# PIXE and Other Applications of Nuclear Physics

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# PIXE AND OTHER APPLICATIONS OF NUCLEAR PHYSICS

R. AKSELSSON AND THE PIXE-GROUP

THE PIXE-PART OF THE REPORT FROM THE DEPARTMENT OF NUCLEAR PHYSICS, UNIVERSITY OF LUND AND LUND INSTITUTE OF TECHNOLOGY, SEPTEMBER 1978.

# 4 PIXE AND OTHER APPLICATIONS OF NUCLEAR PHYSICS

A project at the Department of Nuclear Physics, Lund, Institute of Technology, partly supported by NFR through the contacts

1. F7487-004 Roland Akselsson salary for RA

2. F7487-005 Roland Akselsson material

and indirectly through

3. 02-056, 02-057 Sven A E Johansson, salaries and material partly covering the expenses for research at the Pelletron laboratory.

Table of contents - see appendix 1.

## I Introduction

PIXE is the acronym for Particle Induced X-ray Emission Analysis. In this method for trace element analysis, MeV particles bombard the sample to be analysed. Characteristic X-rays are induced, which are detected with an energy-dispersive high-resolution detector, e.g. a Si(Li)-detector. PIXE is a fast multielemental method with very low detection limits in small samples. For elements lighter than sulphur, absorption in the sample makes the quantification uncertain or impossible. However, there are nuclear methods, which may be used simultaneously to PIXE, giving the mass of low-Z elements.

The properties of PIXE mentioned above, including those of complementing nuclear methods, make the PIXE method unique among methods for elemental analysis. New types of important experiments e.g. in the domains of environmental health, biology and technique may be planned and performed, if PIXE is fully developed and used. However, then physicists have to 1) further develop the method, 2) be responsible for the analysis at least in the introductory period and

3) cooperate with scientists from other fields pointing out the possibilities of PIXE and actively taking part in planning, sampling and analysis. The last point is important because PIXE has special properties which make it strong - when those properties are used.

There are very good conditions for a successful PIXE-programme in Lund, if NFR supports an active group of physicists around PIXE.

The activities of the PIXE-group may be divided in the programme for applied nuclear and atomic physics and the programme for technical hygiene. In this report the emphasis is laid on the first programme, as it is the part under expert evaluation.

## II History with the most important results

In 1970 the Lund-group was publishing the first brief paper about PIXE /Ref 1/. Another paper from the same group /Ref 3/ pointed out fields of applications. In exploration of the basic properties of PIXE, the variation of K-ionization cross section with protonenergy and atomic number were carefully investigated and a universal expression for these cross sections was derived /Ref 6/. Such a formula is very useful for computor evaluation of masses of elements in thin samples because in calibration of the analysis system the formula allows us to interpolate and extrapolate from a few elements analyzed at one energy. A key component in the analysis is the computer unravelling of the pulse height spectrum. This procedure should be fast, accurate and should normally not require interaction with an operator. Kaufmann and Akselsson designed a first version of such a programme, which used a physical model of the processes taking place in the detector /Ref 34/. The universal formula is still more important for thick sample analysis, a field also thoroughly evaluated at our laboratory /Ref 20/. Many important procedures for accurate analysis have been presented e g beam mapping /Ref 2/, elimination of charging /Ref 25/ and mass calibration /Ref 70/. The unique possibilities offered by an accelerator laboratory in allowing simultaneous use of particle elastic scattering analysis, nuclear reaction and PIXE have been partly explored /Refs 5, 27, 87, 101/ and already the $^{19}F\ (p,\alpha\gamma)^{16}O$ reactions is routinely in use simultaneous to PIXE in our laboratory. An extensive review of PIXE is given by Johansson and Johansson /Ref 50/.

