COMMERCIAL NEUTRON ACTIVATION ANALYSIS
Is it a success? Evaluation of a 28 year experiment

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1. INTRODUCTION

Imperial College chose to introduce a commercial neutron activation analysis (NAA) service in order to increase income to the Reactor Centre following a reduction in government funds in the early 1980s. At the time three university research reactors plus a number of other reactors in the UK were capable of carrying out analyses using neutron activation techniques, and several offered commercial analyses. Although competition existed the number of providers also meant that there were potential customers who were aware of the technique and its capabilities. The work developed slowly, allowing time to increase staff in a step-wise manner to keep pace. Initially the work was centred on mineral exploration and geochemistry, but soon the work became diverse, including chemicals, plastics, catalysts, pharmaceuticals, forensic materials, biological samples, food and environmental materials. Much of the work was straightforward instrumental NAA, but some of the most rewarding depended on specialist techniques such as delayed neutron counting, cyclic activation analysis and radiochemical separation procedures. During the service's busiest period we were processing thousands of samples per year, representing an annual income of several hundred thousand US dollars. By 2003 academic activities had been transferred to a new department of the College, and the activation analysis business was handed over to the Reactor Centre, where it has continued to operate on a much reduced scale. The reactor is to close at the end of 2012, marking an opportune time to review the operation of a NAA service over 28 years.

2. REASONS FOR GOING COMMERCIAL

There are several reasons why an institution may wish to start analysing samples for industry. The obvious one is to provide an income in direct support of operations, if that is possible. Some public organizations do not have the mechanism to benefit directly in this way, and it may require a change in mindset to establish the environment where income can be retained by an organization for its own benefit. For example, if a university department does not receive overheads brought in by its staff, there will be little incentive to gain external income. On the other hand those universities with consultancy businesses, and senior management involved with attracting external funding, will be more accommodating with the way that profit is dispersed and will be happy to see staff involved in consultancy work that is benefiting the institution. Even if it is not possible for income to be retained, it is important for any institution to support the economy of the country, and this can be a real benefit for those establishments with government funding. It can provide an institution with a valuable purpose and raise its profile in a way that may result in further funding in the future or at least guarantee its survival.

Interactions with industry can generate consultancy work and provide collaborations in support of research. Such contacts have benefited Imperial College in many ways over the

years. For example, contacts with the nuclear industry at Imperial College, which began with a request to develop a method for the determination of radioactivity in milk, resulted in a series of research collaborations that included three PhD students, several publications in scientific journals and ten years of commercial work. Similarly development work on chlorine in reactor steels funded research work that resulted in a publication in Analytical Chemistry as well as provided a large source of income for several years. Companies are often happy to see the results of their work published, provided that there are no confidentiality restrictions. On the other hand if there are issues of intellectual property rights, it may not even be possible to discuss the work with others.

Teaching activities can be enhanced by collaborations with commercial organizations, providing contacts for student visits, external lecturers and potential supervisors for research projects. The MSc in Environmental Diagnosis at Imperial College had over thirty sponsors who offered five month research projects for the students each year. Many of those sponsors were the result of contacts through commercial work, and they now employ a number of our graduates.

3. IMPLEMENTATION OF THE SERVICE

3.1. Management support

The decision to form a commercial facility is an important step that requires full commitment from the management of the organization. Support at the very top is essential if the service is to be successful in the long term, because it will probably require significant investment. Some time is required to develop sufficiently to be offered as a professional facility, and during that time there will be little return for necessary staff investment. Infrastructure, including space, equipment and administrative support, must be committed by management. In summary, with support from the top the business could flourish; without it, it will definitely not succeed. It is essential to view the venture as a professional business and plan it accordingly.

3.2. Business plan

A proper business plan should include staff, equipment, consumables, irradiations, maintenance and also overheads including space. Overheads applied depend on the organization; for example, 100% on staff costs is used in some UK academic institutions. If a full business plan is developed, costing everything realistically, the price per analysis becomes so high that there can be no possibility of gaining business. Figure 1 is a breakdown of costs for commercial services at Imperial College in 2002–2003. The income that year was several hundred thousand US dollars, and the main costs were staff and associated overheads plus irradiation charges. Reactor charges were based on full economic cost of running the reactor shared among users. Typically the irradiation cost per sample is around US $50. The overheads were effectively the profit element for the department, to support activities associated with the staff working with the service, including space, radiological protection provision, health and safety and administration. The cost under administration in the pie chart is the fee charged by the College for managing the finances, including invoicing and insurance. This model represented full costs associated with the business.

