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Laboratory work in changing society : Neutron activation analysis in a research laboratory

Introduction

The original motive of this study was to gain understanding of the division of labor in laboratory work and the contents of the work of the laboratory assistants. The motive expanded to an attempt to analyze the development of work in the analytic section of the Reactor Laboratory of the Technical Research Centre of Finland. During the 25 years of its activity the dominant method used has been neutron activation analysis (NAA). Accordingly the major work done in the analytic section can be called neutron activation analysis work (NAA-work).

Some pioneering laboratory studies have been done within the tradition of the constructivist sociology of knowledge. This tradition has a definite epistemological program. It attempts to explain the development and nature of knowledge by studying empirically how it is produced in concrete laboratory settings (Latour & Woolgar 1979, Knorr-Cetina 1981). To omit the old objectivist and idealizing concepts of science, the laboratory should be studied as a "tribe", with an etnograpahic approach.

From the point of view of the present study this approach has at least three limitations. First, because of its epistemological commitments it focuses on certain aspects of laboratory life, first of all on the discussions, interpretations and decisions of the scientists. The labs seem to be manned by scientists only. The contribution of the laboratory assitants is largely omitted. Secondly, the constructivist interpretation of the social determination of laboratory work and its results seems too narrow. Its radical emphasis on the particularity and occasioned nature of laboratory work seems to omit important societal aspects of the objects, the instruments and the division of labor of research work. Third, to retain objectivity the researchers studied are not allowed to reflect and interpret their own work processes. In this study this principle has not been followed, because the researchers and research assistants evidently were capable of reflecting on important aspects of their work. These reflections are used in the reconstruction of the development of NAA-work.

This study is not primarily an attempt to contribute to sociology of knowledge. It represents rather, a tradition of psychological and sociological studies of work. Its general frame of reference is the cultural-historical theory of activity. This depicts human activity as object oriented, material activity mediated by cultural artefacts, signs and tools (Vygotsky, 1979). During the last years this approach has been used in research on the development of work and qualifications. Work is undertood as an *activity system* with a division of labor and rules (Engeström, 1987). There is an interdependence between the main elements of the work (subject, tools, object and division of labor and rules). Contradictions and tensions within the system and between the elements of the system are a central "moving force" of development. This approach has been developed in studies on automated industrial work (Toikka & al. 1990), general practinioners' work in health centres (Engeström, 1990) and in the work of teaching (Miettinen, 1989). Science, as well, can be understood as such an activity system (Ruben, 1979; Miettinen, 1988). As societal work science, of course, has a historically specific nature that concerns both its object, results and means.

Human activity is always object orientated. The object of work forms the basis for the "motive" of the activity: what the problem is, how it is understood, and why it is studied (Leont'ev 1978). The object and result of a certain work process is related to other societal activities. Any work process must be analyzed in the network of other societal activities. Analytic chemistry produces methods and results that are used, for instance, in environmental research and quality control of metal industry. To understand the nature and content of the work in a specific analytic research laboratory, it is important to understand the sources of the object of research.

On the basis of this conception the following questions concerning the work of the analytic section of the Reactor Laboratory were formulated:

1. How were the objects of research formed, and how have they influenced the analytic activity and the development of its methods?
2. How were the tools and instruments developed, and how has this development influenced laboratory work ?
3. How did the division of labor between researchers and laboratory assistants develop?

The material of the study consists of interviews, publications, project plans and memos, and of observations and notes of unofficial coffee meetings of the section.

The interviews were done at different times and in different situations in 1987, 1988 and 1990. The relation of the interviewees to the work process differed. Hence, they provide a multitude of narratives, with different interpretations, about the development of work. It has been tried to allow the voices of the researchers and research assistants to speak in the study. By this procedure, I have tried to retain the richness, the *multi-voicedness* of the activity — to use the concept of Mikhail Bakhtin. The aim has been to reach cultural sensitivity and historical specisifity in the analysis of the activity (Calhoun 1990). Moreover, it seems important in science studies, to let the researchers of different fields to speak about the nature and the problems of their work.

2. The complementary levels of analysis

To understand the particularities of NAA-work in the Reactor Laboratory at least five cultural determinants should be taken into account. The first and second of them refer to the general cultural characteristics of the tools of the work. The remaining three refer to the national, economic and organizational determinants of the work.

1) NAA-work is analytic chemistry. It is one of the modern methods of analytic chemistry. It shares problems typical to this discipline. Analytical chemistry always works with real analytical samples — industrial, geological, biological or environmental — the composition of which are never known beforehand (Hulanicki, 1986: 14). It is interdisciplinary, oriented to using chemical, physical or biological methods. The typical problems of analytical chemistry are interferences and matrix effects. When measuring a certain

element from the sample, the other elements and the chemical composition of the sample (matrix) influence the behavior of the element under scrutiny. No analytical method or apparatus is free from matrix effect. As a result, these effects have always to be taken into account when a new kind of sample is measured.

The formulation of this problem (matrix effect) and the principles and procedures to handle it (developed within analytic chemistry) are culturally generalized artefacts, generalizations of collective practice. They help to understand what is happening in a laboratory — of course in a specific form, because the real analytics is always done with a specific method and instrument and with specific samples.

2) NAA-work is an application of the neutron activation analysis method. In NAA the samples are irradiated in the neutron flux of a nuclear reactor. Elements of the sample become radioactive isotopes and the characteristic gamma-radiation of the isotopes can be measured. NAA is tied to the neutron source, a nuclear reactor. The rule is : where there are research reactors, there NAA is done. The method is tied to the fate of the few hundred research reactors (443 in the whole world in 1986) that were founded as part of the civil nuclear energy programs in the 1950's and 1960's. NAA as a method will survive as long as the research reactors survive. Already in the 1970's more research reactors were shut down than comissioned and this trend is accelerating.