As seen from the list of publications (Chapter VI), a considerable amount of work has been carried out by members of the PIXE-group in Lund concerning transport of airborne particulates and concerning welding aerosols. In these fields multielemental analysis of many samples is necessary and it is a great advantage, if small samples are sufficient for accurate results. Thus, PIXE has opened new possibilities for important research in fields of environmental hygiene /Refs 8, 9, 14, 15, 19, 28, 42, 43, 49, 51, 52, 56, 59, 62, 78, 81-84, 86-88, 102, 105, 106, 110, 112, 113/.

A single orifice cascade impactor has been found which gives size-fractionated aerosol samples, suitable for PIXE-analyses. The impactor is of Battelle design, however it has been modified to include one impactor stage more, to include an after-filter for the smallest particles (<0.25µm aerodynamic diameter), and to have two stages rotating eccentrically in order to spread the sample on a larger area.

Another sampler, which has been used and will be used, is the "streaker". It is a long filter with a moving, small, sucking orifice arranged to give time resolution (2h resolution and about one week per sample). This sampler is designed at Florida State University especially for PIXE analysis.

In aerosols generated in welding on stainless steel insoluble chromium VI is a key factor for health effects. In the project "Characterization of Welding Aerosols", we have developed a procedure for quantification of soluble and insoluble chromium VI as well as soluble and insoluble chromium III /Ref 108/. ESCA, TEM, the DPC-method and PIXE are used in this procedure.

Although the accelerator change in Lund 1974-1976 hampered our activities considerably for almost three years, we now have a laboratory well suited for applications. The status of current arrangement is reported in appendix 2.

Many useful international contacts have been created. The First International Conference on PIXE and its Applications was held in Lund, August 23-26, 1976. Many researchers from different parts of the world have visited our laboratory for longer or shorter periods. Likewise, members of the PIXE-group have visited many PIXE laboratoires and participated in many conferences.

## III Economy 77/78

The activities of the PIXE-group were supported 77/78 by

| | |
|---|---|
| 1. NFR (The Swedish National Science Research Council) by contract | |
| F 7487-004 - salary for Roland Akselsson | 100 kkr |
| F 7487-005 - material, travels | 6 kkr |
| and indirectly by | |
| 02-056 - research at the Pelletron and VdG laboratories in Lund | |
| 2. ASF (The Swedish Work Environmental Fund) | |
| 74/109:5 - airborne particulates from welding operations | 305 kkr |
| 3. SNV (The National Swedish Environment Protection Board) | |
| 7-147/77 - aerosol composition | 75 kkr |
| 7-303/77 - multivariate statistical analysis of aerosol data | 25 kkr |
| 4. Miscellaneous sources (for special applications) approximatively | 60 kkr |

In addition, basic facilities and some important service functions from the University of Lund have been used. The Department of Environmental Health has contributed with salaries corresponding to about 1 man/year. The lack of support for work

## IV Status, September 1978

### a) Persons engaged in the PIXE-group

| Member of the PIXE-group | Titles | | Engagement in PIXE-work | Main source of salary * |
|---|---|---|---|---|
| Mats Ahlberg | Tekn dr | Res assoc | 1/2 | Dept of Env Health |
| Roland Akselsson | Ph D | Researcher, NFR | 1/1 | NFR |
| Erling Andersson | - | Student | parttime | - |
| Mats Bohgard | Civ ing | Grad stud | 1/1 | PIXE-group |
| Lars Eric Carlsson | Civ ing | Grad stud | 1/1 | PIXE-group |
| Hans Christer Hansson | Civ ing | Grad stud | 1/1 | SNV |
| Eva Marta Johansson | - | Student | 1/2 | PIXE-group |
| Gerd Johansson | Civ ing | Grad stud | 1/1 | ASF |
| Katarina Johansson | B S | Staff (chemistry) | 1/2 | ASF |
| Sven Johansson | Ph D | Professor | parttime | LTH |
| Erik Karlsson | Ing | Staff (electr) | parttime | LTH |
| Hans Lannefors | Civ ing | Grad stud | 1/1 | SNV |
| Klas Malmqvist | Civ ing | Grad stud | 1/1 | ASF |
| Bengt Martinsson | - | Student | parttime | - |
| Jan Pallon | Civ ing | Grad stud | 1/2 | PIXE-group |
| Bertil Rudell | Civ ing | Grad stud | 1/2 | Dept of Env Health |
| Knut Sjöberg | Staff (mechanics) | | 3/4 | LTH |
| Leif Spanier | Civ ing | Grad stud | - | - |

