ARCAL

ACUERDO REGIONAL DE COOPERACION PARA LA PROMOCION DE LA CIENCIA Y LA TECNOLOGIA NUCLEARES EN AMERICA LATINA Y EL CARIBE

PROPUESTA PARA NUEVO CENTRO DESIGNADO

"LABORATORIO DE ANÁLISIS PIXE Y DETERMINACIÓN GRAVIMÉTRICA DE MUESTRAS DE CONTAMINACIÓN ATMOSFÉRICA"

IX REUNIÓN DEL ÓRGANO DE REPRESENTANTES DE ARCAL (ORA)

VIENA, AUSTRIA
3 DE OCTUBRE DE 2008

ORA 2008-06

OCTUBRE 2008

INTRODUCCION

En atención a la solicitud de México durante la IX Reunión del Órgano de Coordinación Técnica de ARCAL (OCTA) realizada en la Salta, Argentina del 12 al 16 de mayo del 2008, se acordó incluir en las conclusiones y recomendaciones (recomendación No. 16 del Informe Final OCTA 2008) que la Secretaría presentará a aprobación del ORA en su próxima reunión, la documentación del "Laboratorio de Análisis PIXE y Determinación Gravimétrica de Muestras de Contaminación Atmosférica" ubicado dentro de las instalaciones del Instituto de Investigaciones Nucleares (ININ) para ser seleccionado como Centro Designado de ARCAL.

Para la consideración del Órgano de Representantes de ARCAL (ORA), adjunto encontraran todos los datos referentes al Laboratorio de Análisis PIXE y Determinación Gravimétrica de Muestras de Contaminación Atmosférica enviados por México.

A fin de facilitar la labor de aprobación y para fácil referencia también se adjuntan en este documento:

- La lista de los criterios para la selección de los Centros Designados que fueran aprobados durante la última sesión del ORA.

CRITERIOS PARA LA SELECCIÓN DE LOS CENTROS DESIGNADOS POR ARCAL

1. Los centros/instituciones deberán poseer un reconocimiento nacional, regional o internacional en el área (o áreas) seleccionada y en las cuales las actividades nucleares tienen un peso importante. En otras palabras, los países de la región deben reconocer que el referido Centro reúne los requisitos indispensables para que pueda ser utilizado por estos países para realizar la actividad (o actividades) seleccionada.

2. Los Directores de los centros/instituciones identificados deben aceptar que sean presentados como Centros Designados por ARCAL en el área (o áreas) seleccionada.

3. Los centros/instituciones que sean identificados para que sean Centros Designados por ARCAL no requerirán del apoyo financiero del Organismo para iniciar sus actividades. Las actividades o servicios que se ofrezcan deben ser de interés para la región, estar vinculado al uso pacífico de la energía nuclear y estar en correspondencia con las prioridades establecidas en el Plan de Cooperación Regional aprobado.

4. Los centros/instituciones que sean identificados para que sean Centros Designados por ARCAL deben estar en la disposición de prestar sus servicios al programa ARCAL al costo. La ganancia dejada de percibir por este concepto se reportará como aportes del centro y del país al programa ARCAL.

5. Sería conveniente que el centro / institución tenga relación con las actividades del OIEA, o haya sido utilizado por el Organismo de forma regular para la ejecución de cursos o eventos de capacitación, para la ejecución de proyectos en el país, o en otros países, solicitado sus servicios en el marco del Programa de Cooperación Técinca.

3. FORMULARIO PARA SELECCIÓN DE LOS CENTROS DESIGNADOS POR ARCAL

DATOS DEL CENTRO (nombre, dirección completa)
Instituto Nacional de Investigaciones Nucleares (ININ)
Carretera México-Toluca S/N
La Marquesa, Municipio de Ocoyoacac
CP 52750, Estado de México
MÉXICO
Tel: 00-52 55 5329-7345
Fax: 00-52 55 5329-7388

DIRECTOR DEL CENTRO
Dra. Francisca Aldape Ugalde

SERVICIOS O CAPACITACIÓN CONCRETOS OFRECIDOS
***Análisis Gravimétrico**
***Análisis Elemental por la Técnica PIXE.**
***Innovación Tecnológica (producción de partes de colectores y dispositivos para manejo de filtros o de muestras).**
***Asesorías por expertos en estrategias de colección, localización de sitios representativos de monitoreo e implementación de redes de monitoreo, identificación de fuentes contaminantes usando técnicas de análisis estadístico de datos.**
***Participación en ejercicios de intercomparación entre Laboratorios Analíticos involucrados en Estudios de Contaminación de Aire.**

INFRAESTRUCTURA EXISTENTE

A) INSTALACIONES/EQUIPAMIENTO
*** Acelerador de 2MV dedicado a aplicaciones.**
***Línea PIXE y accesorios**
***Cámara "PIXE" marca Atomki con accesorios y dispositivo para uniformizar haz.**
***Cuarto Limpio para gravimetría:**
2 microbalanzas Mod. Cahn 35, Higrotermógrafo, Humidificador, Dehumidificador y calentador.
***4 colectores tipo Gent.**
***2 colectores BGI PQ-200.**
***2 medidores de flujo.**
***2 Reflectómetros.**
***Equipo de Cómputo: 6 computadoras, 4 impresoras, 1 escáner**

B) PERSONAL (cantidad, calificación, etc.)
Investigadores:
2 Investigadores de alto nivel (nivel Doctorado en Ciencias)
1 Investigador (Nivel Licenciatura)
Personal Técnico:
3 Profesionistas (nivel Licenciatura)

Capacitación (Estudiantes):

Un promedio de 3 estudiantes se capacita en el área cada año a nivel lecenciatura, maestría y doctorado.

EXPERIENCIA ALCANZADA EN LOS SERVICIOS O CAPACITACIÓN OFRECIDOS Y BENEFICIOS FUNDAMENTALES OBTENIDOS

*Técnica PIXE fué instalada en el año 2000, esta ha sido validada contra un laboratorio de prestigio internacional (Crocker Nuclear Lab) y calibrada usando estándares de alta pureza (Micromatter). El sistema se verifica por lo menos 2 veces al año.

*Participación en los estudios que dieron lugar a la base científica para la instalación de la Primera Red Oficial para medición de partícula fina ($PM_{2.5}$) de la Ciudad de México por el Gobierno del Distrito Federal.

*En los últimos 6 años el principal usuario ha sido la Secretaria del Medio Ambiente del Gobierno del Distrito Federal a través de Proyectos, Convenios y Contratos.

SERVICIOS PRESTADOS A INSTITUCIONES DEL PAÍS

* COPERA: Consejo de Proyectos y Estudios para la Recuperación Ambiental del Valle de México (1993-1994). Proyecto CO-053: Metales en aerosoles de la Ciudad de México. Ingresos obtenidos: $ 300,000.00.

* Contrato IMP-2706, (1997-1998). Ingresos obtenidos: $334,717.82.

* Convenio: ININ-Consejo Estatal de Ecología del Estado de Hidalgo, (1998). Ingresos obtenidos: $138,549.30.

* Apoyo del Fideicomiso Ambiental del Valle de México a través de la Secretaría de Ecología del Gobierno del Estado de México (1998). Ingresos obtenidos: $150,000.02.

* Proyecto CONACyT No. 3952PT-9608. (1997-1999) Ingresos obtenidos: $120,974.00.

* CONSERVA: Consejo de Estudios para la Restauración y Valoración Ambiental. Proyecto "Estudio Retrospectivo del Indicador Ambiental de Materia Particulada Aerotransportada" (1999). Ingresos obtenidos: $ 357,304.65.