NAA has its own scientific community. Every fourth year the International Conference on Modern Trends in Activation Analysis is held. The methodological problems are discussed, and the results are delivered in these conferences. NAA is one method of analysis competing with other methods. It has strong and weak points (Revel, 1987). The specific characteristics of the method explain to what elements, what kinds of samples and what kinds of problems it is used. NAA can also be regarded from the point of view of its life cycle and from its comparative advantage to other developing methods (Girardi, 1981). The NAA-work in the Reactor Laboratory can be interpreted as a part and a specific case of the broader development of the method.

3) The NAA-work studied here is done in a small, semiperipheral industrialized country (Finland). The characteristics of a small industrialized country like Finland influence the demand for analytic services. Research expenditures are scarce. The Finnish strategy of economic growth is based on the "exploitation of the advantageous position of the follower" (Lemola & Lovio, 1988). The role of research has mainly had the character of transferring technology or following the progress of the technological frontier of international basic electronics technology. Advanced chemical analytics develop in close connection with basic research in other fields. That is why the national particularities of research and industrial development influence the problems and objects of the analytical work, and the possibilities and the contents of the analytical research itself.

4) NAA-work is done in a research Institute with — among other things — a specific financing system. The Technical Research Centre of Finland is an unusual kind of public research institute. All fields of technology are concentrated into one institute. The Centre has traditionally received the major part of its funds from the state budget. During the 1970's the situation changed radically. In the beginning of the 1970's the share of budget money in the research centre's operating expenditures was about 60%. By 1988 it had decreased to 34 %. Service research and the responsibility for the financial "results" (acquisition of money for projects) has become more and more important. This change had a profound impact on the nature of research work.

5) NAA work is done in a specific unit (the Reactor Laboratory) of the Centre. The Reactor Laboratory has its own characteristic features among the laboratories of Technical Research Centre. It was removed to the Research Centre from the Technical University of Helsinki in 1971. The academic tradition of producing many dissertation and other publications is strong, and not typical of many of the engineering laboratories in the Research Centre. The researchers of the analytic division

have mainly been radiochemists, and half of them have been women (79 % of the researchers in the Technical Research Centre are males and 78 % engineers). These features influence the way the research is done and the relations between researchers and research assistants.

In sociological laboratory studies microanalysis and the local, contingent, idiosyncratic and opportunistic nature of laboratory practice have been stressed (Knorr-Cetina, 1983). On the basis of the above-said it is quite logical, that in any concrete laboratory work both micro and macro, both the general and the particular, are present. But the macro- or general aspect of work cannot be found inside the walls of the laboratory without analyzing the generalized cultural and instrumental aspects of the work. The real societality is found in the tension between the generalized cultural content and cultural intermediation of the work, and the particular circumstances and special characteristics of work in a laboratory. Accordingly, a continuous interaction between the levels of analysis is needed in the research process (Cicourel, 1981).

3. The NAA method in the Reactor Laboratory

Neutron activation analysis is a very sensitive method for analyzing the contents of elements in different materials. The results are expressed in general in terms of parts per million (ppm). This means that very small amounts of elements are detected. This high sensitivity is needed in many fields, such as environmental research or semiconductor production. For instance, the mercury content of biological material is normally 0.01—0.05 ppm (Häsänen, 1970: 251).

In the NAA the sample is put into the nuclear reactor, the Triga Mk II research reactor in the Reactor Laboratory. The elements of the sample are changed into radioactive isotopes in the neutron flux of the reactor. The atomic nuclei of radioisotopes are unstable and emit gamma rays. The gamma rays of each isotope have definite energies and hence they can be detected by a gamma-ray spectrometer. This apparatus is composed of a detector (NaI(Tl)-crystal or GE-semiconductor), and the transistorized multichannel analyzer, which sorts the gamma-rays to different channels according to their energy level. As a result a gammaspectrum of the sample is received. Simultaneously with the samples, a standard sample is irradiated. The quantities of the elements in the standard are known. The concentrations of samples can be calculated by comparing their spectra to the spectrum of the standard.

The "instrument" of the NAA is actually quite a huge technical system. It is composed of the reactor with its implementations like the pneumatic transfer system to get the samples into the reactor, and the automatic gamma ray analyzer with its sample changer and computer.

The problem in the development of methods can be described as follows. Different isotopes have very different half-lives (from minutes to years) and hence they are active for different periods. On the other hand different isotopes have gamma-rays of the same energy and this can interfere with the measurement. When measuring a certain type of sample where certain elements should be detected, the irradiation (type, intensity, time), the decay time before measurement and the measurement time should be designed in such a way, that the irradiation 'peaks' of the elements to be detected can be measured without interference of other elements in the sample. This is a complex task. On the basis of the knowledge concerning the nuclear characteristics of the isotopes and the possible composition of the sample, a hypothesis of a good procedure can be made. But the composition of the samples is not known well beforehand and that is why experimentation is always necessary. The problem is still more complicated when many elements are to be measured from the same sample (multielemental analysis).

As a result of experimentation, an optimal procedure of detection is developed and documented. For instance, in a routine method of analyzing 11 lanthanides from geological samples, the samples are irradiated for one week, one lanthanide is measured eight days after the irradiation, five of them nine days after irradiation (with a different detector), and the rest of them four weeks after the irradiation. The whole process takes five weeks and is always done in the same way.

But what kinds of samples are the methods being developed for, and where do the objects of analysis come from? The concepts 'analysis' and 'type of sample' are in many ways connected to societal practices (Nygård & Petterson, 1990: 186). The objects literally determine the nature and content of the method to be developed and in addition, to a large extent create the motive of the analytic work and method developing.