* NFR Swedish Natural Science Research Council
SNV National Swedish Environment Protection Board
ASF Swedish Work Environment Fund
LTH Lund Institute of Technology

Only Professor Sven Johansson, Mr Erik Karlsson and Mr Knut Sjöberg have permanent positions.

b) Experimental arrangements - see appendix 2.

c) Applications

PIXE is a method especially suitable for detecting small amounts of elements in small samples. Other features of PIXE are its multielemental character and its speed. These properties make it very favourable to use PIXE in investigations of airborne particles, because in field measurements it is desirable to have small sampling devices and because often a large number of samples has to be analysed for several elements. In projects supported by the Swedish Work Environmental Fund, the National Swedish Environment Protection Board and others, 1 l/min single-orifice cascade impactors are used for size fractionation.

Analysis of trace elements in water is another field of great promise. Some preliminary investigations indicate that detection limit in the 0.01 - 1 ppb range may be obtained for several elements. Procedures have to be optimized and consolidated.

Biological samples constitute a third type of samples which may be analysed by PIXE. In an investigation concerning the lead content in teeth of children, the possibility to guarantee a narrow beam has proved to be very advantageous.

Summaries of several applied projects in progress are given in appendix 3.

## V Plans (Letter of intent)

a) Objectives of the PIXE-group in Lund

The objectives of the PIXE-group is to develop and apply the unique possibilities, which an accelerator laboratorium offers for trace elemental analyses of high priority in fields as technology, environmental hygiene, medicine and biology. Another important goal is to train physicists. The volume of this training-programme has to be in some harmony with the labour-market for doctors.

The activities of the PIXE-group may be divided in two programmes - on one side "PIXE research and development" and on the other side "Technical Hygiene". The same persons, with a few exceptions, are engaged in the two programmes today, but as the tasks get more complex, it may be feasible and necessary with further specialization.

b) The programme for PIXE research and development

In the following fourteen paragraphs fourteen important projects are briefly presented.

1. One of the major advantages with PIXE compared to other X-ray methods, is the possibility of simultaneous backscattering analysis (PESA - Particle Elastic Scattering Analysis). The mass resolution of PESA is not good for 2.5 MeV protons, but it improves considerably if α-particles are used. Such a change should not significantly impair the properties of PIXE. Backscattering would increase the number of analysed elements per run and also give information about the total mass of the sample. This information (mass/cm$^2$) is also of great value in evaluating the PIXE-spectrum. During the autumn 1978, α-particles may be obtained from the Pelletron. Then we plan to optimize the α-particle energy and the analyzing arrangement for combined PIXE/PESA analysis. The usefulness of other nuclear reaction will also be investigated. There is also a challenging task in developing a computor-programme for fast and accurate unravelling of backscattering pulse-height spectra.

2. Another unique advantage of PIXE is the possiblity of focusing the beam to obtain low detection limits in 10μm samples. By cooperation with the Department of Physical Biology in Uppsala, a microbeam arrangement is planned to be set up during 1978/79 in Lund. The halo-effect will be studied and minimized. Feasibility tests for several applications are also planned.

3. For some applications the resolution of semiconductor detectors is not sufficiently good. Then at low X-ray energies chrystal spectrometers may be useful. Design and construciton of a curved chrystal spectrometer has started and will be finished during 1979. The first version will be used to study L- and M-line relative intensities in the 3-7 keV range. These values are crucial for the resolution of pulse-height spectra. The variation of these intensities as a function of particle energy is also interesting from a theoretical point of view. The chrystal spectrometer may also be used to resolve interferences in routine PIXE/PESA analysis. The combination of microbeam and curved chrystal may offer further advantages, since chrystal spectrometry is favourable for point sources.

