SCIENCE AND SERVICE AT A UNIVERSITY RESEARCH REACTOR

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1. INTRODUCTION

University research reactors are under continuous threat of being closed down because of the costs of the facility, priority settings forthcoming from mid-term strategies (with associated reductions of budget allocation for the reactor) and inabilities to fulfill vacancies in staffing and thus loss of technical competence. Some research reactor centres try to compensate for this by generating income by services. Neutron activation analysis (NAA) is often the most appropriate opportunity for smaller research reactors, but such a service can turn into a threat as it may affect the scientific output of the centre.

There are more reasons why neutron activation analysis groups are nowadays requested to identify beneficiaries (customers) for their technique and to start ‘commercial’ activities. The existence of (industrial) customers is considered important as a tool for visibility, i.e., to demonstrate the reactor’s role in the country’s social-economical society. Such an NAA laboratory has to shift part of its attention from self-directed scientific research to customer directed scientific services. This implies a fundamental change in culture, policy and in the technical and organisational management at the laboratory.

Several university NAA laboratories worldwide have proven to be successful in acquiring contracts for analyses. A few industries have established their own NAA laboratories to support their companies’ requests [1, 2]. Chemical analysis service centres exist, offering a wide range of analytical techniques for element analysis including NAA [3]. Some experiences of the Laboratory for Instrumental NAA (INAA) of the Reactor Institute Delft at the Delft University of Technology are presented here on the basis of more than 30 years of experience with INAA services to others. Recommendations are given to NAA groups starting as a service provider, but also some pitfalls are identified.

2. TECHNICAL AND ORGANISATIONAL ASPECTS

The Delft University of Technology concluded in 2004 that the cost of scientific research at the Interfaculty Reactor Institute in Delft, operating the 2 MW Hoger Onderwijs Reactor at 100 h/week on a continuous basis and at 40 weeks/year, was too high compared to the cost of research at other faculties. The permanent shut down of the reactor and ending of the associated scientific research was seriously considered. However, a proposal for reorganization of the Institute and scientific program was accepted, including a strategy for an organizational separation of science and service. A new department “Radiation, Radionuclides and Reactors” was initiated within the Faculty of Applied Sciences, whereas the Reactor Institute Delft became an entity for management and exploitation of the reactor and its facilities and laboratories. Both were given specific quantifiable performance indicators for the year 2008 as a basis for eventual continuation of this new structure. The targets have been reached and by 2010, all sections in the scientific department are headed by new young full professors, and plans have been approved for upgrading the reactor and expanding the various reactor and irradiation and beam facilities.

This reorganization resulted in a separation of the Laboratory for INAA from the Department Radiation, Radionuclides and Reactors towards the Facilities & Services (F&S) section of the Reactor Institute Delft. F&S' task is to make the Institute's facilities available for use by others. This applies to the neutron and positron beams, the reactor's irradiation facilities, the laboratories for INAA and for luminescence dating, and for group training courses on mainly radiation protection [4].

The facilities of the Laboratory have been described elsewhere in detail [5]. In short, 3 spectrometers are equipped with well type detectors (125–250 cm^3 active detector volume) and 3 with coaxial detectors (20–60% relative efficiency); these spectrometers are all equipped with automatic sample changers allowing for around the clock counting. Two spectrometers, one with a sample changer, are at the fast rabbit systems. A separate spectrometer is available for large sample NAA although this type of analysis is not included in the accredited scope. The management system of the laboratory for INAA is accredited by the Dutch Council for Accreditation for compliance with the requirements of the ISO/IEC17025:2005 for a 'flexible scope'. This quality management system has been operational since 1992 [6].

The Laboratory for INAA identifies 'internal' and 'external' customers. The internal customers are scientists from the Department Radiation, Radionuclides and Reactors, who carry out the analyses on their own after an appropriate training. Bench fees are transferred to F&S as research grants allow. The second category, external customers, includes scientists from other universities or research establishments, but also governmental bodies, NGOs and industry. These external customers are fully charged for the analyses, whereas the internal customers often only pay for the consumables such as capsules and internal quality control samples. The laboratory is a member of the network of the European neutron facilities for transnational access EU-FP7-NMI3, which offers an opportunity for scientists from eligible member states to have part of the analysis costs covered by this network.