4. The development of the NAA work in the analytic section

On the international level, the three principal application fields of NAA are biology, geology and environmental studies. The distribution of papers given in the 7th International Conference on Modern Trends in Activation Analysis in 1986 was as follows: biology 31 %, geology 27 %, environmental studies 26 %, metals and semi-conductors 10 % and the rest 5 % (Revel, 1987: 178). In the Reactor Laboratory the main fields have been environmental research and geological research. In the beginning there was a strong ideal of national service research. All those who needed analyses of very small amounts of elements, not accessible to other analytical methods, were to get them from the Reactor Laboratory. As a result very many types of samples were studied. In the words of the researchers (Rosenberg & Lakomaa, 1984:18):

> "The richness of the service analytics has been in the diversity of samples. It is difficult to imagine a type of sample that hasn't been analyzed. Geology, ore prospecting, metallurgy, paper industry, toy industry, crime investigation, archeology, ect. have been represented."

The 25 years of NAA-work in the Reactor Laboratory can be divided into five stages (Table 1). In every stage the emphasis of the research has been on a certain type of samples. Research in NAA-work is the development of methods for certain kinds of samples. The "type of samples" can be defined by studying who needs the results, of what elements, and why.

The division presented in Table 1 is schematic. Environmental research, for instance, has continued also in the years 1976-1986. But the phases help to describe the cyclic nature of the activity and the dynamics of reorientation in NAA work. In addition each phase has its own story to tell.

The stage of environmental research, 1966-1975

From the year 1966 until 1975 extensive studies on mercury concentrations in the natural environment were carried out. This work was done in collaboration with a number of research institutes and the Reactor Laboratory. The most comprehensive project was organized by the National Water Board to determine the

Table 1. The stages of development of the NAA-work in the Reactor Laboratory

Years	Stage	Object/activity
1964-1965	beginnings	various
1966-1975	environmental research	mercury in biological samples environmental research/protection
1976-1980	instrumental analysis of geological samples	uranium prospecting
1981-1986	multielemental analysis of geological samples	gold prospecting
1987-1990	decline and transition to other methods	various fluoride/environmental research

mercury level in fish and bottom sediments in 1966-1968. In this study, NAA was used and the role of the Reactor Laboratory was decisive.

The responsible researcher, who came to the Reactor Laboratory from the Radiochemical Institute of the University of Helsinki in 1966, describes the beginnings of the research project. In Sweden, an extensive study on fish had been carried out in 1964-1965. In this study it was discovered that in the waterways polluted by the paper and chlorine factories, the mercury contents of the fish exceeded the natural level. In Finland high residues of mercury had been discovered in white-tailed eagles. The researcher had studied the cesium content of fish at the University of Helsinki and it was known that NAA is the best and most sensitive method to determine mercury contents. Accordingly the idea to study the situation in Finland, using NAA, was born. The researcher describes :

> "The first samples I took from the lake Päijänne, and some samples from the Lapland. It seemed that the mercury content in the fish of Päijänne clearly exceeded the natural level. So there was good reason to survey the situation in Finland. Then I contacted the Finnish industry and asked where it would be worth taking samples (. . .) Then I contacted the fishing biologist XX and with him we started the study. He acquired the samples. We got a series of 170 samples, which was soon analyzed, and we got a picture of the situation in Finland."

The researcher developed the method for the determination of mercury in fresh biological material (Häsänen, 1970). It was later widely used to analyze the mercury content of various kinds of biological samples (Häsänen, 1974). A few characteristics of these studies deserve to be mentioned.

First, the studies were carried out in collaboration with several Finnish research institutes and the Reactor Laboratory. This collaboration was not controlled administratively. There was no "official project" with its concurring organizational body, only the state budget financing of the institutes involved. The collaboration can be characterized as free interaction of the researchers or as an "unofficial national research program" within the network of institutes and researchers. This collaboration was productive : 30 publications reviewed in an overview article in 1975 (Häsänen, 1975).

Secondly, the object of the study in the Reactor Laboratory was not only the mercury content in biological samples. The analytical results became an instrument to understand and control the mercury pollution as a societal problem as well. Not only fish and bottom sediments were studied, but later also the aquatic food chains and the sources of mercury discharges were traced. Lastly, the replaceability of mercury in industry and agriculture was analyzed (Häsänen & al. 1972). As such, the analytical work was a part of the solution of a national problem. The researcher acted as a secretary in a team founded by the National Water Board and with the participation of representatives of the Finnish industry. Its task was to survey the situation and suggest possible measures. In 1975 the results could be reported as follows (Häsänen 1975: 527):

> "During the last twenty years, 50 tons of mercury a year have been used as metallics and as different compounds. It has been estimated that 20 % of that amount has got into the environment with the waste waters of the above-mentioned industries. On the basis of the research results, the paper and pulp industry has given up the use of smilicides and fungicides containing mercury from the beginning of the year 1976. (. . .) The three clorine factories in Finland have invested over 2 million FIM for the treatment of discharge waters containing mercury, and removing the remaining mercury from caustic soda. As a result of these measures a decline of about 90 % has been attained in the amount of mercury that gets into the environment. Because of these abrupt limitations in the mercury discharges the mercury content of fish has begun to diminish in polluted water areas (. . .) The width of the contaminated water areas has declined up to now by 30-40 % as a result of the measures of the industry."

When the method for studying the mercury content of fresh biological samples was developed, the reliability of the method was secured by comparing the results with the results obtained by three other methods from the same samples. The method was also used to analyze four International Atomic Energy Agency intercomparison samples (Häsänen, 1974: 149). These are normal procedures in analytic chemistry and, at the same time, concrete means to limit and eliminate the 'contingent, local idiosyncratic' nature of the method, instruments and research results.

Obviously it can be said, that the above-mentioned methods were used to assure the scientific community of the validity of certain research results. These procedures were also material means to standardize the research methods and instruments, and to eliminate the locality of the results. They represent the general societality of the research work in any single laboratory.