* OIEA: Programa de Cooperación Técnica para América Latina. Bienio 1999-2000, ARCAL XXXIX: Proyecto RLA/7/007. (1999). Ingresos obtenidos: USD$26,250.00.

* OIEA: Programa de Cooperación Técnica para América Latina. Bienio 1999-2000, ARCAL XXXIX: Proyecto RLA/7/007. Ingresos obtenidos: USD$33,112.50.

* CONSERVA: Consejo de Estudios para la Restauración y Valoración Ambiental. Proyecto: "Caracterización de Partículas Aerotransportadas menores a 2.5 micrómetros y determinación de Elementos Tóxicos a la Salud Humana" (2001). Ingresos obtenidos: $ 299,999.93

* Secretaría del Medio Ambiente. Ingresos obtenidos: $999,999.75 (2002).

* OIEA: Evaluation of Airborne Fine Particles in Mexico City (MEX/1/021). Ingresos Asignados: USD$105,310.00 (2003).

* OIEA: "Identificación de fuentes de Partícula Fina en el Área Metropolitana de la Ciudad de México (AMCM) usando Técnicas Nucleares" Proy. Nacional MEX/1/021, 2004-2005, 2005-2006, .Ingresos Asignados: USD$247,034.95 por año.

* OIEA: "Assesment of Atmospheric Pollution by Particles" Proyecto ARCAL LXXX, RLA/7/011, 2005-2007. Ingresos Asignados:

* CONACYT: "Evaluación del comportamiento de las Partículas Finas (PM2.5) en la atmósfera de la Ciudad de Toluca. EDOMEX-2005-C01-01 (2006-2007). Ingresos Asignados:
$399,405.00.

PAÍSES DE LA REGIÓN QUE HAN UTILIZADO LOS SERVICIOS O CAPACITACIÓN OFRECIDOS Y BENEFICIOS FUNDAMENTALES OBTENIDOS

Guatemala: Se capacitó al grupo en estrategias de colección, selección de sitios y el uso adecuado de equipos de colección así como calibración de los mismos.

Cuba: Se capacitó al grupo en estrategias de colección, selección de sitios y el uso adecuado de equipos de colección así como calibración de los mismos.

Bolivia: Se capacitó al grupo en estrategias de colección, selección de sitios y el uso adecuado de equipos de colección así como calibración de los mismos.

OTROS PAÍSES QUE HAN UTILIZADO LOS SERVICIOS O CAPACITACIÓN OFRECIDOS Y BENEFICIOS FUNDAMENTALES OBTENIDOS

UTILIZACIÓN POR PARTE DEL OIEA DE LOS SERVICIOS O CAPACITACIÓN OFRECIDOS

Guatemala: Entrenamiento a personal.

Cuba: Entrenamiento a personal.

Bolivia: Entrenamiento a personal.

IMPACTO QUE HA TENIDO LA UTILIZACIÓN DEL CENTRO EN LOS SERVICIOS O CAPACITACIÓN OFRECIDOS

El personal que ha sido capacitado a puesto en práctica en sus respectivos países los conocimientos adquiridos con éxito.
Los equipos generados por el grupo mexicano han sido puestos en operación en los países de la región a través del OIEA.

NIVEL DE RELACIONES DEL CENTRO CON OTROS DEL PAÍS, DE LA REGIÓN Y FUERA DE LA REGIÓN Satisfactoria. México ha compartido en proyectos con los países de Argentina y Chile. Los 3 países hemos sido considerados como países expertos en el tema.
CONDICIONES PARA LA UTILIZACIÓN DEL CENTRO POR PAÍSES DE LA REGIÓN De acuerdo a los requerimientos de los servicios que se necesiten que serán cotizados al costo directo.
Otros

M. en C. José Raúl Ortiz Magaña
Nombre y firma Director

14 de Mayo de 2007
Fecha

MINUTA EJECUTIVA
Propuesta de MEXICO para un Centro Designado por ARCAL
MEXICO

El grupo PIXE-Aerosoles que trabaja en el centro (Laboratorio Tandetron de 2 MV), ha sido reconocido a nivel internacional [1].

El grupo ha realizando capacitaciones ya que dispone de todas la infraestructura física, así como de personal y de los equipos indispensables pues posee reconocimiento nacional e internacional [2, 3, 4, 5, 6, 7]. Así mismo, está siendo regularmente utilizado por el Organismo para tal fin.

Participa activamente en la ejecución de los proyectos ARCAL, con el fin de resolver problemas concretos que se presente en el país o en otros países [8, 9, 10, 11, 12].

REFERENCIAS:

1. Survey of PIXE programs – 1991, Thomas A. Cahill, Javier Miranda and Roberto Morales. Air Quality Group, Crocker Nuclear Laboratory, University of California, Davis, CA 95616, USA. *International Journal of PIXE, Vol. 1, No.4 (1991) 297-310.*

2. Curso "Caracterización de Contaminantes Atmosféricos usando Espectroscopía de Rayos X con Protón" a Nivel Nacional – Manual Interno del ININ, 1997.

3. IAEA, Oficio 601244, 07 Marzo, 2007.

4. IAEA, Oficio 601243, 09 Marzo, 2007.

5. Misión de Experto, Bolivia, C3-BOL/8/009 03 01 (M.en C. Javier Flores Maldonado) dentro del Proyecto BOL/8/009.

6. Misión de Experto, Guatemala, GUA/2/006-4 (Dra. Francisca Aldape Ugalde) dentro del Proyecto C3-GUA/2/006 04 01.

7. Misión de Experto, Cuba, C3-RLA/7/011 92 02 (Dra. Francisca Aldape Ugalde) dentro del Proyecto

8. Participación en el Proyecto Bienio 1999-2000, ARCAL XXXIX: Proyecto RLA/7/007. (1999).

9. OIEA: Evaluation of Airborne Fine Particles in Mexico City (MEX/1/021), 2003.

10. "Identificación de fuentes de Partícula Fina en el Área Metropolitana de la Ciudad de México (AMCM) usando Técnicas Nucleares" Proy. Nacional MEX/1/021, **2004-2005, 2005-2006.**

11."Assessment of Atmospheric Pollutants by Particles" RLA7011 (ARCAL LXXX), 2005-2007.

12. Diseño y construcción de cortadores de filtros especiales para colección de muestras atmosféricas, así como adaptadores para muestreadores de material partículado aerotransportado.

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11. J. Miranda, **F. Aldape** y J. Flores M., "Análisis Elemental de Partículas Suspendidas de Tamaño Respirable", Ciencia y Desarrollo 19(1994) 42-43.

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CAPITULOS EN LIBROS

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* Contribución a Capítulo: *Uso de los Aceleradores en la Búsqueda de Soluciones a la Problemática Ambiental: Trascendencia Social.* Francisca Aldape. **Libro: Experiencia Mexicana en Aceleradores de Partículas**..Serie: CIENCIA Y TECNOLOGIA EN LA HISTORIA DE MEXICO. Editorial Siglo XXI Editores. Primera Edición 2004.

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1. **F. Aldape**, "Caracterización de metales pesados en la atmósfera", Periódico El Nacional. 4 de Mayo de 1997.

2. P. Ávila P, J Pacheco, **F. Aldape**, J. Flores M. y G Piña, MEXICO NUCLEAR, No. 3 No. 8 octubre de 1997.

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International Journal of PIXE, Vol. 1, No. 4 (1991) 297–310

SURVEY OF PIXE PROGRAMS — 1991

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ABSTRACT

A survey has been made of PIXE programs, updating and extending a similar one published in 1981. Significant changes have occurred in the past decade, especially in the use of focussed ion beams in PIXE microprobes, milliprobes, and external beam systems. Some programs have achieved success and even dominance in one type of application, while others continue to show innovation and flexibility in many areas. The total number of active programs has increased modestly from about 95 in 1981 to 110 in 1990, with much of the increase due to new proton microprobes.

