be fulfilled by non-accelerator-based techniques, and thus the fourth point is critical.

Keeping these points in mind, it is now possible to look at the field of elemental analysis of environmental, medical and industrial specimens by accelerator beams.

First, is there a need? The answer is most assuredly "Yes!" Any reading of reports on elemental contamination of air, water, soil and biological tissue by the effluvia of modern man makes this point clearly. Is the need satisfied? The answer must involve a careful analysis of what data are needed by public health and environmental agencies, and what methods presently exist for generating these data. One immediately finds that, by and large, for a single element or compound, very sensitive methods exist using either chemical or spectroscopic techniques. When one looks for methods capable of surveying many elements in a given sample, especially when the elements in question are present in microgram quantities or less, then one is basically forced to use spectroscopic methods or neutron activation analysis (NAA). Spectroscopic methods are quantitative, reasonably inexpensive, and generally interference-free. However, only a limited range of elements are seen, and the method is destructive. For a very sensitive method that is broad range, quantitative, and non-destructive, NAA is the only choice. However, it has problems, too, in that it is slow, expensive and its sensitivity (especially to light elements) may be poor. It is a pity that some important elements in environmental work are seen either not at all or poorly by NAA. For example, in a sample of smog aerosol from Los Angeles, the most common elements probably include oxygen, carbon, hydrogen, nitrogen, sulfur, silicon, chlorine, potassium, calcium, iron, bromine and lead. Of these, only chlorine, potassium and bromine are easily seen by NAA. Some excellent studies of smog have been done by using NAA, but the fact remains that it will probably have its greatest impact in this field as a research tool rather than a method of routine analysis.

Therefore, in summary, one can state that an unsatisfied need does exist in the field for a broad range method that is sensitive, quantitative and inexpensive.

Are there funds available? In principal, yes, although disappointingly small amounts are available for innovative programs. For example, California alone spends above $20,000,000 in air quality monitoring and control per year.

Only at this point can the physicist safely expend time and effort developing an accelerator-based method. In practice, of course, the method usually comes first, and only then does the question of "Who needs it?" get treated. This approach can lead to disappointment and disillusionment.

At this point, one can consider possible accelerator-based methods for elemental analysis. Some presently-used techniques include:

Nuclear	a. Elastic scattering b. Reactions of the primary beam c. Reactions of secondary beams
Atomic	a. X-rays produced by the primary beam b. X-rays produced by secondary beams c. Other atomic phenomena such as Auger emission and optical emissions.

Since accelerator-based nuclear methods of elemental analysis must always contend with the existence of the highly-sensitive reactor-based method, neutron activation analysis, they tend to emphasize the light elements which are generally hard or impossible to detect by NAA. As an example, elastic scattering of alpha particles has been used at Michigan State and Davis to detect a wide range of elements, although at Davis we tend to use it only for those light elements not detected by alpha-induced X-ray emission (see below). In Sweden, diffusion of ink into paper is analyzed by this method, while it was used to perform elemental analysis of the moon in the U.S. Surveyor program (using a source, not an accelerator).

Reactions of primary and secondary beams, both in-beam and remote, have been used at many laboratories, again generally to look for light elements. Lawrence Livermore Laboratory has studied water pollution this way, while in Europe, much work is being done on such problems as analyzing diffusion and layering of dopants in semiconductors. In Namur, Belgium, there is a new laboratory based upon a 3 MeV van de Graaff generator, designed solely for the purpose of performing various types of elemental analyses.

Accelerator-based atomic methods of elemental analysis received a sharp boost after a group in Lund, Sweden quoted 10^{-12} gm sensitivity for a wide range of elements using 1.5 MeV protons from a van de Graaff generator to excite X-rays in a sample. They then illustrated this technique in problems of air pollution. The beauty of this method is that, for thin samples, accelerator beams provide an extremely potent method of exciting the characteristic X-rays and, by coupling the fast Si(Li) X-ray detector developed at the Lawrence Berkeley Laboratory to the accelerator, one can detect all the elements from sodium (and below) to uranium quickly and quantitatively. A group at the University of Colorado has used this method extensively for water analysis, while that group and numerous others have analyzed biological, soil and water samples by the technique. At Davis, the California Air Resources Board has funded the design and construction of a system that can presently handle up to 2500 smog samples/day. By modifying aerosol collection techniques to match this system, sensitivities of about 1 ng/m^3 of air are achieved at a cost of under $2.00/sample. The utilization of this system and others like it for monitoring and source localization studies of elemental contaminants in air, water, and biological tissue should result in a significant improvement in our control of pollution.