From lunar rocks to uranium analysis, 1975-1979

The beginning of the geochemical research in the Reactor Laboratory is exotic. In 1970 a young chemist came into the service of the Reactor Laboratory. He had just completed his MSc thesis on the use of instrumental activation analysis of 30 elements in seven Apollo 14 samples and one Apollo 15 sample. Why and how did the samples come to Finland? In the words of one the researchers:

> "I think it was because of personal contacts. The researchers of meteorites (. . .) had a considerable role when the taking and the analysis of the samples was planned. In Finland Birger Wiik was one of them. He was in charge of the meteorite collection of the Geological Survey of Finland. He had detailled results of 500 meteorites and he had published them. He was known as a reliable meteorite researcher and a real professional. He is an element analyst, and knew NAA, and that it was done here. And so he contacted us."

Personal contacts were one of the factors influencing the inception of geochemical research. Another reason was that the new detector acquired by the Reactor Laboratory in 1968 proved especially suitable for the analysis of lanthanides. This in turn was important in geological basic research (Rosenberg, 1972). This gave birth to a long-lasting collaboration between Finnish geologists and the Reactor Laboratory. The study of lunar samples showed that instrumental activation analysis was sensitive enough for detecting uranium in backround concentrations.

In 1974 the Geological Survey of Finland started a large-scale geochemical mapping program to find uranium. The Ministry of Trade and Industry financed uranium prospecting with 5 million FIM a year. The reason for this program was the energy crisis, and subsequent ambitious plans to develop nuclear energy (Björklund & al., 1976). The need for national self-sufficiency of uranium was emphasized. The Reactor Laboratory was financed by The Ministry of Trade and Industry to design an automatic uranium analyzer efficient enough for large-scale uranium detection. The analyzer was ready in 1975 and in the following years it was used for the analysis of 25 000—30 000 samples per annum (Rosenberg & al., 1977). The researcher describes the situation as follows :

> "Then the question was raised, of who was to do the uranium analyses.. And we managed to get the decision that all the analyses to be made in Finland of solid samples - were to be made here".

Two things made the decision possible. The superiority of NAA in uranium analysis and the poor preparedness of the institutes responsible for the explorations to make the analyses. The significance of these analyses for the Reactor Laboratory was at least threefold. First, the first step towards mass analytics was taken. Second, in the planning and design of an automatic uranium analyzer, much was learned about the design of the systems of instruments. The analyzer was later sold to Iran and to the International Atomic Energy Agency. Third, during the years 1976—1979, 85 % of the money obtained by service analytics came from uranium analyses.

The crisis and the orientation towards mass analytics and the instrumental multi-elemental analysis of geological samples, 1980-1986

In the beginning ot the 1980's three interrelated tendencies influenced the NAA-work at the Reactor Laboratory. First, the share of public expenditure on the Technical Research Centre began to decrease, and there were strong pressures to finance the activities by contract research. Second, the Ministry of Trade and Industry had traditionally — as a part of the Finnish nuclear energy program — given a considerable amount of money to the Reactor Laboratory. Now this source of finance was declining. Third, the uranium exploration was reduced radically. The crisis was not only economic. It profoundly influenced the direction of the development of the method and the tradition of the laboratory, as expressed in a review of the activity (Rosenberg & Lakomaa 1983: 5):

> "It has always been a characteristic feature of NAA-activity, that we analyze samples and elements that are difficult or impossible to analyze with conventional methods. In general they have been single samples or analyses needed for an academic thesis. It has been typical to all these tasks, that the expenses per sample have been very high and the persons needing the analysis have not had money. Still, the analyses have been done without invoicing or for a nominal price. Now this kind of activity is no longer possible. It is necessary to concentrate on big series that can be automated and on big clients. This considerably limits the old tradition of the laboratory".

In 1980 the laboratories of the Technical Research Centre prepared a 'strategic analysis' for future activity as part of a management training program. In the analysis of the Reactor Laboratory one of the goals was : "to develop a superior method of multielemental analysis and to conquer domestic, and a part of foreign, markets". In the years 1980—1982 a new epithermal multielemental method of solid geochemical samples was developed (Rosenberg & al., 1983). The routine analysis method was constructed for the elements that are most interesting to ore prospecting, first of all for gold. An automatic gammaspectrometer was planned and built (Vänskä & al., 1983). Six automatic gammaspectrometers were acquired. In the beginning of the 1980's vast programs of explorations for gold were initiated in Finland and Sweden. In the years 1982—1985, more than 10 000 geological samples were analyzed annually for gold and for 23 other elements. The main clients were the Geological Survey of Finland, the Outokumpu Mining Company and the Boliden Company from Sweden.

The explicit goal during these years was to develop a commercially profitable service analytics. This was brought about by rationalizing the whole system "to get the price down and the capacity up." In 1983, it was reported (Rosenberg & al., 1983): "One laboratory technician can manage the irradiation and sample handling of the 20 000 samples analyzed with two gamma spectrometers. Thus the cost per sample amounts to 2.5 US$, which is comparable to or lower than that incurred by most other analytical methods."

Table 2. The invoicing of the service analytics in the 1980's at current price (FIM)

1981	565.000
1982	983.000
1983	1.120.000
1984	1.303.000
1985	1.017.000
1986	804.000
1987	—
1988	670.000
1989	600.000

The years 1982—1985 were commercially the "golden years" of activity. Because of an active gold exploration, the service analyses were very profitable. The 'strategic goal' of profitable mass analytics had been achieved, but only for a while, even though the automatic analysis system was technically, without doubt, an unique one.

The new crisis and an orientation to other methods, 1985—1990

The situation of the service analytics became worse in 1985-1986. The number of received geological samples decreased radically for two reasons. The gold exploration was decreasing and the main clients acquired analytical capacity of their own. Today the Geological Survey of Finland makes all its gold analyses in its own laboratory, using a modern mass spectrometer. The capacity of its laboratory has risen from 10 000 samples to 40 000 during the 1980's. Outokumpu Oy founded a new geoanalytical laboratory.

This new situation implies that NAA has lost its superiority as a method of analyzing geological samples. Other sensitive, more convenient and useable methods are available now. All the researchers interviewed in 1990 estimated that the ICP mass spectrometer will become a standard instrument in many laboratories. It is sensitive, quick, suitable for multielemental analysis and it can be bought for half a million dollars.