1. Introduction

There have been numerous surveys of PIXE programs, including Valkovic in 1973,[1] Johansson and Johansson in 1976[2] and Cahill in 1980,[3] which contains an essentially complete survey of the literature. The latter serves as the basis for the present summary, since few surveys of that scope have been done since 1981. For proton microprobes, the summary of Cookson in 1979[4] is the key reference to that time. Through this summary, it is hoped that communication between active PIXE laboratories can be enhanced. The data included in the summary was derived primarily from three sources:

1. A survey form was sent to over 100 laboratories, a list derived from the 1981 summary and all published papers in either the proceedings of the 2nd, 3rd, 4th, and 5th International Conferences on PIXE and its Applications, or the regular summaries of the Ion Beam Analysis conferences. Both occur as issues of *Nuclear Instruments and Methods*. Sixty responses had been received at the time of this writing, and the results of the survey provided the primary information for these programs.

2. The publications noted above in the period 1980–1991 served as a back-up method of completing the survey form. In some cases, other information was known to us personally, and this was also used in the survey. Clearly, this is not as

*Present address: Universidad Nacional Autonoma de Mexico.

†Present address: Universidad de Chile.

satisfactory as the survey results, but does serve to improve the scope of the survey.

3. Lacking either of the sources listed above, the data from the 1981 survey was included for completeness sake. Since there is no published evidence that some of these programs are still active, most of these listings are included for completeness sake only. It is as important to understand the reasons that PIXE was terminated at these laboratories as it is to understand why other laboratories are continuing with PIXE programs.

This paper will summarize ony part of the data contained in the survey, but the full results have been returned to all respondents. We encourage laboratories to complete the survey in any case, and we will periodically update the results. As part of this process, a list of addresses has been developed, and this is also available from the authors upon request.

2. Results

Table 1 summarizes the results of the survey. There are 127 laboratories or programs listed in Table 1, but for a number of them, we were unable to find any evidence of activity since 1981. We estimate that there are about 110 to 115 active programs in this list, and there are certainly new programs that the survey has missed. Nevertheless, we hope that this list, even if incomplete and inaccurate, will form the basis for an improved list prior to the 6th International Conference on PIXE and its Applications in Tokyo, 1992.

Figure 1 shows the year of initiation of programs in Table 1, based upon only the 60 laboratories who provided responses to the survey. The period of greatest growth was between 1976 and 1980, but new programs continue to be initiated. It is interesting that many of the early PIXE programs begun before 1976 continue to be active.

Figure 2 shows the type of accelerator used for PIXE programs. This table is based upon both the survey results and literature searches. As can be seen, more than half the programs are still based upon Van de Graaff accelerators, most of which were built for other purposes such as nuclear physics experiments. However, based upon the survey responses, many groups are now using newer machines such as tandem pelletrons designed specifically for PIXE programs. Nevertheless, higher-energy machines such as cyclotrons continue to be used, and offer some options such as ion scattering and nuclear reaction analysis not available on low-energy accelerators.

Figure 3 shows applications of PIXE derived from the survey responses and the literature. The diversity of PIXE applications continues to be a distinguishing characteristic of the field, with an approximate balance between the three major types of program: biological–medical (23%), materials (21%), and aerosols (17%). Archaeological, mineralogy, and other uses, including forensic ones, sum to 22% of all programs. While this listing is based upon the pr
almost all laboratories have multiple programs, further increasing the diversity of

Table 1. PIXE Research Programs.

Country/Institution	Respondant	Accel.	Part.	Energy	BeamSize	Appl.1	Appl.2	Techn.	Paper
Argentina									
C. N. E. A.	A.J. Kreiner	T	C,O	20	3 mm^2	Aerosols	Environment	RBS ERDA	ATEN23
Australia									
A. N. S. T. O.	David D. Cohen	VDG	p,d,He	0.2-3	20μm;10mm	Archaeology	Biological	NRA RBS PESA	PIXE89
CSIRO	C.G. Ryan	T	p	3	10 μm d	Mineralogy		RBS NRA	PIXE89
Univ. of Melbourne	G.J.F. Legge	NA	p	3	1 μm d	Materials	Biological	RBS NRA	NIMB22
Austria									
Johannes Kepler Univ. Linz	M. Geretschläger	VDG	p,He	0.1-0.8	1 mm^2	Materials		No	NIMB28
Bangladesh									
Atomic Energy Centre	A.H. Khan	NA	p, He	3	NA	Fluids		EB	NIMB3
Belgium									
Cent. Bur. for Nucl. Meas.	Uwe Wätjen	VDG	p	2-3.3	4-6 mm d	Aerosols	Biological	RBS AA ICP	PIXE89
L. A. R. N.	Guy Demortier	VDG	p,d,He	3	3μm-3mm d	Archaeology	Materials	Moss SEM ESCA	PIXE89
Univ. of Gent	Willy Maenhaut	Cycl	p	2	17-54 mm^2	Environment	Medical	RBS	PIXE89
Univ. of Liège	J.-M. Delbrouck	VDG	p	3	6.5 mm	Materials	Geological	XRF PIGME	XRS19
Brazil									
Pontif. Univ. de Rio de Jan.	E.C. Montenegro	VDG	p	6		Medical	Materials	RBS	NIMB43
Univ. de São Paulo	Paulo Artaxo	Pell	p,He	3;8	0.8 cm^2	Aerosol		No	PIXE89
Canada									
Queens Univ.	J.D. MacArthur	VDG	p		10 μm d	Aerosol	Mineralogy		NIMB45
Univ. de Montreal	G.E. Kajrys	Dyn T	p,He	1.-3.	15μm;10mm^2	Polymers	Aerosols	RBS ERD	JMS25
Univ. of Guelph	John L. Campbell	KN3000	p	1.-3.	50mm^2-10μm^2	Mineralogy	Metals	RBS	PIXE89
Univ. of Manitoba	J.S.C. McKee	Cycl	p	20-50	NA	Aerosols	Mineralogy	ACT	NIMB80
Chile									
Univ. de Chile	J.R. Morales	Cycl	p,d	6	NA	Aerosols	Mineralogy	RBS	JRNC140
China (PR)									
Academia Sinica	Liu Nian Qing	VDG	p,He	3	4-6 mm d	Biomedical	Aerosols	No	PIXE89
Beijing Normal Univ.	Guanghua Zhu	T	p	3	5.5 mm d	Aerosol	Soil	RBS NRA	IJPIXE1
Fudan Univ.	Xianzhou Zeng	VDG	p	2.3-3	4 μm;8 mm d	Archaeology	Biomedical	RBS ICP XRF	IJPIXE1
Sichuan Univ.	Zhang Dazhong	VDG	p,d,He	0.8-2.5	0.1-10 mm d	Biology	Materials	No	NA
China (R)									
Natl. Tsing Hua Univ.	C.C. Hsu	VDG	p	3	4 mm^2	Medical	Atomic		IJPIXE1

Table 1. Cont'd.