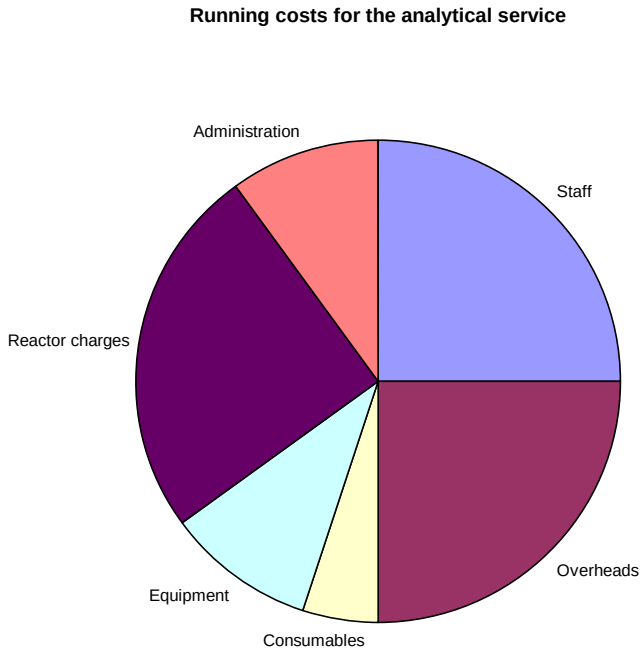

Fig. 1. Typical breakdown of the proportion of running costs for the analytical service.

There are a number of factors such as full economic cost of irradiations that may be shared or avoided altogether. Space may be provided by the institution, and equipment and staff may be shared. In my experience this is probably the only way that an NAA service can be a commercial proposition.

4. NATURE OF THE WORK

The nature of the work that can be offered as a service depends on what facilities and skills are available in the organization. Having a niche is very useful, particularly if it is unique in the country. It is worth spending some time discussing the characteristics of the facility, using workshops and brainstorming methods, to ensure that the ground work is done thoroughly. This should include an understanding of what the organization wants to achieve and what customers it wishes to target. At Imperial College the NAA service started up just as inductively couple plasma mass spectrometry (ICPMS) was being commercialised so it was still at the stage where one could offer rare earth element determinations as a straightforward alternative to inductively couple plasma atomic emission spectroscopy (ICPAES). One should not try to follow that market now, unless there are no commercial organizations offering ICPMS in the country.

4.1. Facilities

It is important to evaluate which available facilities can be offered as part of the service. In NAA it is useful to have both instrumental and radiochemical methods available. Specialised techniques such as epithermal NAA, cyclic NAA and delayed neutron counting can be applied to special measurements, plus the use of large sample irradiation devices and prompt gamma ray systems should be highlighted. Figure 2 shows a typical distribution of work broken down by type of analysis.