As a result of the above-described development, the analytics section had to consider extending its repertory towards new analytical methods. This became even more important when the discussion of the possibility of shutting down the Triga-reactor of the Reactor Laboratory began in 1989. The orientation to other methods also meant breaking the dependency of the analytics on the reactor.

The first new method was the Laser Ionization Mass Spectroscopy (RIS) in 1983. This method is one of the most sensitive available. Detection limits of parts per trillion can be achieved, and even detection of a single atom is in principle possible (Auterinen & al., 1987). The way in which the RIS-project was established is interesting. The management of the Centre and the Reactor Laboratory considered it important to do laser research in Finland. As a part of the scientific-technical cooperation between the Soviet Union and Finland contacts with the Moscow Institute of Spectroscopy were established. One of the researchers of the analytic section of the Reactor Laboratory happened to visit the Institute as a member of a delegation of chemists. As a result the idea of utilizing RIS in analytics was born.

There proved to be two kinds of difficulties in the RIS-project. First the apparatus itself had to be constructed, by combining the main components (laser devices and the mass spectrometer) into a functioning system for analytic work. This proved to be difficult for the chemists and young physicists involved in the project. For a long time, electric disturbances in the devices hampered the development of the method. The second difficulty was, that the object of application remained open. In the plans of the Reactor Laboratory it was presented, that the method should serve the needs of the growing electronics and semiconductor industry in Finland. However, no company in the field was interested in utilizing the method. The same lack of interest appeared when the acquisition of a Secondary Ion Mass Spectrometer (SIMS) was prepared in 1989. SIMS is an apparatus suitable for surface and depth analysis of materials. Internationally it is almost exclusively used by electronics industry and research. In Finland instead, other fields of industry and labratories in the field of metal research expressed their interest in using the apparatus.

The researchers argued that the main reason for the limited interest was in the "mentality of Finnish industry". They compared it with the work in the analytical laboratories of big electronics firms in the USA and Europe as follows:

> "If we look at how research is done in international research institutes, the mentality is completely different. When some component, material of device is developed, their starting point is, that they go to the atomic level to understand how it functions and what it is. But here in Finland, engineers have not been taught this way of thinking. Here the development work is done with the principle of "it seems to me". "Lets try this - it does not function, very well - lets try that". The proper mentality of research is lacking. And the utility of our methods is in that part of the process - when something is being developed. And because we don't have such research in Finland, we can not apply our methods anywhere."

The viewpoint is that of an ambitious analyst. Finnish research is measured with a yardstick of the most advanced analytic laboratories of the biggest firms in the world and in terms of the possibilities inherent in the development of the methods of analytical chemistry. But maybe he found an important characteristic of the Finnish economy and industry. Why is advanced analytics not used? According to the economist's view, the electronic component firms are only a small fraction of the Finnish electronic industry, concentrating mainly on telecommunications and consumer electronics (Lemola & Lovio 1988). There is also a problem of scale. Only one of the Finnish electronics firms (Nokia) is to some extent comparable in size with the international competitors. Small or medium-sized firms are hardly in a position to invest in basic research of any kind. Moreover many of the products and production processes have been licensed and introduced directly without any original research or development. These national circumstances evidently constrain the oppotunities to develop advanced analytics in Finland.

During the later part of the 1980's, a gradual change of orientation in the analytic section took place. The developmental work was concentrated first on RIS and from the beginning of the 1990's on SIMS. However, during all of 1980, environmental research has been continued. Among important projects have been: a study on the emissions from power plants fueled by peat, coal and oil in 198—-1984 (Häsänen & al., 1986), studies on the elements composition of pine tree rings (Häsänen & Huttunen,1989) and on organically bound clorine and bromine in water, on sediment and biological samples (Häsänen & Manninen, 1989). These studies are based on research collaboration. They are concerned with important environmental problems in Finland.

5. The automation of NAA

The automation of NAA has been a prominent feature of the development work in the Reactor Laboratory. The early history of the NAA-work, from 1966 to 1975, is a history of incredibly laborious handwork. Since 1972, the rate of automation has been rapid. As a result, the nature of NAA-work in the Reactor Laboratory has changed profoundly in ten years.

The automation of NAA has been partly a natural development process based on the technical development of detectors, computer hardware and programs. But it has been a deliberate policy as well. It was planned to facilitate work, to protect the workers from irradiation and to secure the reliability of the method. It was also seen as a method of economic competition (Rosenberg 1982:14):

> "It was realized already very early that the absolute condition of the competitiveness and marketability of the activation analysis is automation. There are two reasons for this. There are several phases in the analysis, and it presumes expensive instruments. As a result, the expenses of both the labor and the equipment easily rise to a very high level. With the help of automation it is possible to decrease the expenses of labor and to raise the capacity used. Because adequate equipment is not for sale, we have been obliged to develop it ourselves."

An additional reason for automation were the pressures created by the decline of public financing. As a result the strategy of the Reactor Laboratory in the beginning of the 1980's was to achieve profitable mass analytics with the help of automation. The aims of developmental work fused with the 'financial strategy' of the laboratory.

An important condition for the success of the automation was a fruitful collaboration of the electronics engineer of the section and the researcher in charge of geological applications. As a result, the analytical know-how and experience and the technical know-how were united in the development work. The automation process can be divided into the following four stages.

1) Automation of the calculation of results in 1972

The calculation of the concentrations of elements manually from long sheets full of numbers was a laborious and tiresome phase in the analysis work. One of the laboratory assistants describes the kind of task the calculation of results was in the last years of the 1960's :

> "It took some 15-20 minutes to calculate the concentrations of one sample. But it was quite easy compared to all the handwork that was done in the preparation of the samples already before it. Many chemical separations were made already at that time. The NaJ-detector gave such gentle peaks. You couldn't differentiate many elements with it. For instance in the analysis of mercury, gold had a disturbing peak. It came in exatly the same area. It was a very annoying peak. Then you had to check from another peak what the proportion of gold was and make an additional correction calculation. If you had to make that correction calculation, the time was prolonged to one hour."