3. CUSTOMER CHARACTERISTICS

There are numerous areas in which NAA could be the preferred technique for element determinations [7]. To some extent, these areas can be specified among the country's social-economical priorities. The mineral and mining industry may have a large potential for service analyses; in other countries environmental problems may require trace element determinations, whereas in other parts of the world the focus may lie with assessment of contamination of food products. Customers may come from industries such as mining or agriculture, trade companies including customs, governmental agencies, medical centres, universities and research institutions. Each of the segments may have specific requirements with respect to turnaround time (the time elapsed between providing the sample and reporting), the typical number of samples offered, the ease of analysis (element or interference levels) and willingness to pay. An overview, based on experiences of the laboratory in Delft is given in Table 1. It may serve to support business plans for a NAA laboratory starting its services. As an example, industry usually does not quarrel about costs of analyses, but the need for short turnaround times may present some difficulties. Governmental agencies may generate a continuous flow of samples, but they may argue that analyses should be done for free because the nuclear centre exists by governmental support.

TABLE 1. OVERVIEW OF SOME CHARACTERISTICS OF CUSTOMERS FOR NAA

	Requested turnaround time	Willingness to pay	No of samples/regularity	Ease of analysis
National economy: e.g. - industry - mining - agriculture	medium	+++	+	+/-
Trade: e.g. - companies - customs	fast	++	++	+
Governmental agencies: e.g. - environmental - health - agriculture - mining	slow	+/-	++	++
Universities/research institutes	slow	-	+++	++
Medical centres	medium/fast	+/++	+/+++	-/+++

+++: Very Favourable; -: Unfavourable

4. RECOMMENDATIONS FOR CUSTOMER ORIENTED SERVICES

4.1. Fitness for intended purpose

Customers often have an entirely different perception of what NAA has to offer as an analytical technique. They often apply for the use of NAA when all other techniques have failed. The strong and weak points of NAA are balanced against the in house techniques and the disadvantage of contracting out. The view of outsiders helps the NAA laboratory to understand the potentials of the technique to provide scientific services.

Customers ask for quality but not always in terms of accuracy and precision but merely as fitness for intended purpose. Customers simply expect that a laboratory, especially a university laboratory, must have a good performance with respect to accuracy and precision. Fitness for the intended purpose should be better interpreted as “good is good enough,” providing the answer asked for, within the time frame agreed upon and optimized towards the customer’s needs. This is one of the most difficult steps to take for academic laboratories; analyses have to be optimized to provide the proper answer, not always to result in the best measurement.

4.2. Fitness of intended purpose: Turnaround times

One of the measurements in INAA is traditionally done 3–5 weeks after irradiation. “Traditionally,” because in many cases laboratories rather blindly follow analysis schemes published in literature rather than searching for the real optimal conditions. Often already reasonably good results can be obtained some 10–12 days after irradiation when, e.g., the ^{24}Na background has decreased substantially. Satisfactory results can similarly be obtained after three days decay rather than to wait a full week after irradiation. Modern counting equipment can easily handle moderate or high counting rates. There should be, on the basis of first principles, no significant difference in the trueness of results obtained via a measurement with 5% dead time and with 60% dead time, if using the pulser method at a constant decay rate, or loss-free counting. It all can contribute to a quicker and thus higher throughput and more customer satisfaction.

In many cases there is no need to reach a better than 5% counting statistics precision, and even 20–30% may suit equally well. This may imply that a measurement, resulting in an indicative value of, e.g., 0.1, 1, 10 or 100 mg/kg, or, similarly, a yes/no presence of a certain element, may be obtained already after a few minutes of counting even though the uncertainty of measurement is still in the order of 50% or worse. Such answers may be fit for the intended purpose and do not need a measurement during four hours to reduce the counting statistics to 1% or better.

4.3. Multi-element or single element

The traditional protocol for multi-element analysis was, and still is in many INAA laboratories two irradiations and three measurements (one for the short half-life radionuclides, one after 1 week and one measurement after about 1 month) for 50–60 elements reporting. It is the experience of the laboratory in Delft that most external customers are not interested in such full multi-element analysis, not even when the data is given for free together with the data requested in the first place.

The majority of the work in Delft for external customers deals with one measurement 2–4 days after irradiation and a single element determination, or a group of some 12 elements which can be determined in this manner (Table 2).