4. With another chrystal still lower X-ray energies may be detected. Then it will be interesting to investigate energy shifts and identify them with the chemical compounds of the sample. It is often very important to know the chemical compounds in samples especially in biological samples and it may be possible to obtain some information from PIXE-runs about that.

5. Bremsstrahlung and characteristic X-rays from the backing is often a limiting factor. By using chrystaline material as backing and by mounting the sample in certain angles these bothering contributions may be significantly reduced. Some preliminary investigations will be done during 78/79.

6. X-ray absorption and particle slowing-down effects may be significant and good corrections are crucial for the accuracy of analysis. Helpful information may be obtained from the continuous part of the X-ray spectra and from the PESA-spectrum. Such information may also be obtained in separate runs, where the transmission of the sample for certain X-ray energies is measured. We plan to do systematic investigation of absorption and slowing-down effects.

7. Today PIXE is used mostly at proton energies above 1.5 MeV. However, although the cross sections are lower at lower energies, it may be feasible to use lower proton energies in certain cases, e g for elements having X-rays in the 2-3 keV range. Also smaller accelerators may be used, which implies lower cost and a wider use of PIXE. Since there is a lack of basic information about cross sections for X-ray production and bremsstrahlung production for 0.6-1.2 MeV protons, we plan to investigate these areas and survey the properties of PIXE at low proton energies.

8. A larger detector is ordered and a closer geometry will be arranged in order to achieve lower detection limits with less intense beams.

9. An on-line computor and an off-line computor will be ordered during the fiscal year 78/79. Then there will be a strong need for designing procedures for efficient analysis giving maximum information per time unit. Almost all the projects mentioned above (IV b 1-8) involve computor routines. The count rate from the different detectors (X-ray detector, particle detector and the chrystal spectrometer) should be optimized automatically and the parameters registered by the computor. All the information obtained should be synthesized in the final calculations of the sample composition. For some applications it is crucial to implement further effects in the physical model, which forms the base for the computor programme currently used for pulseheight spectrum resolution. Such effects are e.g. particle slowing-down, pile-up tails on the peaks in the spectra.

10. By mixing complexbinding compounds into water, adsorb the complexes on active carbon, filter off the carbon and make pellets of the carbon, detection limits in the range of 0.01 to 1 ppb are obtained for several elements. We plan to optimize the technique for different kind of water and measure the yield for different element. Also, it would be desirable to modify the technique,as only small volumes

of water is needed, for other liquids in limited supply.

11. Detection limits on small samples of protons should be investigated since 1) many biochemical fractionating techniques give small amounts of proteins in certain fractions, for which elemental information is of great interest 2) in the study of metabolism as well as in biological sampling (an interesting manner to obtain information about health hazards due to exposure), elemental analysis of small protein samples is often required.

12. Elemental concentrations in saliva from exposed welders will be analysed to investigate the feasibility of saliva as an indicator of retention.

13. Microbeam applications are planned in cooperation with the Department of Physical Biology, Uppsala (Ulf Lind - biological samples) and FOA (Lars Henrik Andersson - 10µm particles).

14. An investigation of the applicability of nuclear and X-ray techniques to analysis of mineralogic samples is planned in cooperation with Svenska Gruvföreningen and Boliden Metall AB.

c) The programme for technical hygiene

As this part is outside the area under evaluation, only a brief listing of planned projects will be given.

1. We plan to test and further modify our cascade impactor in order to get the loading on the last stages spread out on a larger area. This would decrease bounce-off effects and also allow longer sampling times without introducing problems with too thick samples. As mentioned above, a prototype is already built and is partly in use.