Today the computer makes the same calculation in a few seconds. A researcher describes his experiences of this stage of work in the beginning of the 1970's:

> "From the printer we got a list, where the number of pulses of each channel was printed out. There were 2 000 channels at that time. . . incredible lists of figures and you had to try find the peak there. And then you multiplied the channels by hand. Heavens, it was a job (laughing), absolutely absurd work."

In 1972 a Fortran computer program STOAV81 was developed to analyze the gamma spectra of the samples and to calculate concentrations (Rosenberg & Seppä-Lassila 1972). It was a modification of a program published a few years earlier. The spectra were transfered from the multichannel analyzer onto a magnetic tape. The tape was carried to a UNIVAC computer in the main building of the Technical Research Centre, half a kilometer from the Reactor Laboratory. In the program description of STOAV the necessity of automation is described as follows (ibid. p 3):

> "When for instance 30 elements were analyzed, as many as 8 000 figures of six numbers were got per sample. So the normal series of eight samples and eight standards produces 80 000 figures measuring results. It is clear, that it is necessary to remove the handling of such a quantities of results to the computer"

2) Automation of measurements in 1975

The next bottleneck of the analysis process was measuring. A researcher tells :

> "When I was preparing my thesis, I was measuring samples with three different spectrometers. One of them was at the Department of Radiochemistry of the University of Helsinki, two of them here at the Reactor Laboratory in Otaniemi. I went by bus to both places every day, including weekends for months. First I went by bus to the Department of Radiochemistry, changed the sample, then by bus to Otaniemi to change the samples. I did it in the morning and in the night. I got the results of three samples a day with every spectrometer... It was terribly slow and expensive"

In 1975 an automatic sample changer was designed and connected to the spectrometer. The computer program controlling the whole system was made. The capacity of this automatic gammaspectrometer was fourfold compared to the manually handled apparatus (Ruoti & al., 1976).

3) An automatic gammaspectrometer was obtained in 1982. It both measured and calculated the results

A continuous problem was, that the results of the measurements had to be carried to the CYBER 170 computer in an another building for the calculations. In 1980 the decision was made to construct a full-automatic spectrometer that both measures and calculates the results (Vänskä & al., 1983). A Rockwell AIM65 computer was connected to the spectrometer and a new, more advanced version of the STOAV81 program was developed.

With the new apparatus, a new task emerged: the preparation of data. This data includes the necessary information of the samples, elements and the instructions for the measurement and analysis process. The data is normally prepared by the laboratory assistants. In 1984 a still more advanced program for the analysis of spectra and calculation, STOAV84, was developed (Rosenberg & Vänskä, 1985). It included a "data control" program, which detects the possible mistakes of the data given to the computer.

4) The automatic spectrometers are connected to a central computer and terminals in 1988.

In 1988 the six automatic gammaspectrometers were connected to a new central computer and terminals. A few improvements in efficiency were gained. Calculation became quicker. All raw data of measurements are now recorded into the memory of the central computer and recalculations can be done. The process can be controlled by the terminal-screens during the measurement. Different kinds of output formulas can easily be written out for different purposes.

It is a paradox that once the ambitious work of the automation of NAA was completed, the use of the method began to decrease.

6. The commercialization of research : "the good old days" lost

In the previous chapters, three kinds of developmental processes of NAA-work have been described. : 1) the changing objects of research in environmental and geological research, 2) the development of automation and 3) the change in the financial basis of the work. These components of development are interrelated. Economic pressures had an impact on the quick and deliberate automation, as well as on the necessity of mass analytics in the beginning of the 1980's. They also determined, what kind of samples were searched for, e.g. those suitable for mass analytics.

How did this process influence work in the laboratory? At least three aspects can be mentioned: the nature of the collaboration with outside researchers, the share of 'chemistry' in the work, and the the role of developmental work.

When its activity began, the Reactor Laboratory held a strong ideal of service. The reactor is a national property, and as many users as possible should be able to utilize its unique possibilities. This idea was realized in analytics in the free collaboration of researchers. Very many different kinds of problems were solved, without any selection. The other side of this collaboration was the variety and the constant developmental nature of the work. Two researchers describe the work in the 1970's (Rosenberg & Lakomaa, 1983:11) :"When a problem was brought to the group to detect some element in some type of sample, the method was developed. The samples were analyzed, and a new problem was brought and this in turn was solved". Such collaboration was no longer possible in the 1980's, because an outside researcher had to pay for the analytical services.

Another aspect of the early work was the frequent use of chemical separations as a part of NAA. With the orientation to profitable long series of samples based on efficient use of instrumental activation analysis, the number of chemical separations decreased radically. The reason was again evident. Chemical separations are time-consuming and expensive. One of the researchers explains: "They are expensive compared to direct detections. Nobody is prepared to pay the price, although we would like to do them." Both the researchers and laboratory assistants wanted to do more chemistry. It is an essential part of their education and it is fun compared to instrumental analysis, which is mostly done in a routine way once the method has been developed.

The early stage of NAA gained in the minds of the researchers a nostalgic tone of "the good old days". "It was fun. The old good days. . . there could be four researchers and the laboratory assistants in the laboratory at the same time developing some special methods. . . (. . .). . . for something that happened to be the problem. It was an action-packed time."

The changing financial realities lead to a redefinition of research in the laboratory. The former "academic conception" of research, oriented freely according to interesting and important problems, changed into a conception, in which the necessity of the acquisition of money became ever more important. This was expressed in various and contradictory ways during the interviews. A researcher, whose dissertation had been in the field of biomedicine, says in 1987 when speaking of the future possibilities of NAA:

> "There are of course these medical applications. . . But they are so marginal from the point of view of finance, that we have not invested much in them. I have done collaboration with a few physicians. We have contacts but it is maybe more of a hobby or a secondary work here."