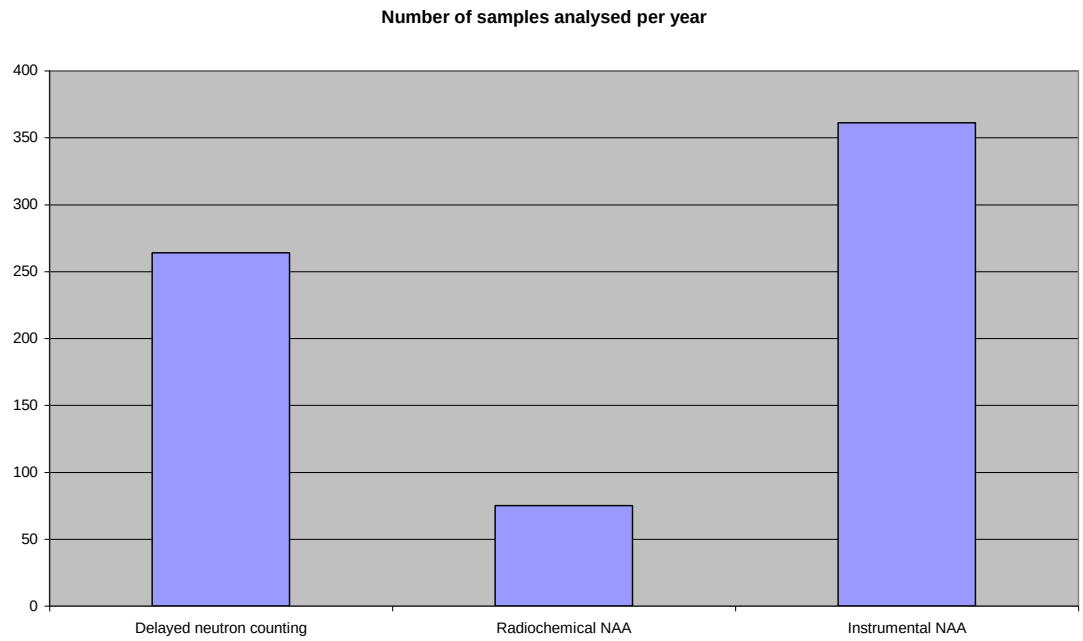

Fig. 2. Typical number of samples analysed per year by type of analysis.

We are fortunate at Imperial College that we can irradiate liquids, which has been a great advantage over other higher flux reactors. We are also able to irradiate samples in polyethylene for two weeks which makes sample preparation easier in some cases.

Consideration should be given to what supplementary techniques are available. For example, the ability to handle medical samples safely or having clean room facilities can be an advantage. Crushing and grinding facilities are important for rock analysis, and Imperial College implemented fire assay preconcentration at the request of a customer, and at his expense, in order to determine the platinum group elements in exploration samples. Experience in digesting large crop and food samples for analysis is valuable, and microwave digestion techniques can be useful. In other words, experience in sample preparation is just as important as the analytical stage.

Having other analytical techniques available in the same establishment is often attractive to customers who want more than one method of analysis. For example, NAA is fine for the determination of heavy metals in environmental samples, but if the customer is also interested in lead, then it could be useful to have atomic absorption spectrometry, ICPAES or ICPMS. Companies are happy to visit a ‘one stop shop.’

4.2. Skills

The service will only be as good as its people, and most nuclear establishments already have staff with the skills to provide specialised analytical capabilities. These specialised techniques are a key asset and can be offered commercially with less danger of competition than for more general analytical services. For example, the author’s expertise was in geochemistry when the Imperial College NAA service was started. This formed a base from which the work expanded over time, but initially the customers were from the exploration and minerals industries. In time additional staff can be taken on specifically to work on the service, but to start there are obvious advantages in specialising in areas of expertise. Certain skills will be particularly helpful when operating an analytical service, and radiochemistry is one that offers a unique capability compared to other more common analytical techniques.

4.3. Capabilities

As well as addressing what staff and equipment is available, it is important to consider what type of service can be offered. At Imperial College the reactor can operate from 9 a.m. until 5 p.m. on Monday to Friday, so weekend working is generally not possible. However, the reactor staff were sufficiently flexible to operate during a weekend when a company needed immediate turn around and was willing to pay a premium for that. It is possible to offer same day turn around for quality control samples, and this is essential for an operating plant. Staff must be flexible and willing to work in the evening, but this is acceptable if it means that the business is a success. Automation allows hundreds of samples to be analysed per day if necessary, and that can be important for screening work or contaminated land studies. It may be that some investment is required to implement the necessary devices, but this can be done as the work builds.

Reactor shutdown for maintenance is a real problem and can interrupt essential work that has been procured from a particular customer. It is possible to find alternative services for a customer to keep them supplied with data over a one month shutdown and still retain their business once the reactor is at power again. This can be done if the customer sees that the quality of work cannot be matched by an alternative. An important question is what priority is given to the customer. At Imperial College the income was initially essential for the continued operation of the reactor, so the reactor gave the work priority. Samples arriving at short notice were accommodated and extra time given if necessary.