2. Using our experiences of the Tallahassee-streaker, we plan to design a sampling device giving size fractionation (two fractions) and time resolution. By using PIXE for the analysis it should be possible to design a small, maybe

portable, sampler with 15 minutes resolution for work environment and an outdoor sampler which could be steered by weather conditions or a clock.

3. In order to test the efficiency of sampling devices, a good facility for aerosol generation should be provided.

4. We plan to follow up the project "welding aerosol characterization" with cooperative projects in which welding procedures are optimized. In such optimizations weld quality, economy and work environment should be taken into consideration.

5. Long range transport of airborne particulates.

6. Variation in urban aerosol composition. Sampling strategy will be considered in the first phase.

7. Special applications of trace elemental water analysis.

8. Continued cooperation with the Department of Environmental Health, e g in studies of lung deposition and toxicology.

d) Proposals for NFR

PIXE has been applied to analysis of sampled airborne particulates since several years and the feasibility of PIXE for this kind of samples is well established. As seen above there are several research and developmental projects planned which could further strengthen the power of accelerator-based trace elemental analysis. These methods for trace elemental analysis offer unique characteristics which make new types of important investigations possible.

The potential for further meaningful development is one strong reason for NFR to support the programme for PIXE research and development. Another reason is that such a support would be beneficial and probably necessary for a successful programme for technical hygiene as PIXE still is new as a method for trace element analysis.

To assure a progressing programme for PIXE research and development, we suggest NFR to support a person (e g 1:e forskn ing from July 1980) who would be responsible for the analysing system and the development of computor routines as mentioned in section IV b 9.

For electronics, chemicals, standards, material, travel, temporary hands, we ask for 100 000 Sw cr/year.

There is also a need for at least some basic aerosol research in Sweden, because there are many projects going on in which aerosol sampling and/or measurements take place. The programme of technical hygiene may be well suited as an embryo. Because of symbiotic reactions between the programmes, a development of the technical hygiene programme to include basic aerosol physics would guarantee high quality, ambient and work environment aerosol investigations and an efficient use of the analytical capability of the PIXE-method. We suggest that our visiting committee should urge NFR to investigate these ideas.

## Appendix 1

## Table of contents

PIXE and other applications to Nuclear Physics to trace elemental analysis.



References 1, 3, 6, 33, 34, 38, 50, 70, 82, 102 and 108 are enclosed.

## Appendix 2

## Experimental arrangements

In the currently used routines for PIXE analyses at the Pelletron laboratory in Lund, Sweden, 2.5 MeV protons are used. The beam is made uniform by an aluminium diffuser foil, with thickness of 6 µm, placed about 50 cm before the sample. Carbon Collimators of different diameters may be rotated in the beam position, such that a homogeneous beam of a diameter of about 3, 4, 5, 6, 7 and 9 mm may be obtained. X-rays are detected in 135$^{o}$ and the sample is oriented so that the angel between the proton beam and the sample normal as well as the angle between the sample normal and the detected X-rays are 22.5$^{o}$. The collimator nearest the sample is held at a positive potential (+30V) to keep secondary electrons from the collimator from entering the Faraday cup. An electron suppressor at -50V is inserted between the +30V-collimator and the sample to stop secondary electrons from the sample from escaping backwards through the collimator. The linearity of the current integration has been tested from 0.5 nA to 200 nA.

The X-rays from the sample pass an optional absorber, a 6 µm Mylar window of the sample chamber and a 13 µm Be-window of the detector-house before reaching the detector. The Si(Li)-detector used has an area of 10 mm$^2$ and a depth of 3 mm. The resolution is about 175 eV at 6.4 keV. The pulseheight spectra recorded on a ND 4420 are written on magnetic tape and unravelled by a computor program, HEX, at the main computer center of Lund (Univac 1108).

Samples are mounted in slideframes (2" x 2") and loaded in a box with space for 40 slides. By a pushbutton at the operator's desk, samples may be changed.