In a way, only economically profitable research is considered as "real research" in the laboratory. Maybe we can see in the development of NAA in the Reactor Laboratory, the process that Jean-Francois Lyotard (1985: 82) has described in his analysis of knowledge in the postmodern society. Lyotard says that the prior question is no longer "is this true" but "for what can this be used." The latter question, when connected to the commercialization of knowledge, means in most cases "can this be sold?".

The researcher responsible for the development of automatic NAA is bitter about this development, when comparing the situation of this group with other NAA groups. He says he is envious of the groups with state budget financing. The development of automatic instrumental activation analysis in the Reactor Laboratory is internationally unique (see e.g. Revel 1987), but it could secure only four commercially profitable years - and even these because of the gold exploration boom. From the "functional point" of view, the 'right' or 'natural' way of using NAA would be on difficult problems, i.e. analyses of rare elements not accessible to other methods. "But it is expensive and in no way profitable".

He also expresses that in terms of publication activity and dissertations made, the activity analysis group is of high quality. In an international comparision the most cited articles in the "Journal of Radiochemical and Nuclear Chemistry" came from Finland (Braun & Schubert 1990,181). Of the twenty articles written by Finns in this journal, ten were written by researchers of the Reactor Laboratory. Of the eleven researchers working in the analytic section since the 1960's, eigth defended their doctoral thesis. But, the researcher thinks, financial results are appreciated above all in the Research Centre.

7. The automation of the NAA and the work of the laboratory assistants

Every stage in the automation of the NAA has influenced the work of the laboratory assistants. These influences can be best analyzed by following the stages of automation presented above.

The automation of calculation (1972) and measurement (1975) meant a radical reduction of laborous and relatively monotonous tasks, which in the case of calculations demanded very alert attention to control the quality of results.

The influence of the full-automatic gammaspectrometer, developed in the beginning of the 1980's, was more complex. In 1982-1985 the two main types of routine instrumental analysis were the epithermal analysis of geological samples (mainly for gold) and the analysis of lanthanides from rock samples. These analyses were always made in the same way. They were called 'routine analyses'. From the point of view of service analytics 'routine' meant effectiveness and reliability of the results. From the assistant's point of view it meant an unexchangeable, repetitive procedure of two or five weeks. The research assistants expressed (as researchers did) that they would like to do more chemistry. But the big series of instrumental routine analysis took up a major part of their time.

On the other hand, this stage of automation removed the control of the whole process more and more from the researchers to the laboratory assistants. Control measures in the instrumental NAA include:

1. The preparation of the data that control the processes of measurement and calculation
2. Checking the calibrations of the spectrometer
3. Studying the results immediately after the measurement has begun

The last measure includes checking that the results of standards and first samples are 'normal', that the so-called dead times of the detector are not excessive, that the forms of the peaks are within acceptable limits, ect. If there is something exceptional, something has to be done and quickly, because otherwise the measurement of the whole series of samples will fail. The significance of control and the search for mistakes has strongly increased. A laboratory assistant explains:

> "If there is some mistake left - it begins to go wrong - you have to realize it immediately. When everything is automatic and mechanical, if you don't notice the mistake immediately, its is possible that you get completely mistaken results for a week or for even a month. If they are unique samples, they are lost. Automation naturally diminishes handwork, but the demand of know-how increases (......) You have to know what you are calculating (...) In the manual phase it was the rough share of the work that was left to the laboratory assistants .. Now we really check that there are no mistakes."

A group consisting of one researcher and the laboratory assistants was formed in 1982. It was responsible for the service analyses. The researcher described what happened: "I have taught them to understand .. this whole system, what it is all about. After you have understood, you can also control better .. the checking of these control samples, the checking of dead times etc.."

After 1986-1988 the situation has changed again. The amount of geological samples has diminished drastically and the laboratory assistants do smaller, more various analyses. The automatic system cannot be fully utilized in these analyses, which are small and unique. The procedure must be decided every time again, and the preparation of samples and standards takes more time. The work is again more varied - and the services more expensive.

8. The division of labor between the researchers and the laboratory assistants.

The content of the work of the research assistants is naturally dependent on the division of labor between the researchers and the assistants. As described above, the assistants have gained more independent responsibility for the routine analysis through NAA. On the other hand, the research assistants do not participate in the development of the new methods (RIS and SIMS). So it could be said that the extensive and well established know-how of NAA has been transmitted to the assistants to be used in service analytics.

But how has the know-how of the procedures, developed for hundreds of types of samples, been transmitted in the group ? There are three methods:

1) Publications
2) Tradition transmitted by daily speech communication
3) The blue notebooks

The procedures are described in the publications and in reports of the smaller research projects. But mostly, only results of the service analyses are documented.

There is a very strong tradition of communality in the group. No noticeable hierarchical differences can be seen between researchers and laboratory assistants. The group has a tradition of having a common coffee meeting every morning. In this meeting the tasks and problems of the day are discussed. Constant communication takes place. Those who are starting to analyze a certain kind of sample ask those who have analyzed such samples before. As a rule, when a new kind of (not surely known) sample is recieved, the assistant always asks the researcher what to do and the researcher makes a decision or suggestion of the procedure used in the analysis.

The research assistants have an instrument of their own to transmit know-how, "the blue notebook". Every time they make an analysis of a certain type of sample, they write down the procedure and everything problematic and noteworthy happening during the process. Every time a similar sample should be analyzed, they can consult their blue notebooks. With their notebooks, the laboratory assistants also can transmit know-how to each other.

The notebook has had its role in the development of procedures and methods too. Traditionally, the organization for the development of a new procedure is the researcher-assistant pair. The work proceeds in the following way :

1) The researcher either a) searches for the method (procedure) from the literature or b) makes an assumption about a good procedure on the basis of her experience and knowledge.
2) She gives the instruction in the form of a handwritten paper or a microcomputer printout to the laboratory assistant.
3) The laboratory assistant tests the procedure and writes down in her notebook what happens, especially the failures and the problems.
4) She discusses the reasons of each problem with the researcher — or during a coffee meeting with several researchers. The researcher (or some of the reseachers) suggests a solution.
5) The research assistant tests it.
6) After every phase of the method (procedure) has been tested succesfully, the researcher writes a description of the method used (developed) in the report.