Country/Institution	Respondant	Accel.	Part.	Energy	BeamSize	Appl.1	Appl.2	Techn.	Paper
Czechoslovakia									
FJFI CVUT Praha	Vaclav Potocek	VDG	p	2	3-10 mm d	Aerosol	Medical	XRF AA	ISOT24
Denmark									
Niels Bohr Institute	Kåre Kemp	VDG	p	2.0-3.0	1 mm d	Aerosol	Emission	PESA	NIMB22
Univ. of Aarhus	Finn Folkmann	VDG T	p	5.0;6.0	NA	Materials		Crystal Spect.	PIXE89
England									
A.E.R.E. Harwell	J.A. Cookson	VDG	p	3	$4\mu m^2$-$4mm^2$	NA		RBS NRA	NIMB30
Univ. of Birmingham	R.S. Sokhi	Dyn	p	3	$4mm^2$;$25\mu m^2$	Environment	Biological		PIXE89
Univ. of Manchester	R.A. Jarjis	NA	NA	NA	NA	NA	NA	NA	NA
Univ. of Oxford	Frank Watt	Pell	p	3	1 µm d	Medical	Geochemical	RBS STIM	PIXE89
Univ. of Surrey	Karen J. Reeson	NA	p,He	0.3-2	NA			RBS	NIMA299
Finland									
Univ. of Helsinki	J. Räisänen	VDG	p	3	.1-5 mm d	Biomedical	Materials	RBS PIGME	PIXE89
Univ. of Kuopio	Taisto Raunemaa	NA	NA	NA	NA	NA	NA	NA	NIMB22
France									
C.E.N. Bordeaux-Gradignon	Yvan Llabador	VDG	p,d,He	4	10 mm^2	Biological	Pollution	RBS NRA	PIXE89
C.E.N. Saclay	Ch. Engelman	VDG	p,He	4	0.5-1 µm d	Materials	Archaeology		PIXE89
C.R.N. Strasbourg	C. Heitz	VDG	p,He,Ar	1.-3.	0.8-3 mm^2	NA		NAA AA	IBA86
CERI-CNRS	E. Zine	VDG	p	4	NA	Mineralogy			PIXE89
Inst. de Phys. Nucl. Orsay	Ivan Brissaud	VDG	p	2	NA	Materials	Archaeology	SRXRF	PIXE89
Inst. de Phys. Nucléaire Vill.	J.P. Thomas	VDG	p	4	NA	Materials		Elastic Recoil	TDI
Musées de France	Michel Menu	Pell	p,He	4	1 mm d	Art	Archaeology	RBS NRA SEM	PIXE89
Germany									
Akad. der Wissenschaften	Volker Rössiger	Implant	p	0	NA	Materials		NRA	NIMB3
Hahn-Meitner Inst.	K.H. Ecker	NA							NIMB15
Inst. Kernphysik Karlsruhe	D. Heck	VDG	p,d,He	3	10 μm^2	Medical		None	Inactive
Inst. Strahlenschutz Neuher.	K. Witmaack	NA	p	3		Agricultural		RBS	PIXE89
J.W. Goethe Univ.	K.O. Groeneveld	Frankf	p	2.-3.	1 mm^2	Materials	Aerosols		NIMB3
Karl-Marx Univ.	J. Vogt	NA							NIMB30
Ruhr-Univ. Bochum	Burkhardt Raith	Dyn	p	2.0-3.0	10 µm d	Biomedical		p Elastic Scat.	NIMB3
Univ. Bonn	Hans Mommsen	Cycl	H2	7	1 mm	Materials		RBS NRA NAA	PIXE89
Univ. Frankfurt	D. Kraft	VDG	p	3	1 mm^2	Aerosols	Materials		NA

Table 1. Cont'd.

Country/Institution	Respondant	Accel.	Part.	Energy	BeamSize	Appl.1	Appl.2	Techn.	Paper
Univ. Göttingen	K.P. Lieb	VDG	p	0		Materials		RBS NRA	NIMB50
Univ. Hamburg	Manfred Niecke	VDG	p	2	9 μm^2	Biological	Aerosol	p Ener Loss	PIXE89
Univ. Heidelberg	R. Nobiling	T	p	3	6 μm^2	Biomedical	Mineralogy	NA	NIMB14
Univ. Konstanz	R.G. Lindner	VDG	p	0		Materials			NIMB3
Univ. Marburg	F.W. Richter	VDG	p	2.0-4.0	6 mm d	Medical	Aerosol	RBS Channeling	NIMB22
Greece									
N.R. C. DEMOKRITOS	A.A. Katsanos	VDG	p	2	2 mm d	Archaeology			NIMB14
Hungary									
Cent. Res. Inst. for Physics	Z.Szökefalvi-Nagy	VDG	p,d,He	2-3.5	0.01-6 mm^2	Biological		NRA XRF	PIXE89
Hungarian Acad. of Sci.	Ede Koltay	VDG	p	2-2.3	5-10 mm^2	Aerosols	Biomedical	PIGME	PIXE89
India									
Bhabha Atom. Res. Cent.	P.S. Dhami	T				Materials			JRNC141
Indian Inst. of Technology	K.M. Varier	NA	p	2		Fluids			NIMB10
Punjabi Univ.	Harsh Mohan	NA	p	0					NIMB26
Iran									
Atom. Ener. Org. of Iran	S.Mousavi-Y.	VDG	p	3	50 mm^2	Medical			NIMB3
Italy									
CISE Technologie Innovative	Ezio Cereda	T	p,d	4	1 cm^2	Aerosols	Materials	RBS NRA PIGME	PIXE89
Ist. Naz. Fis. Nucl. Genova	A. Zucchiatti	NA							NIMB28
Ist. Naz. Fis. Nucl. Padova	G.P. Buso	VDG	p	2		Materials	Environment		PIXE89
Univ. di Catania	Lorenzo Torrisi	VDG	p,He	0.5-3	0.1 mm^2	Biomedical	Materials	RBS NRA ERDA	NIMB7
Univ. di Firenze	Pietro Mandò	VDG	p	3	1.2 mm d	Art	Biomedical		IBA89
Univ. di Napoli	R. Moro	NA				Biomedical			IBA87
Univ. di Padova	R. Cecchi	NA							PIXE89
Japan									
Hiroshima Univ.	F. Nishiyama	VDG	p,He	0.5-2.5	0.7-8 mm d	Materials		RBS	NA
Hosei Univ.	H.Hamanaka	VDG	p,He	1.-2.	1-4 mm d	Materials		RBS	IBA89
Inst. Phys. Chem. Res.	K. Maeda	T	p	2	1-3 mm d	Biomedical	Archaeology	ICP AES XRF	NA
Iwate Medical Univ.	Koichiro Sera	Cycl	p	3	1 mm	Medical	Aerosol	No	No
Kobe Tokiwa Junior Coll.	M. Tanaka	Kyoto							NIMB22
Kyoto Univ.	S. Shimoura	T	p	3.-6.	8mm d;1μm^2	Medical			NIMB22
Nagoya Univ.	Susumu Amemiya	NA	p	0.15-2.					NIMB23

Table 1. Cont'd.