4.4. Investment

Clearly, setting up a service requires considerable investment in staff, equipment and reactor time. Sharing staff, space and equipment is a helpful cost saving strategy, but care must be taken when applying it. Using the expertise of staff will enhance the service, particularly in the area of radiochemistry, but as the work builds it may be necessary to consider dedicated technicians to ensure that deadlines are met. The staff at Imperial College were generally dedicated to the analytical service, although occasionally additional people were employed for particular contracts. There is a particular danger associated with the use of students in such a venture, because the customer may have the perception that you are using untrained staff. Also care must be taken over whether students and other staff are allowed to use the equipment that is part of the service. The best approach is to introduce a quality system and train users to work within the system. Then there is control over what they are doing, and they have the advantage of working with equipment that is regularly calibrated and maintained. Consequently there are properly trained staff, who may also be students, available should extra work appear, and the students can benefit both financially and by gaining QA experience.

5. SOURCES OF BUSINESS

5.1. Type of analyses

Once the decision has been made on what skills and equipment are available and what capabilities are achievable, a strategy can be developed for the analytical service. Imperial College began with experience in instrumental NAA, radiochemistry and a special expertise in geochemistry and the platinum group elements in particular. A radiochemist was employed specifically for commercial work, and the author managed the service among a number of other academic duties. For a number of years the main work of the service was mineral exploration and geochemistry plus some quality control for industry. A chemistry technician

was employed as work increased and the income allowed. As a number of other reactors shut down their NAA work was taken over by the service, which expanded the range of analyses, introducing delayed neutron counting at the request of a customer who paid for installation of the necessary irradiation and counting equipment. This allowed the addition of two more members of staff: A physics technician to support delayed neutron counting and a physicist to manage the service under the author's direction. To concentrate on one's areas of expertise is practical since it is what you are well known for and initially will provide your best quality analyses. As the business expands, it is possible to broaden the expertise of the staff and attract work from other areas. Radiochemistry is a specialist area that can generate income, and Figure 3 highlights that although the number of samples analysed using radiochemistry is lower than those analysed by instrumental methods, the income is greatly in excess.

5.2. Industry

Customers in industry expect a professional service with good communication and rapid turn around for their samples. They are often not familiar with nuclear analytical techniques and therefore will require some information regarding what is happening to their samples. They will appreciate the expertise that is offered, and initial success in one area may lead to further work from other sources in the company. The range of work from industry is almost endless. Examples of work Imperial College has had in the past include both solids and liquids and both inorganic and organic materials. The analyses ranged from the determination of sulphur for the chemical industry, fluorine in rubber, trace elements in silica, platinum in minerals, iodine in milk and pet food, assorted elements in pharmaceuticals, precious metals in catalysts, cadmium in plastics, analysis of industrial diamonds and uranium in graphite. Batches of samples are generally not large, except for uranium determinations using delayed neutron counting, for which hundreds of samples can be processed rapidly. Fast turn around may be required and we have had customers who sent samples in the morning and expect the report by evening. This is perfectly achievable if a short irradiation is used. Work for industry may be commercially sensitive, and staff must be made aware that the work is confidential. Figure 3 is a typical breakdown of sources of income that demonstrates the importance of work for industry.

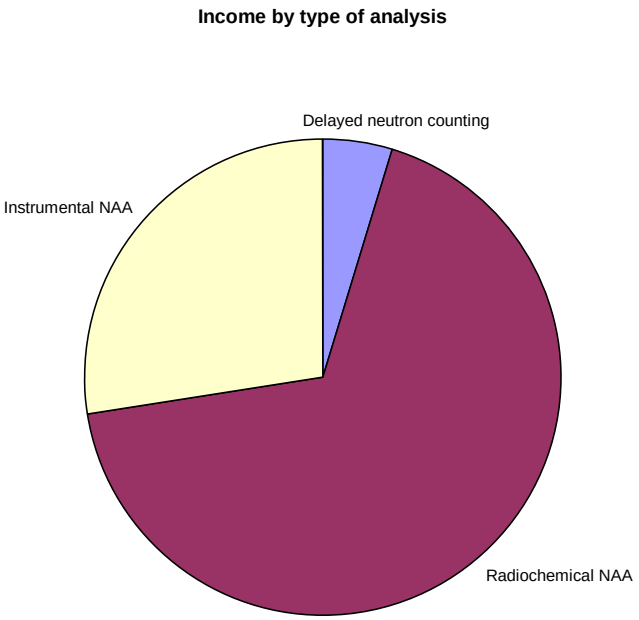

Fig. 3. Typical sources of income by type of analysis.