Other accelerator-based techniques are being developed, and the list of methods is growing rapidly. These merely give some of the

ones presently being used.

The satisfaction of the first three criteria is not enough in itself to insure a long-term viable application. One has to also consider the disadvantages inherent in accelerator-based applications, some of which are:

1. Existing accelerators were generally built to emphasize performance, often at the expense of reliability and economy of operation and maintenance.
2. Accelerator beams are small in area and are usually assumed to service a single user who must then bear the full pro-rata costs of the operation. A nuclear reactor, for example, does not suffer this handicap.
3. Accelerator beams are normally present in a vacuum and, being charged, may deposit significant energy in a target.
4. Nuclear reactions can usually occur in the target, and an undesired byproduct may be an intensely radioactive sample.

Considering these problems, and adding the problem of access to such facilities, it is not surprising that applications of accelerator beams have been generally limited to those tasks that can only be solved by such techniques. Good examples are production of short-lived, positron-emitting isotopes for medical work and space simulation of proton fluxes from natural sources.

To reduce these disadvantages, in particular, the high cost/hr of accelerator operation as compared to standard analytical instrumentation, one has a number of strategies:

1. Multiple acceleration of primary beams (TRIUMF, LAMPF).
2. Shared use of a primary beam by:
   a. Tandem targets in the same beam
   b. Pulsed switching of beams from target to target
   c. Multiple experiments per target
3. Reduction of time necessary to perform an operation.
4. Effective use of secondary beams, which may be neutrons from a beam dump or pions, muons, etc., produced by high energy machines.
5. Efficient accelerators, heavily used.

Not all of these can be used in any given facility or at any given time, but use of as many of these as possible results in an operation which is highly cost competitive with other methods of analysis.

In summary, partly as a result of choice and partly as a result of necessity, we are seeing a new aspect in many accelerator laboratories - that of a mixed basic and applied research program. I feel that this diversification can lead to a new decade of excitement and progress, a fulfilling of the promise of our profession in new and interesting areas.

DISCUSSION

RICHARDSON: Do you have anything to say about the use of microprobes?

CAHILL: Yes, very much so. We had to delete a number of areas which accelerators have been using. One of the most exciting ones was the use of accelerators as a proton microprobe where you perform spatial analysis over a 100 micron grid. This is a method that was pioneered at Harwell using a 2 MeV Van de Graaff, and it was recently installed at UCLA by John Verba and associates. It is a very potent technique of associating an x-ray detector, a charged particle beam, providing information which is very hard to get in other ways. In particular, what you gain is the fact that the sensitivity for x-rays is maybe a factor of 10^4 or 10^6 better than it is using electron beams like a normal microprobe. And here is a method which can help, now that Van de Graaffs at 2-4 MeV are being closed up almost daily. I should mention, by the way, that a cyclotron is not required for this work. It is nice to have it but almost any machine that has about 4 MeV per amu plus or minus a factor of two in either direction can do just as well. In fact, even if you don't have that you come very close. So it is a very broad-range system.

Microprobe is only one of a number of very exciting techniques. Another is a group at Arizona looking at chemical information from accelerator beams, looking at the optical spectroscopy of beam-excited samples in a very interesting way.

AULD: During your talk you mentioned that you had a Machiavellian scheme for the charge of these services that the cyclotrons or accelerators might provide. Could you give us that now?

CAHILL: Our facility was recently given to the University, which gives us all kinds of flexibility in our charge rates--basically unsubsidized charges--and we folded into that the improvements made by nuclear physicists working at the accelerator to keep the beams going. Now if you start putting in your extra evening hours and late nights, and putting it on the accelerator as a charge, you find that you have literally $100,000 of resources floating around in the form of a few people just upon their voluntary efforts. So we feel it is well and right for outside users, who have no information whatsoever, let's say, on beam optics, to help pay these charges. And so we made our beam rate high enough so that these are fully unsubsidized rates. These are actually what it costs us. Now people like the NSF Physics program--they are our biggest users still--of course, don't have to pay these charges because people are working voluntarily.