In routine analysis the beamtime per sample is 2 - 4 minutes with a countrate of 1000 pulses/s. To be able to increase the countrate and decrease the beamtime/sample a fast deflection system has been constructed and it is now being tested. The rise-time of the 1000V deflection pulse is 30 ns.

For biological samples we have extracted the beam to an air or nitrogen filled chamber. A Kaptonfoil with a thickness of 7.5μm is used as an exit window.

Fluorine is measured simultaneously with the PIXE-analysis by detection of γ-rays from the reaction $^{19}F(p,\alpha\gamma)^{16}O$. A 5" x 4" NaI crystal is used and the detection limit is about 50 ng in our set up.

To get information about the low Z elements in the sample a silicon detector for backscattered protons has been mounted in the chamber. It is situated in $155^{o}$ and the area used is 3 $mm^2$. The full width at half maximum of the system for 3.72 MeV protons is 27 keV. The prelimunary choice of particle and particle energy for excitation (2.5 MeV protons) may be changed to increase the information from the backscattering.

In analysing thick nonconducting samples their charging introduces a severe increase of bremsstrahlung. A carbon filament with a grid for suppressing positive ions is included in the system. This solves the charging problem without introducing any noticeable contamination.

## Appendix 3

## Summaries of Current Applied Projects

## September 1978

## Characterization of welding aerosols

### Introduction

The electric arc welding is a common method in industry. Welding aerosols, some of which may be hazardous, are formed during the welding. We are characterizing such aerosols by a reproducable sampling procedure and subsequent elemental analysis. By varying the welding current and voltage, information is gained about the particle formation processes in the welding processes.

### Method

The welding aerosol produced is collected in a hood. Samples are taken for elemental and gravimetric analysis as well as particle size analysis. The elemental analysis is performed with the PIXE-method and simultaneous nuclear methods.

### Results

The welding parameters play an important role in the aerosol formation and will affect the particle size distribution as well as the elemental composition. The most common elements are F, K, Ca, Ti, Cr, Mn, Fe, Ni and Zn, but the composition is very dependent on the method used.

As most aerosol particles have an aerodynamic diameter in the interval 0.05-2 μm most of the aerosol may be deposited in the lung with its slow clearance rate. Finally the work so far havs demonstrated that the PIXE-method is highly suitable for this kind of work.

Characterization of airborne dust from metal spraying processes

In metal spraying a material is heated to a molten condition and deposited to a workpiece by a high velocity gas stream It can be used to produce coatings with high corrosion and wear resistance.

The health hazards, due to inhalation of the fume produced by the process, depends on the particle size distribution of the aerosol, the chemical composition of the particles and the dust concentration in the breathing zone of the workers. Metals, which can form cancerogenic compounds, as chromium and nickel,often exceed the hygienic threshold limit values.

PIXE is a superior method to determine the elemental composition of the small size - fractionated samples from a Battelle impactor and its multielemental nature make it possible to reveal unexpected elements in the fume.

When the fume contains chromium, the oxidation state is of importance for toxicity evaluations. Electron Spectroscopy for Chemical Analysis (ESCA) and spectrophotometry are used as complements to PIXE. The multielemental nature of PIXE is essential to eliminate the interferences from other elements in the samples.

The analytical techniques developed in this project, with PIXE as the basic method, can be used in the health hazard assessments of existing and coming processes in metallurgy where toxic fumes is expected.

Airborne particulates in ambient air

Studies of the composition of the atmospheric aerosol are of basic importance for judging the air quality. Adverse effects on both man and the environment from airpollution are well established facts for several elements in heavily polluted areas. To prevent future damage, a great need for measurements of different components in the atmospheric aerosol has come up. The atmospheric aerosol consists of several components, both with a natural and an atmospheric origin. Our interest is focused on the elemental composition of the airborne particles. Conclusions on dominating sources, transportation properties and possible medical effects of the aerosol could be drawn when the elemental concentrations on different particel sizes are known.