5.3. Research and government organizations

Researchers in other organizations will appreciate high quality work and are unlikely to want to process large batches of routine samples. Their request may require some development work, and therefore the collaboration could result in joint publications. Examples of work I have been involved in with research organizations include analysis of organic dyes, bromine in neonatal blood, analysis of carbon, uranium in ashed tissue, aluminium in proteins, rare earth elements in soils, bromine in organic liquids, arsenic in hair for the forensic services, platinum in bitumen, calcium on air filters, arsenic in plastics, uranium and thorium in porcelain, uranium in waters, iodine in rice, precious metals in glass and steel, and zinc in insects. Uranium analyses were also carried out for the Food Standards Agency as part of their annual monitoring programme around nuclear installations.

5.4. National standards programmes

Work for national standards organizations can be particularly rewarding since it identifies the analytical service as a high quality facility. Such work will raise the profile of the service with the government and the community, ensuring that the facility survives. In the UK the service has worked with both national and overseas standards organisations such as the Institute for Reference Materials and Measurements (IRMM), the Joint Research Centre (JRC) and the National Institute for Standards and Technology (NIST). The UK organizations are the National Physical Laboratory and the Laboratory of the Government Chemist. Collaborations have included the development of a reference material for paints used in children's toys, homogeneity testing for a catalyst reference material and development of standard Al/Au and Al/Ag alloys.

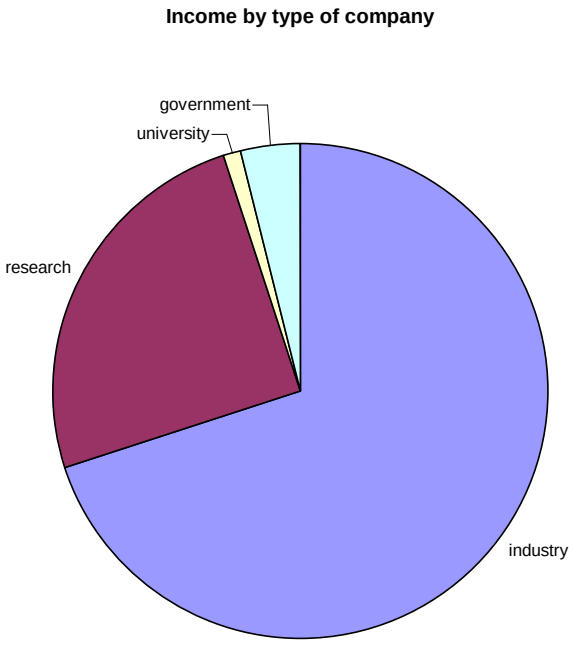

Fig. 4. Typical sources of income by type of company.

6. GAINING BUSINESS

During 28 years of operation of the NAA service the majority of work came by word of mouth. In the 1980s there were several facilities offering NAA with some public understanding of its capability. Once Imperial College was the only institution in the UK that offered NAA, the technique had a lower profile. If a customer is actively looking for NAA, an

internet search will locate suitable sites, including Imperial College, very rapidly. However, a potential customer often is not aware that he or she needs NAA, and attracting work requires skill.

6.1. Leaflets and brochures

In the past Imperial College has produced leaflets and advertised the NAA service in journals, indicating the nature of work that can be undertaken. Distribution of leaflets is an expensive business, and targeting is important but very difficult and rarely cost effective. However, it is important to have a leaflet or brochures available when speaking to customers, so it is certainly necessary to produce a limited number. It is worth investigating whether a journal or manufacturer would be willing to distribute leaflets with their mailings if the cost is small.