Developmental activities are necessarily collective in collaboration of this kind, because the researcher's instructions are by nature a supposition or hypothesis of the right procedure. But the researcher does not know beforehand the exact composition of the sample. The procedure taken from the literature must often be changed because the sample or the circumstances differ in some respect. The experimentation inherent in elemental analysis of real samples is realized here in a collaboration and in dialogue between the researcher and research assistant. One of the researchers describes how a problem was resolved:

> "We had a big project in a nuclear power plant. We had to detect a few radionuclides from the wall of the primary pipe. P made the analysis, I directed. ..it involved quite coplex chemistry and other complexities .. I took the recipes from the literature and gave them to P and asked her to try them. When it was ready the recipe was not at all the same as it was in the book (laughing). There were millions of things to change and to develop in it. It was a very interesting interaction. It took three months (. . .) But how such a division of labour is formed, .. it is the result of a long process. It

is not necessarily formed actively.., rather by its own logic".

The contribution of the participants to this kind of collaboration is hard to define. The division of labour and responsibility between the researcher and the laboratory assistant can be discussed, but "it is an obscure thing, where the boundary lies", says the researcher. It is something that cannot be defined in a job description. Rather it is constantly constructed in mutual interaction. This is an example of the "shared cognition" described in the psychological and anthropological studies of work processes (Hutchins, 1988).

But let us return to the blue notebook. Its significance for the development is evident. The results of the experimentation are written down in it. The researcher can use it when writing the results or the report. At first it evidently was the laboratory assistants' way of remembering the procedures. But it has changed into an instrument of collective development and transmission of know-how as well.

9. On the concept of scientific research

It is hardly possible to have any unifying theory of science other than studying the diversity of problems and developments of different fields of the scientific endeavor itself. "Science does not speak with one voice today", says the chemist Peter Markl (1990). The researchers of the analytical section of the Reactor Laboratory explained that in analytics, research means the development of new methods.

The development of methods is scientific research, because the advancement of science is more and more dependent on the development of methods and devices and because new natural phenomena are used and studied when developing methods as well:

"The creative capacity can be used in many ways. In my opinion, behind the scientific merits, for instance the Nobel prizes - the importance of apparatuses and the development of apparatuses is increasing. I think that the development of some apparatus expresses at least as much creativity as doing research. At least there are no differences of value - it is positive. In my opinion the Nobel prize could well be given to the developer of tomography, which makes a short and painless study of human organs possible."

"When methods are developed, that, if anything ,is research. Because then you are obliged to use new basic phenomena that have not been used before for such purposes. For instance laser resonance spectroscopy (. . .) The phenomenon is that the valence electrons of atoms can be exited selectively, resonantly, and that this can be used in analytics, in other words ionizing only the atoms of one element. And how this is transferable into an analytic method. In my view,that, if anything, is research. .... And in the case of SIMS there is a phenomenon of ion sputtering when bombarding the surface. But what is needed to use that phenomenon in analytics? (. . .) This, in my view, is basic research".

I think these statements are essential in many respects. The extremely rapid development of new analytical methods and apparatuses - and new kinds of combinations of them: systems of analysis - is maybe the most striking feature of the development of analytics (Hulanicki, 1986).

As a matter of fact, Derek de Solla Price, for instance, called for a philosophy of scientific instruments in his late writings (1980; 1984). He states that scientific progress is essentially dependent on the development of scientific instrumentalities - a neglected theme in the cognitively biased history of science. He analyzes how, very often, both the new results and the technique that yields them have been born in the research process (1984, 13). He further analyzes the nature of "a high proportion of the world's most cited scientific papers that come under the category of "method papers" (p. 15). What is their status? Can they be distinguished from the apparatuses and procedures to which they refer? Are they not the results of science? If they are, why should the apparatuses and procedures to which they refer not be results of science as well? Is it essential to make a distinction between statements, physical models, and apparatuses and procedures? Are they not all cultural artefacts produced by intelligent human activity to understand, study further and influence reality?

One aspect of the instrumentality in analytic chemistry is the relationship between the development of methods and the problems. In many cases the methods are developed to study specific real objects. Henrik Lundgård, the father of flame spectroscopy analysis, was a Swedish botanist who needed a good method to study plant roots and the combination of nutritive substances in soil (Nygård & Petterson, 1990). Nowadays the production of scientific instruments is a specialized and growing field of industry. An economist, Eric Von Hippel (1988;13) has demonstrated in his *Sources of Innovation* that the *advanced users* made 77 % of the decisive innovations in the field of scientific instruments.

In the social studies of science the particular, local and occasioned nature of scientific work and results has been emphasized (Knorr-Cetina, 1983). It has been asked, whether it is possible to find any general or universal (objective) basis of knowledge any more. But maybe the basis of generality and objectiveness can be found in the common instrumental basis and cultural intermediation of the work and its results - not in any abstract ideal of scientific method in general. In analytical chemistry, for instance, the locality of the results is minimized by measuring the same samples with different methods in different laboratories and by using international reference standards. This activity could well be compared with international standardization. They are material means which create general societality.

Peter Markl has analysed the possible contribution of analytic chemistry to the problems of epistemology. He describes the cultural evolution of instruments by saying that they are "new sense organs" He states (1990: 171): "Seen from the evolutionary perspective we have tremendously enlarged the variety of sensors we can use for actively seeking information". He takes an epistemological position of moderate realism according to which our picture of reality is caused both by historically developing instruments or "projection methods" and by objective reality. Such contributions — based on the analysis of concrete developments of a field of science — are important in the dialoge needed in the social studies of science.

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