Using a single-orifice cascade impactor of Battelle-design, the aerosol particles are collected according to aerodynamic size. The elemental composition on each size-fraction is determined by particle-induced X-ray emission (PIXE) analysis.

Studies on the atmospheric aerosol have so far included measurements on both urban and non-urban sites in the three projects described below. The urban aerosol was studied in a small industrial town (Landskrona) in the southern part of Sweden, using four measuring sites. By correlating the measured elemental concentrations with the winddirections it was concluded that emissions from the industrial area heavily increased the concentrations of the elements S, K, Ca, Ti, V, Mn, Fe, Zn and Pb in the town. Possible sources for all these elements were identified.

At the remote site of Velen in the South of Sweden (lat 59$^{o}$), samples were taken every third day during a one-year cycle. The results indicate a strong dependence of the elemental concentrations on the history of the air-mass. Concentrations are a factor of 5-10 higher when the air has passed over the European continent or Great Britain and Sweden than when coming from north over Norway and Sweden.

The transport of pollutants from Great Britain and the European continent to Sweden has been studied using two sampling sites. One of them was situated at the westcoast and the other at the southcoast of Sweden. The results are now being evaluated.

Multivariate statistical (analytic) methods as cluster analysis and factor analysis, are now used to extract as much information as possible from the results. Conclusions on possible sources in different source areas and the transformation of the particles during their transport are two examples of the potential of these powerful statistical mehtods.

Determination of lead levels in the dentine of teeth using the PIXE method (Environmental Health)

The lead level in the dentine of a tooth is a measure of the lead exposure during the mineralisation of the tooth. Premolar teeth from children raised in cities (Stockholm and Malmö) and a rural area (Jönköping) in Sweden will be analyzed for lead with the PIXE method.

The teeth are split in two halves. One of the uncontaminated surfaces is irradiated with 2.5 MeV protons which are brought out to a nitrogen surrounding through a thin plastic foil (Kapton, 1 mg/cm$^2$) and collimated to a diameter of 1 mm. The number of protons hitting the sample is monitored with a surface barrier detector measuring protons backscattered from the exit foil. The nitrogen surrounding eliminates charging and reduces heating of the tooth. The small dimension of the beam and a moveable target holder assure that the same colume in the middle of the dentine is analysed in every tooth. With a set-up featuring a short detector-sample distance and a thick absorber to eliminate negative effects of the abundant calcium K-radiation a high sensitivity for lead is achieved with a moderate proton current.

Even in this application with only single element determination the PIXE method with simple sample treatment and rapid analysis is favourable. By using peak to background measurements the uncertainties in the concentration determinations are kept very low.

Preliminary results show that lead levels of city teeth are higher than those of rural area teeth. Anyhow, the levels seem to be low compared to those obtained by other investigations in other parts of the world. However, teeth from New York children will be analysed with our procedures to get further material for comparisons.

Lungdeposition (Environmental Health)

Man is exposed to airborne particulates in outdoor air as well as in work environment. Particles may be deposited in the human lung and induce toxic effects. At present, there are intense research activities taking place in many laboratories to study how the deposition depends on different parameters as e.g. particle size. Artificial aerosols, often radioactive, are used in those investigations. Frequently animals are used as models for homo. The low limits of detections given by the PIXE-method make it possible to perform deposition studies with aerosols normally encountered in work environment. This means lower exposure to involved persons and easier interpretation of results.

In this project size-fractionated particles are sampled from inhaled as well as exhaled air, while a welder is breathing welding smoke. The results seem to be in agreement with theoretical models. However, there are discrepancies for particles generated in welding operations using coated electrodes. Those particles are hygroscopic and grow in the high relative humidity of the lungs. At present, the growth of welding particles is studied in atmospheres simulating humidity and temperature of the human lung.

## 7:III PIXE AND OTHER APPLICATIONS OF NUCLEAR PHYSICS

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