6.2. Professional activities

It is possibly more effective to inform the potential customer by speaking at conferences, visiting companies, offering seminars and presenting invitations to visit the reactor. In the 1990s I made a special effort to attend conferences that were outside the nuclear field to talk about NAA. The talks generated a lot of interest on the particular day but resulted in few contacts. Visiting companies and offering seminars were useful but only in those cases where there was already some initial work going on. There was certainly an advantage in helping the existing customer understand the full capabilities of the analytical method, and often more work resulted. Operating a stand at one or two exhibitions resulted in visitors who were more interested in academic matters and courses than commercial contacts. Invitations were issued for reactor open days and contacts were made, but little work resulted. In summary, efforts to initiate new contacts were not very successful.

6.3. Personal contacts

In the author’s experience the majority of work that comes to the analytical service is the result of personal contact. In the UK the nuclear industry is a small market, and the author’s work is well known. Consequently people make direct contact or are passed on by a third party, which has been relayed in most of the personal approaches. The research and teaching activities of the institution played an important role in setting the analytical service as a centre of expertise. If an institution is the nuclear centre in a country, such a status is better than any amount of advertising in trade journals.

6.4. Working with others

If the organisation is small, it may be easier to work as a subcontractor for another larger company offering analytical services. If the nuclear analytical techniques that are offered are unique, then the niche capability may be attractive to the larger organisation. If the service is part of a large organisation, there may be other capabilities in house that could be combined to offer a more comprehensive service. Economies of scale in either case are very useful, reducing the cost of administration, advertising and other activities such as invoicing.

7. KEEPING THE BUSINESS

7.1. Quality assurance

If the aim is to bring money into the institution, it should be appreciated that a professional level of service will be expected by the customer. This includes operation of a quality system

that is recognised by business such as ISO 9001 and ISO 17025. This raises a number of factors that must be addressed for compliance, including staff training, equipment calibration and maintenance, the use of traceable standards, reference materials, standard procedures for reporting and written protocols for work completed. Most importantly, someone must be identified as having responsibility for quality management. The cost of implementing a quality system and subsequent accreditation is not cheap. It is estimated that perhaps an additional 25% staff time is required to establish such a system. The additional paperwork is onerous but once checking systems are in place it is unlikely that erroneous data will be reported to the customer. The cost is not just in terms of staff time. The additional cost of regular maintenance and calibration must also be included and the cost of purchasing standards regularly. For example at Imperial College standard solutions for calibration are purchased every 18 months, the date when their certification expires.

Operating under a quality system has many advantages, not least the obvious one of bringing in work. Any business requires a system to ensure that it remains under control as work builds and the facility becomes busier. Businesses working under a quality system are expected to place work with a subcontractor operating under similar standards. Therefore customers will expect some minimum standard of quality assurance and will wish to audit in order to fulfil their own quality assurance requirements. Generally today it is expected that analytical laboratories have some form of accreditation under ISO 17025:2005. Each country has its own national system, and in the UK it is the United Kingdom Accreditation Service (UKAS). Accreditation guarantees to the customer that work is to an acceptable standard and usually means that audits from customers will not be required in addition to the accreditation body. The UK Environment Agency and Food Standards Agency both only place work with analytical laboratories with UKAS accreditation. The exception is where there is no other similar facility available that has accreditation. Customers may not demand a quality system if the method has no competitors or they have no systems in place themselves, for which organizations must be wary the customer's invoice payment system may be ineffective. On the other hand, a lack of competition, of course, is not uncommon with nuclear techniques and may allow work to start before a system is introduced.

7.2. Balancing commercial work with other activities

With the backing of management and the support of staff it is possible to build a significant customer base providing analytical services across the country and abroad. This work should probably be balanced with other activities of the organization such as teaching and training and research. Imperial College is a university and the commercial service was rather an unusual aspect of the college's activities. It was therefore important that service work did not preclude other activities at the reactor. Financial pressures tended to take priority, and over the years the research and teaching requirements on the reactor sometimes had to take second place.