TABLE 2. REQUESTS (IN PERCENTAGE OF TOTAL THROUGHPUT) FOR NUMBER OF ELEMENTS TO BE REPORTED FOR INDUSTRIAL AND UNIVERSITY CUSTOMERS OF THE LABORATORY FOR INAA IN DELFT

	Industrial customers	University customers
1 element	40%	8%
2 elements	20%	4%
3 elements	8%	4%
Group of elements	20%	14%
> 3 elements	12%	70%

The turnaround time of these measurements is about 7–10 days (see Table 3). This is usually acceptable for customers who try to find a compromise between the number of elements surveyed and turnaround time. The perception of a short turnaround time is enhanced when taking advantage of the weekend for decay, e.g., by receiving the samples and irradiation on Thursday, counting on Sunday night and reporting on Monday afternoon or Tuesday morning. In limited cases analyses are carried out with two days turnaround time.

TABLE 3. ANALYSIS PROTOCOLS (IN PERCENTAGES OF TOTAL) APPLIED FOR INDUSTRIAL AND UNIVERSITY CUSTOMERS OF THE LABORATORY FOR INAA IN DELFT

	Industrial customers	University customers
Shorts (S)	20%	13%
Medium (M)	60%	13%
Long (L)	2%	2%
S + M	1%	
S + L	1%	
M + L	2%	
S + M + L	10%	70%
Special optimised	5%	2%

S: NAA applied to short half-life radionuclides,
M: NAA on basis of intermediate half-life radionuclides (e.g. measurement 1 week after irradiation),
L: NAA on basis of long-lived radionuclides (e.g. measurement 1 month after irradiation)

The situation is often different for universities. Here, mainly full multi-element analyses are requested because a large number of elements are needed for factor analysis in the interpretation of the biomonitoring or epidemiological projects. With experience with services to groups at other universities, the laboratory has learned that requests for multi-element data change rapidly to requests for a limited number of elements when the groups were charged for the analyses. An analysis consisting of one irradiation and one measurement is less expensive than an analysis consisting of two irradiations and three measurements.

4.4. Throughput and automation

External customers offer their samples in small batch sizes, and seldom in hundreds at a time or so. The maximum number of samples processed in Delft simultaneously, which can be packed into one rabbit, is 14. The number of batches for external customers is about 200 per year, as of the year 2009. Adding the number of control samples, blanks and flux monitors, and accounting for more than one measurement per sample, it all sums up to approximately 25 000 measurements per year.

Reliability in service provision does not depend on the analytical quality only; it equally depends on the availability of facilities. Whereas the markets for NAA laboratories may have been identified, and quality may have been established, an underestimated problem remains the absence of automation, which limits tremendously the analytical capacity. Most NAA laboratories have only one or two detectors, and commercial sample changers are considered too expensive. Laboratories are therefore not equipped to handle parallel requests for analyses. The capacity is also limited by time-consuming data handling due to the lack of associated automation. The analysts often have to transfer the output of the analyzer, a list of gamma ray energies and peak areas, sometimes topped with element assignment, through various file transformation programs. Firstly they are analyzed through spectrum interpretation software for qualitative analysis, next by a program for quantitative mass fraction calculations and finally by the reporting software. Sometimes two or three measurements are done, and all intermediate results have to be considered for the final output. In this linear chain of processes a missing link is formed by the administration of samples and customers that may be recognizable only in a spreadsheet. The level of automation in most NAA labs does not compare to what modern industry provides for alternative techniques such as X ray Fluorescence Spectroscopy (XRF), Automatic Absorption Spectroscopy (AAS) and Inductively Coupled Plasma (ICP) Spectroscopy.

It is simply detrimental to any NAA service if the analysts have to reject requests for NAA not because of lack of irradiation and counting time, but because of limited capacity in automation and data processing. Fortunately, the IAEA took initiatives in 2009 to assess ways to support improved automation in NAA laboratories.

4.5. Trustworthiness

Finally, customers expect that the analysis can be reproduced and eventually that the laboratory can stand up in court to defend its results. This stresses the importance of quality management [8].

5. SCIENTIFIC CUSTOMERS

Scientific customers are those needing the results of the NAA laboratory for their own scientific research activities but without sufficient resources to pay for the services. Moreover, often their sample types and elements, and levels, to be determined are non-routine; sometimes the problem is not even well defined nor is the number of samples and date of delivery. At first sight, this may be not an attractive market segment; on the other hand, it still may be. The objectives of the customer's research may line up with ongoing research within the nuclear centre. Also, it may be exploring analyses that can end up in a big project with an ample budget for routine analyses, or the objectives are of high public relevance. Public relevance and reactor utilization are often more important than just generating income.