Country/Institution	Respondant	Accel.	Part.	Energy	BeamSize	Appl.1	Appl.2	Techn.	Paper
Natl. Inst. of Radiol. Sci.	M. Ishikawa	VDG	p	3	1.2 mm^2	Biological	Agriculture		PIXE89
Osaka Univ.	Fumiya Shoji	T; Disk	p; He	2; 0.5	2 mm^2; 1μm^2	Materials		No	JJAP28
Tohuku Univ.	Keizo Ishii	Cycl	p	3.-40	4 mm^2	Biological		No	IJPIXE1
Univ. of Tokyo	Akira Ito	Cycl	p, He	25-27	14 μm d	Biomedical			NIMB22
Univ. of Tsukuba	Kunihiro Shima	T	p			Materials			NIMB27
Waseda Univ.	Susumu Morita	LA; T	p, He	8.2;3.2		Materials			IJPIXE1
Mexico									
I.N.I.N. Salazar	F. Aldape	T	p	3	12-30 mm^2	Aerosol	Mineralogy	No	IJPIXE1
Univ. Nal. Aut. de Mexico	Alicia Oliver	VDG	p	0.1-0.7	1 mm d	Materials	Medical	RBS NRA	ASS45
Netherlands									
Eindhoven Univ. of Tech.	H.P.M, Kivits	Cycl	p	3	100 μm^2	Biomedical	Materials	Elastic Recoil	PIXE89
Vrije Univ.	Ronald D. Vis	Pell	p	3	2 mm d	Biomedical	Geological	NRA	PIXE89
New Zealand									
Inst. of Nuclear Science	G. Cootes	VDG	p	3	400 μm^2	Medical	Biology	PIGME	NIMB30
Nigeria									
Cent. Ener. Res. Dev.	S.O. Olabanji	NA				Archaeology			NIMB
Poland									
Inst. of Nuclear Physics	S. Szymczyk	Cycl VDG	p	3	6 mm d	Agriculture	Medicine	PIGME	PIXE89
Jagellonian Univ.	Eugeniusz Rokita	Cycl VDG	p	3	6 mm d	Biological	Aerosols	PIGME	PIXE89
Pedagogical Univ. Kieke	J. Braziewicz	VDG	p,He	0.6-3.5	3-80 mm^2	Atomic	Biological	ACT	PIXE89
Portugal									
Lab. Nac. Eng. Techn. Ind.	T.M. Pinheiro	No accel							PIXE89
Univ. Lisboa	F.B.Gil/L.Rebouta	NA							EuLt14
Romania									
Inst. Nucl. Phys. Eng.	Theodor Badica	VDG	p	3	3-5 mm d	Medical	Biological	NAA	RRP
Saudi Arabia									
King Fahd Univ.	A.B. Hallak	NA	NA	NA	NA	NA	NA	NA	XRS19
Singapore									
Natl. Univ. of Singapore	S. M. Tang	VDG	p	3	4 mm d	Mineralogy		RBS	ApSp43
South Africa									
Atomic Energy Board	D.W. Mingay	NA	p	2		Aerosols			NIMB24
Faure Univ.	Max Peisach	VDG Cycl	p,d,He	6.2;66	1.2μm;250μm	Archaeology	Biological	RBS NRA PIGME	PIXE89

Table 1. Cont'd.

Country/Institution	Respondant	Accel.	Part.	Energy	BeamSize	Appl.1	Appl.2	Techn.	Paper
Univ. Witwatersrand	J.F.P. Sellschop	T	p	3	2-4 mm d	Aerosols	Mineralogy	No	PIXE89
Spain									
Univ. Sevilla	M.A. Respaldiza	T	p,He	2.-3.	7 mm^2	NA		RBS XRF	NIMB50
Sweden									
Lund Inst. Technol.	S.A.E. Johansson	Pell	p,d,He	7	NA	Geology	Aerosols	PESA PIGME	PIXE89
Studsvik Nuclear	Hong-Kou Li	VDG	p,He	6	6 mm d			RBS	PIXE89
Uppsala Univ.	Ulf Lindh	NA	He	2	2.9x2.9μm^2	Biomedical		RBS	PIXE89
U.S.A.									
Bartol Res. Inst. Delaware	C.P. Swann	VDG	p,He	1.3-2	0.02-0.2mm^2	Archaeology	Biology	RBS	PIXE89
Brigham Young Univ.	Nolan Mangelson	VDG	p,He	2.25;4	0.38 cm^2	Aerosols	Military	RBS PIGME	PIXE89
City Univ. of New York	Evan T. Williams	Dyna	p	2	2 mm d	Archaeology			NIMB45
Cole Technology	H. Kaufman	VDG	p	5	NA	Materials	Environment	PIGME	NewPrg
Element Analysis Corp.	S. Bauman	ICT T	p	4	0.1-100μm d	Aerosols	Materials		PIXE89
Florida State Univ.	J.W. Nelson	VDG	p	3	100 mm^2	Aerosols	Archaeology	No	PIXE89
IBM T.J.Watson R.C.	J.F. Ziegler	NA	p	3		Materials		EB RBS ACT	NIMB24
Idaho St. Univ.	John M. Knox	VDG	p, He	2	0.3 cm^2	Environment		RBS NRA	Inactive
Lawrence Livermore Lab.	Ronald G.Musket	VDG	p,He	0.5-4.0	1-4 mm^2	Materials		RBS AES SEM	SPIE911
Los Alamos Natl. Lab.	Pamela Rogers	T	p	3	5-300μm d	Mineralogy	Geology	RBS NRA ACT	NIMB30
M. I. T.	Lee Grodzins	NA							
Ohio St. Univ.	J.R. McClenahen	Rent							CJRF19
Rutgers, SU New Jersey	Gene S. Hall	T	p	4	12 mm d	Archaeology		PIGME	PIXE89
Sandia Natl. Lab.	B.L. Doyle	T VDG	p,He	5	0.25 mm^2	Materials		RBS ERD NRA	NIMB22
SUNY Albany	H. Bakhru	Dynam	p,He	2.0-4.0	1mm^2-.4μm^2	Biological	Materials	RBS NRA	NIMB24
SUNY Geneseo	J.R. Chen	NA							
Univ. California Davis	Thomas A. Cahill	Cycl	p	5	0.5mm^2.3mm	Aerosols	Historical	FAST PESA	PIXE89
Univ. of Florida	H.A. van Rinsvelt	Gent				Materials	Biological		NIMB45
Univ. of North Texas	Jerome Duggan	T VDG	p			Atomic		RBS NRA	NIMB40
Univ. of Oklahoma	H.J. Fischbeck	VDG	p,He	2	2 mm d	Archaeology	Forensic	RBS NRA	NIMB24
Univ. of Oregon	Robert Schofield	VDG	p	5	8 μm d	Biomedical		STIM	NIMB30
Universal Energy Systems	R.S. Bauacharya	VDG	p	0		Materials		RBS	Inactive
U.S.S.R.									
V.I. Lenin St. Univ.	R.A. Ilkhamov	NA				Materials			NIMB47

Table 1. Cont'd.

Country/Institution	Respondant	Accel.	Part.	Energy	BeamSize	Appl.1	Appl.2	Techn.	Paper
Yugoslavia									
J. Stefan Inst.	Milosz Budnar	VDG	p,He	2	15 mm^2	Aerosol		RBS PIGME XRF	PIXE89
Ruder Boskovic Inst.	V. Valkovic	T	p,C	3	3 *mm d*	Environment	Biomedical	RBS	PIXE89

For a description of the accelerator types, see Fig. 2. Programs with microprobes are in bold type. Technique nomenclature and the publications code, "Paper" *follow the list of references in this paper.* The number behind the journal is the volume of the journal, unless it lies between 80 and 90. In these cases, it is the year of publication of recent PIXE and Ion Beam Analysis Conferences.