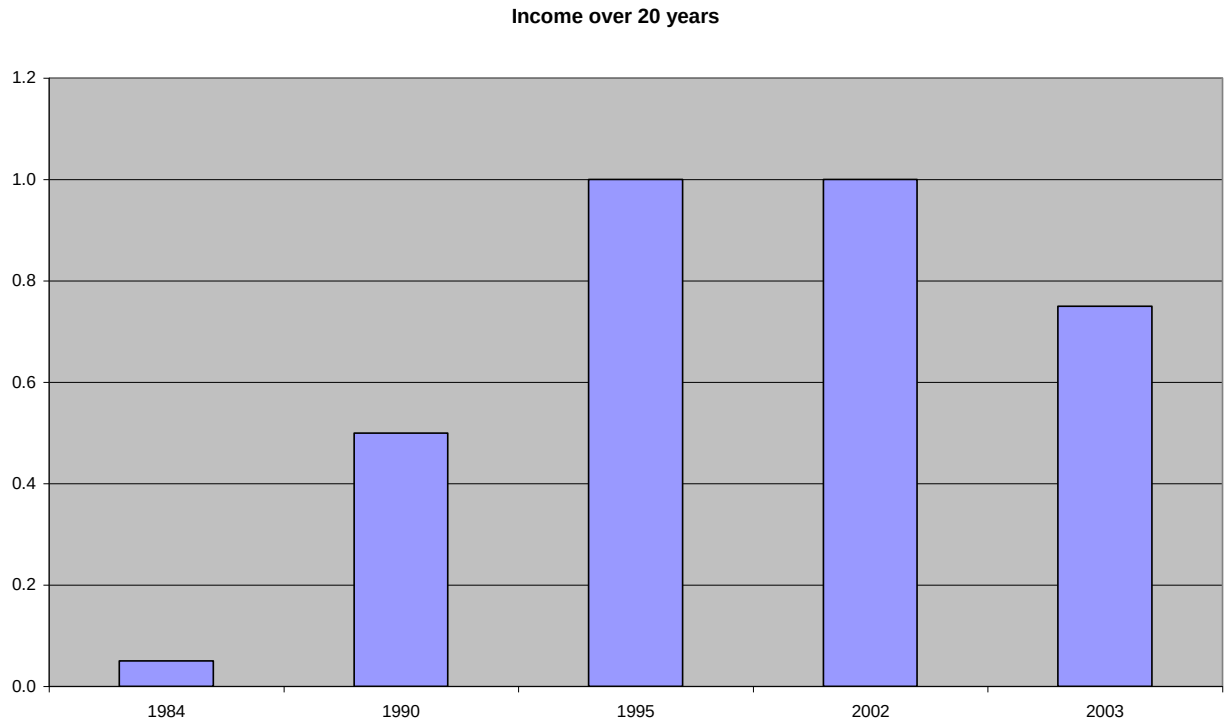

Fig. 5. Income over the last 20 years, normalised to the maximum income in late 1990s and early 2000s.

8. CONCLUSIONS

The commercial service at Imperial College was maintained for twenty years by juggling staff, equipment and irradiation facilities, building when required and downsizing when necessary. At no point was the service entirely self-sufficient since staff had more than one role and participated in teaching and research as well as the analytical service. The balance was of benefit everyone concerned, including students who have studied with us and gained experience of working within a well maintained and quality assured laboratory. The benefits of collaborating with industry cannot be overestimated, with the secondary effects for research and teaching identified previously.

A key change took place in the early 2000s, which can be seen in Figure 5 by the fall in income from 2002. The author's academic department became a separate cost centre to the Reactor Centre, and irradiations were charged at a more realistic price. Once the true costs were built in, including space, overheads and irradiation charges, it was not possible to maintain a viable business plan without reducing staff to a non-viable number. As a result, in 2003 the analytical service was handed to the Reactor Centre, in which the business could remain viable because the irradiation charge became income not expenditure. Without the continued interactions that academic research generated, the NAA service has diminished with very few customers in the past few years. Staff are occupied with internal work for the reactor such as routine monitoring using gamma spectrometry.

In summary the introduction and operation of a commercial service is to be recommended, particularly in those situations where it can complement other parts of the organisation such other analytical or academic activities. It is not practical to fund reactor operations entirely on commercial activities, but it can result in a number of spin-offs that can increase other income streams such as teaching and research projects. Over the past 28 years the analytical service at

Imperial College has brought several million US dollars into Imperial College, which certainly helped the Reactor Centre survive. Sadly the reactor ceases operation at the end of 2012, and subsequently there will be no facility for NAA left in the UK.