Still, a NAA service provider may have some direct benefits from such analyses. A price reduction may be compensated by, e.g., co-authorship in publications, equipment donation, co-applicants for new projects or even additional manpower by the customer for support in performing the analysis (e.g., for sample preparation). Medium or long term payback may come by involvement of the NAA laboratory in other networks, but it results at least in enhanced reactor utilization. Scientific customers are more rapidly becoming stakeholders of the laboratory than industrial customers, and therefore have a higher impact on the sustainability of a facility.

6. PITFALLS IN NAA SERVICES

6.1. Outreach

NAA is generally poorly advertised to potential customers, like in the communities of applied sciences. Usually radiochemists promote their technique amongst radiochemists only at radiochemical conferences. At more general spectroscopic conferences, hardly any contribution is found on the status and opportunities of NAA. It is an illusion to expect that the many publications on NAA and its applications have their impact. Customers, and this counts in particular for the non-university market segment, do not read the Journal of Radioanalytical Nuclear Chemistry, Nuclear Instrumentats and Methods or Analytical Chemistry. They are not interested in the resolution of Ge detectors, k_0 phenomena, nor in the results of reference material analysis. NAA is not an analytical technique that belongs to the package of methods taught and trained at technical schools and at many universities. Taking into account the overwhelming presence of techniques like AAS, ICP and XRF, it should be feared that within other analytical laboratories, there is rather limited awareness even of the existence and accessibility to NAA.

Solutions may be found by presentations at conferences or meetings of the areas targeted, such as geological, medical or environmental fields; technical notes; promotional brochures and inviting websites. The emphasis should be with what has to be offered rather than how the technique is performed.

6.2. Planning and availability

The academic environment is almost synonymous for unreliability in planning and meeting deadlines, as with respect to, e.g., reporting. Laboratories have to introduce a style of working with a commitment to planning all aspects of the analysis, like availability of consumables, equipment checks, use of equipment, etc. There should also be a rigid procedure based on verification with quantifiable criteria for checking the results before reporting.

An unreliable reactor schedule is of course a big threat for the provider of services. This also may apply to full power operating schedules, which may be delayed due to modifications needed for beam experiments, or affected by reactor physics training, isotope production activities and fuel economy.

The quality of services may also be endangered by an unreliable operation of NAA equipment. In principle, a smooth running NAA service provider should have some spare equipment on the shelf, particularly modular amplifiers and HV units, and be able to take immediate action for replacement in case of a main failure. A partial return of revenue can accommodate such replacements and investments. Unfortunately, in many institutions the revenues are not returned. This is a serious threat, since it quickly moves the laboratory in a downward spiral both in motivation of employees as well as in reputation of being a reliable partner. Sometimes this may be bypassed by payment “in kind,” e.g., via procurement of equipment by the customer. However, there are no general guidelines to overcome this threat since it is typically a political problem within the mother organisation.

7. CONCLUSIONS

In many countries NAA laboratories have to face the reality that daily efforts may have to be shifted from self-directed scientific research to customer oriented scientific services. This implies a change in culture, policy, and technical and organisational management at the laboratory. External customers have different requirements for scientific services than internal customers for their scientific research. It should be noted that the examples given in this paper constitute a specific case study. NAA laboratories should be aware of the fact that external customers have their own perception of the advantages and weaknesses of NAA. The advantages of NAA, as found in numerous review articles and books, are strongly biased, as they have been compiled from the inside, rather than from the customers’ point of view. Their view on the strong points and weaknesses of the method may be different from case to case. NAA laboratories should be alert to this and develop a flexibility to respond to it.

A remaining problem is that automation in NAA, indispensable for effective and economic operations, is scarcely commercially available, and often has to be developed in-house. This may hamper many small NAA laboratories in becoming interesting for large scale or parallel requests as well as competitive with other methods of analysis, and in obtaining the funds to compensate for budget cuts.

The return of revenue is indispensable for becoming a successful and, above all, a reliable NAA service provider. Revenue is important for quick action related to repair, modification and expansion of the NAA laboratory's infrastructure and equipment, and for motivation of personnel. Quality management and eventually accreditation is the other pillar under reliability.

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