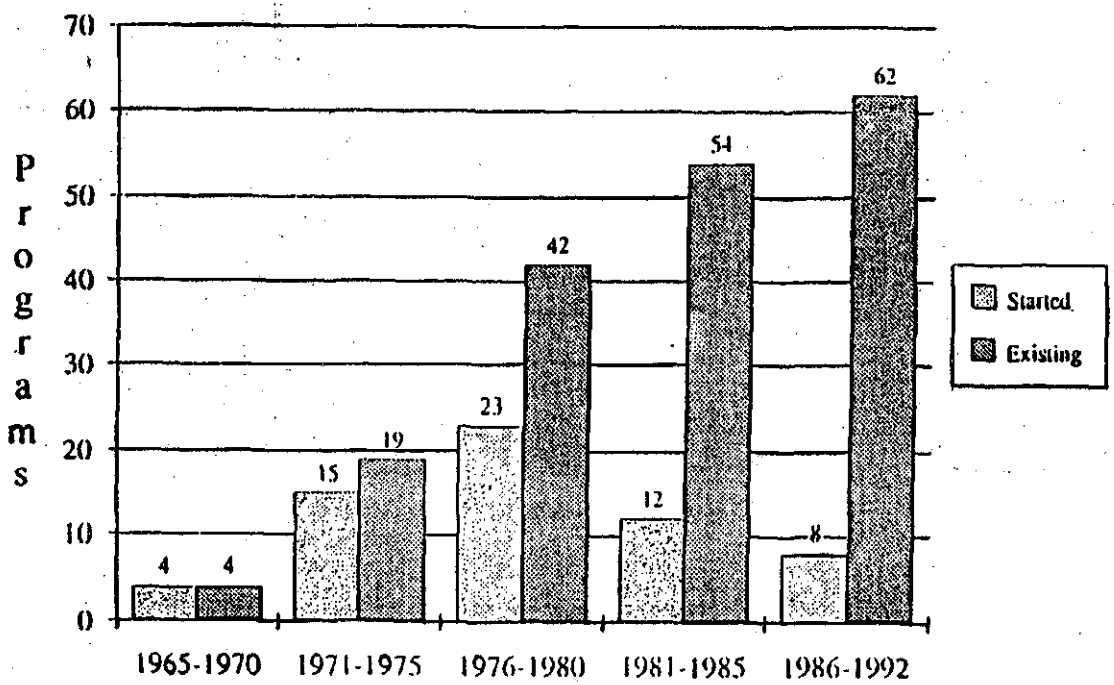

Fig. 1. PIXE research programs started in the period 1965–1992, divided into five-year periods, and total number of existing programs by the end of each program. Based on responses received in this survey and the one of 1981.

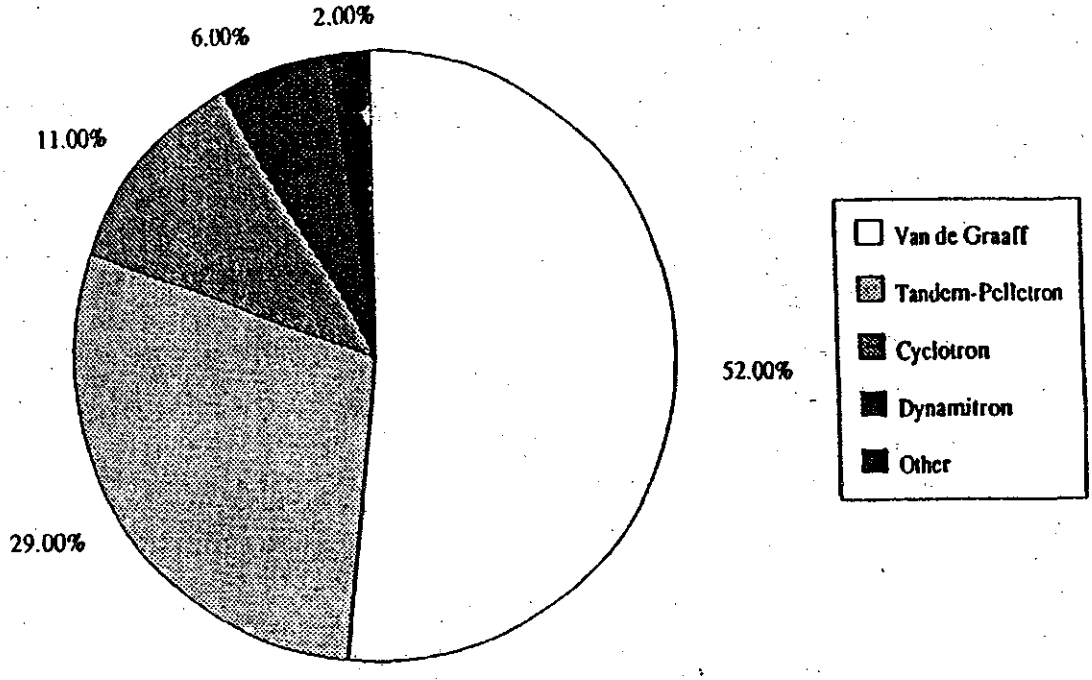

Fig. 2. Accelerators employed in PIXE analysis.

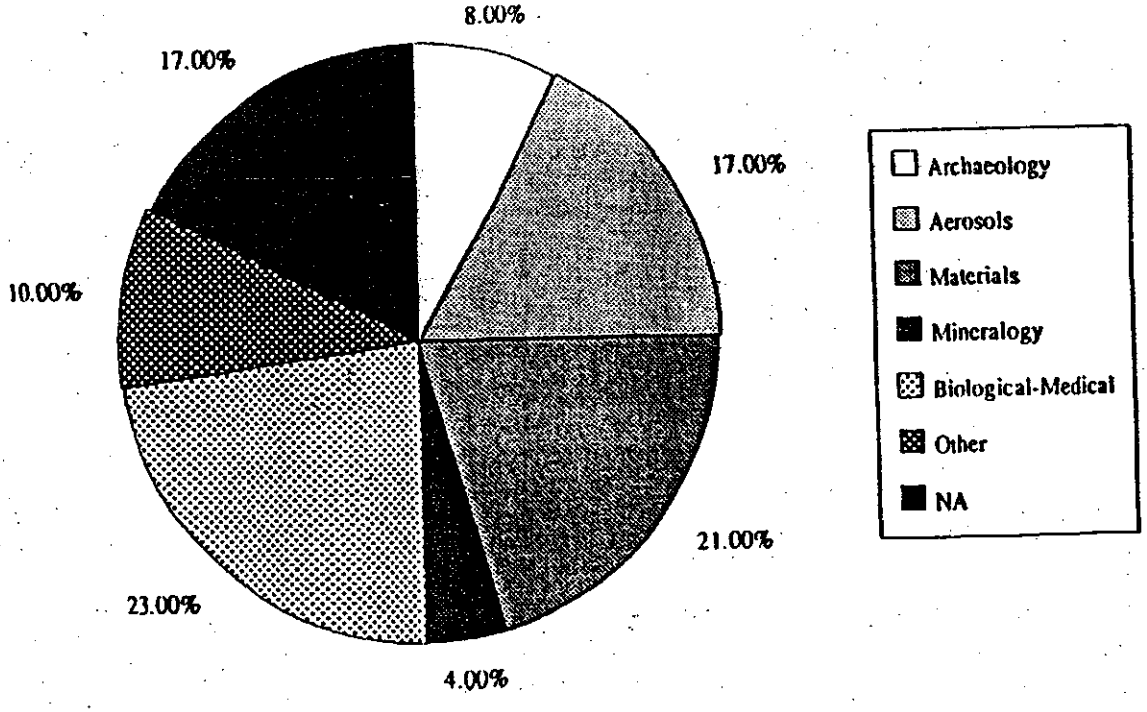

Fig. 3. Major uses of PIXE.

in this survey and the one of 1981.

applications. Most laboratories also have developmental programs for their PIXE programs and other techniques designed to extend and enhance their fields of application.

Figure 4 illustrates one of the strongest trends in the past decade, namely the increasing use of ancillary techniques to support the PIXE applications. In many cases, these programs themselves have reached a high level of sophistication, and give an edge to accelerator-based programs over non-accelerator based programs. The major ancillary technique is Rutherford Backscattering (RBS), widely used for material analysis, and Nuclear Reaction Analysis (NRA) and Proton Induced Gamma (PIGME), both used in material and mineralogical analysis. Proton Elastic Scattering Analysis (PESA) and a version of RBS, Forward Alpha Scattering Analysis (FAST), have given PIXE-based aerosol programs a clear advantage over competitive methods, such as X-ray Fluorescence Analysis (XRF), although again some groups use both to enhance their programs. The largest other techniques are gravimetric and laser analyses, for aerosols, and microscopic analysis for a variety of purposes.

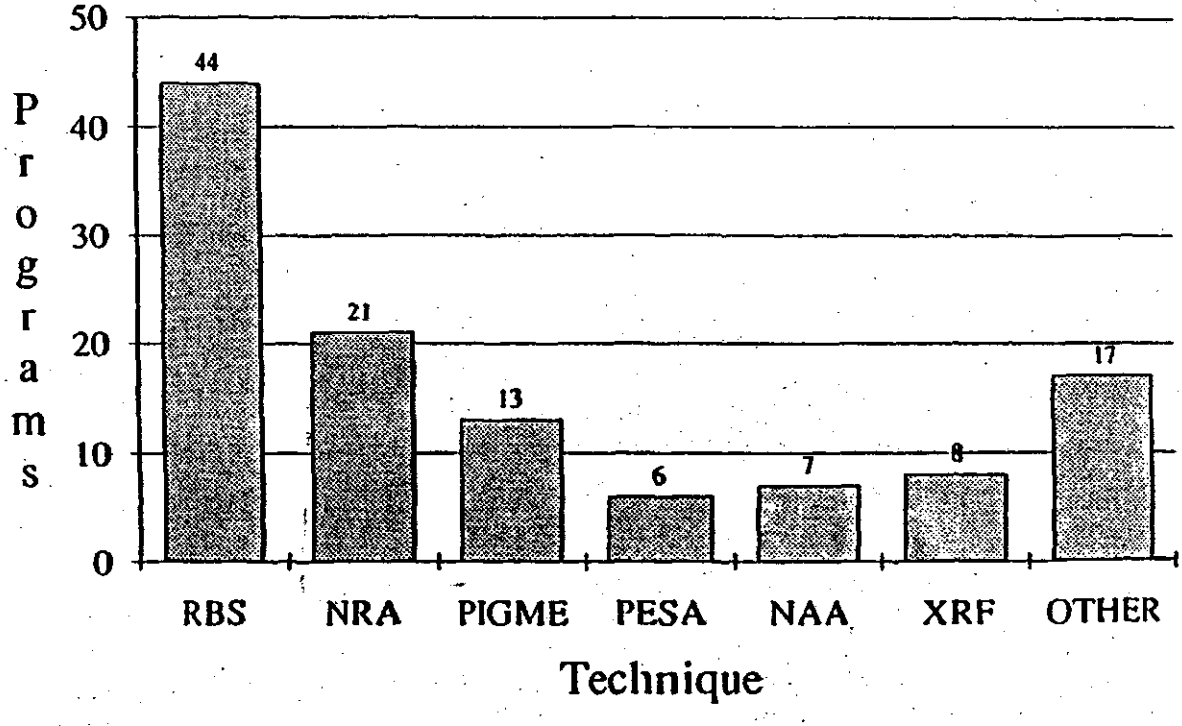

Fig. 4. Complementary analytical techniques used with PIXE.

One of the greatest areas of increase during the 1980s was in the area of proton microprobes. In the 1980 survey,[3] drawn largely from Cookson's definitive work,[4] there were 16 microprobes in operation, with a median beam spot size around 15 micrometers in diameter. The very best programs had beam spots around 2 to 3

micrometers. In the present survey, which was quite complete for the microprobe laboratories, there were 27 active programs, and over half had beam spots below 5 micrometers in diameter. There are nine programs in the 0.5 to 2 micrometer diameter range, some of which (Oxford is a prime example) are available on a contract basis and raise significant income from this source. It is also interesting that about half the microprobe laboratories also operate in a non-microprobe or standard PIXE mode, either in air or vacuum. In the area of materials, the simultaneous or sequential use of RBS or NRA analyses give PIXE microprobes significant advantages over alternative techniques, in addition to the part-per-million sensitivity that translates into extremely small amounts of detectable mass. Figure 5, taken from Ref. 3, shows the sensitivity that one can achieve in a thin or thick target mode PIXE microprobe. Only focussed beam synchrotron radiation can challenge such sensitivities in a nondestructive, multielement technique.

Another area of growth in the applications of PIXE is not as evident in Table 1, but equally as significant to the future of the field. Application of PIXE to aerosols was one of the very first areas of application of PIXE. Johansson *et al.* actually performed a "dry deposition" aerosol experiment in their pioneering article in 1970,[5] and we at Davis actually performed size selected multielemental aerosol analysis in 1970 on a funded contract.[6] Rapid growth followed at many laboratories, with the Lund group, Florida State, and Davis being early advocates of the technique. In the 1980s, there seemed to be a slacking of effort, with PIXE well established in some research modes but barred from large-scale use by pre-existing techniques. One reason for this was the emphasis on aerosols in human health, in which the chemical state of the aerosol was often very important. With a switch of emphasis to atmospheric visibility, long-range transport, and global aerosol dynamics (the Mt. St. Helens, El Chichon, and Mt. Pinatubo eruptions; arctic, Saharan, and Chinese aerosols; "nuclear winter"; smog in Grand Canyon National Park; ...), PIXE came into its own. For all materials in the atmosphere are important in these problems, not just a few toxic elements, and PIXE is the broad-range technique *par excellence*. In addition, ion-beam techniques allow a complete breakdown of mass into all its elements, hydrogen through uranium, nondestructively, a result that cannot be achieved by any other technique.

Figure 6 shows the result of a comparison between the mass of aerosol on a filter, measured gravimetrically, and the sum of all species derived from a single, 100 second long analysis by PIXE plus PESA from a teflon filter. The filter was taken at the NOAA Mauna Loa Observatory on Hawaii, above 3000m elevation. Note the very small total mass. (Sensitivity for trace elements such as Ni, es 25 pg/m^3). While the PIXE + PESA (+ FAST) capabilities are impressive, the real achievement is to weigh a filter accurately to less than 0.1 μm/m^3. The small amount of mass lost is dominated by water, since the mass was determined in air and all analyses were done in vacuum. Even this information is useful to us in understanding the effect of bound water in the hydroscopic acids that dominate visibility reduction at most remote United State sites.

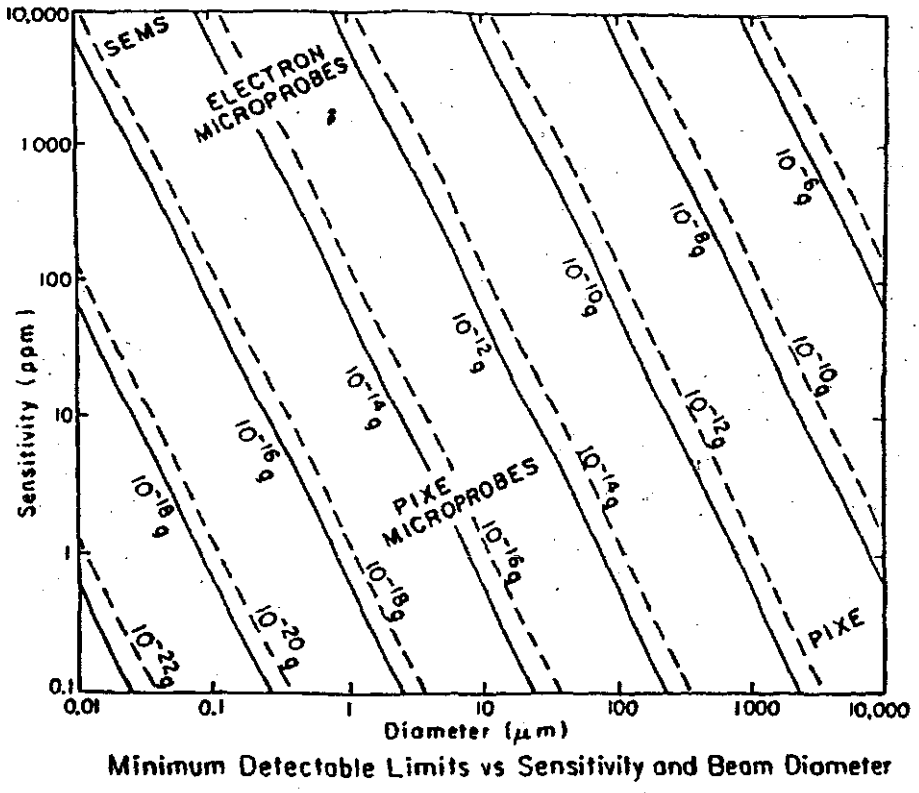

Fig. 5. Minimum detectable mass vs. beam diameter and analytical sensitivity. The dashed curv corresponds to an analysis made on a thin carbon backing foil $pt_B = 65\ \mu g\ cm^{-2}$ and a sample $pt_S = 35\ \mu g\ cm^{-2}$. The solid curves represent thick samples. From ref. Ann. Rev. Nucl. Sci.

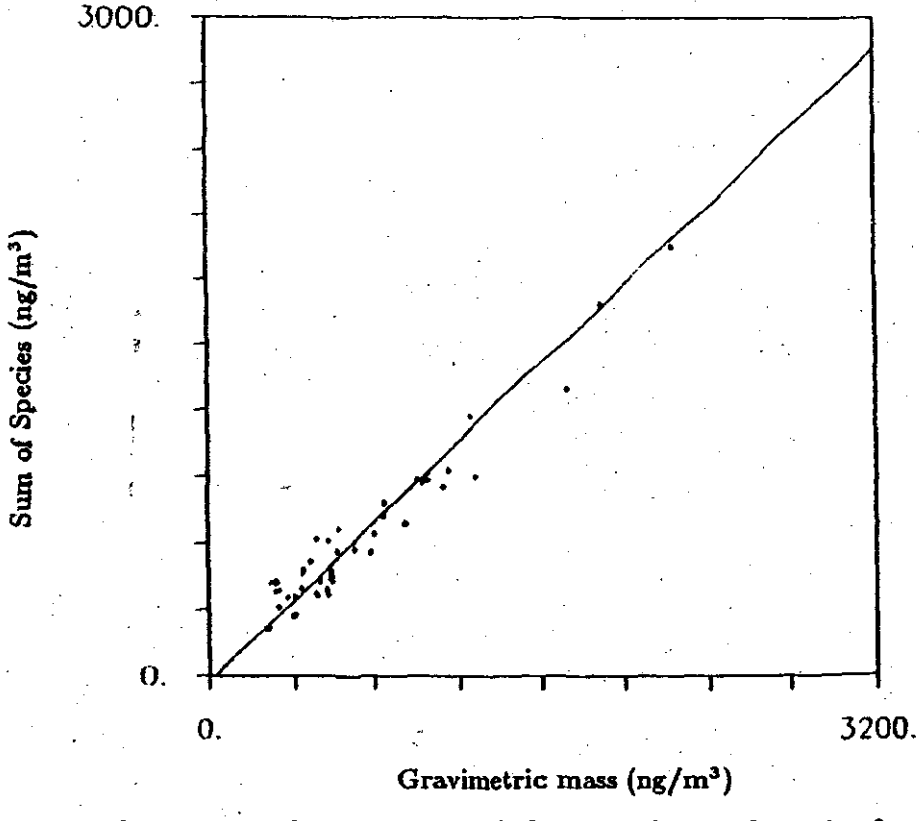

Fig. 6. Comparison between gravimetric mass and the sum of aerosol species from PIXE plus PESA at Mauna Loa Observatory. Only nitrogen species are not measured or estimated.

The problem, of little mass available for analysis, is futher compounded when one must also measure atmospheric particles by size and composition, as in visibility studies. Here the ability to focus an ion beam to a small spot without losing sensitivity gives PIXE another clear advantage. For all these reasons, the survey revealed that several existing laboratories have greatly increased the number of analyses done each year, and built up large research groups in atmospheric science programs. The programs at Florida State, Davis, and in Denmark, Sweden, and in 1991, Australia, Brazil have developed samplers that matched PIXE capabilities, and deployed them in networks of national scale. At Davis over 100 samplers are operating at one time. Now these networks are being extended to global scale,[7] in cooperation with over a dozen countries and the World Meteorological Organization. In all cases, the local PIXE laboratories design and run the networks, with the Davis Air Quality Group offering assistance in sampler design, quality assurance, and data interpretation. In no other way could the world gain such detailed and accurate information at such low cost than by PIXE and its compatible ion beam and non-ion beam techniques.

3. Conclusions

The survey has given us additional information on the growth and maturation of PIXE programs around the world. In general, the most successful programs have focussed not so much on PIXE itself as on the objectives of the larger program, stressing that the goal must be to do the very best work possible. Thus, it is a credit to PIXE and its practitioners that this method has become so much a part of so many exciting programs in so many countries throughout the world. And this is perhaps the last point shown by the survey; the PIXE community is as truly international as any program can be. Pioneering work has been done and continues to be done in countries all over the world, not just the major industrialized countries. For an example, consider the countries involved in the development of external-beam PIXE, Belgium, Greece, China, and Iran all made early and important efforts in the field. We expect no less innovation in the next decade.

Reference Codes

ATEN	=	Atmospheric Environment
NIMB	=	Nuclear Instruments and Methods Sect. B
XRS	=	X-ray Spectometry
JMS	=	Journal of Materials Science
JRNS	=	Journal of Radioanalytical and Nuclear Chemistry
ISOT	=	Isotopenpraxis
TDJ	=	Techniques del' Engineur
IJPIXE	=	International Journal of PIXE
JJAP	=	Japanese Journal of Applied Physics
ASS	=	Applied Surface Science

EuLT	=	Europhysics Letters
RRP	=	Romanian Review of Physics
ApSp	=	Applied Spectroscopy
CJRF	=	Canadian Journal of Forest Research
SPJE	=	Proc. Intl. Soc. for Optical Engineeering

Technique Codes

AA	=	Atomic Absorption Spectroscopy
ACT	=	Activation Analysis
AES	=	Auger Emission Spectroscopy
EB	=	Electron Beam
ENER LOSS	=	Proton Energy Loss Spectrometry
ERD (A)	=	Elastic Recoil Detection (Analysis)
ESCA	=	Electron Spectroscopy for Chemical Analysis
FAST	=	Forward Alpha Scattering Techniques
ICP (ES)	=	Inductively Coupled Plasma (Emission Spectroscopy)
MOSS	=	Mössbauer Spectroscopy
NRA	=	Nuclear Reaction Analysis
PESA	=	Proton Elastic Scattering Analysis
PIGME	=	Proton Induced Gamma Emission
RBS	=	Rutherford Backscattering
SEM	=	Scanning Electron Microscopy
STIM	=	Scanning Transmission Ion Microscope
XRF	=	X-ray Florescence

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1. V. Valkovic, *Contemp. Phys.* **14** (1973) 415.
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