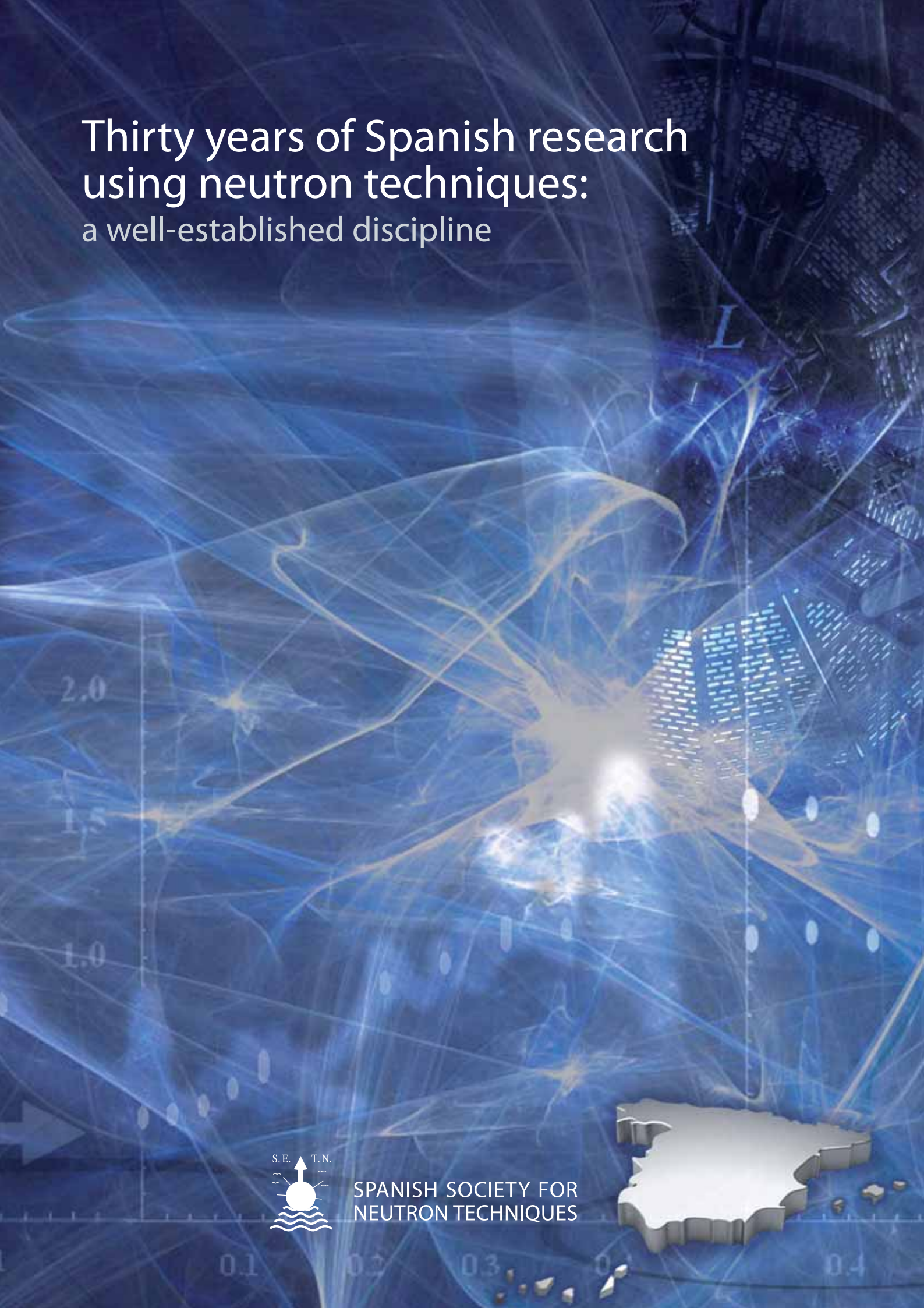
Thirty years of Spanish research using neutron techniques:
a well-established discipline



Thirty years of Spanish research using neutron techniques: a well-established discipline

CONTENTS

1 EXECUTIVE SUMMARY

In Spain, research using neutron techniques began in the 1970s, particularly in areas within the field of condensed matter physics. Thirty years later, this field of scientific research has seen huge growth. A brief summary of the conclusions drawn from this study is given below.

1. A major increase in the number of documents. More than 2000 scientific articles relating to neutron techniques have been published.
2. A scientific community of more than 250 researchers, most of them attached to the Spanish Society for Neutron Techniques.
3. Increase in the scientific output impact.
4. Growing subject breadth of research over the years.
5. Increase in the output of the most active institutions.
6. Increase in the number of active 'frequent scientist' authors.
7. Spain ranks eighth in the world for scientific output, and sixth for the number of citations per document of the twenty countries with most output in the field.
8. A high level of international collaboration in the field.
9. Examination of the scientific collaboration networks of Spanish researchers in the field shows they are clearly centred on the ILL.
10. Although in other disciplines research carried out with international collaboration has shown a greater impact, our data do not show any significant differences in impact according to whether or not foreign institutions are involved in publications.
11. This is **Big Science** in that it is dependent on large, costly facilities shared internationally, but if we look at co-authorship information it does not seem to require large working teams for its experiments.
12. Examination of authors' productivity shows a high proportion of occasional authors and a core of highly productive authors, with a high proportion of their output carried out in collaboration with foreign researchers.
13. Spanish research in this area is closely linked to Spanish researchers' growing access to neutron sources in other countries around the world, which form the backbone of research in the area.

EXECUTIVE SUMMARY

A new spallation neutron source in Europe would undoubtedly stimulate competitive, quality scientific and technological research, and training for young scientists and technology specialists in the field.

One argument in favour of locating this neutron source in Spain is that Spanish research into neutron techniques is currently enjoying major development and growth, in both quantitative and qualitative terms, with an impact well above the worldwide average. There is also a high degree of specialisation within the field in certain regions of Spain.

INTRODUCTION 2

Neutron Techniques

Neutron techniques are techniques which use neutron beams with wavelengths of the order of interatomic distances (λ=1 Å), for the study of matter in any state. In today's world, these are highly powerful, widely-used tools. They are multidisciplinary techniques, as they are used by chemists, physicists and materials science researchers, and there are more and more users from the worlds of medicine and biology, interested in studying biological processes at the cellular and molecular levels.

Research into neutron techniques has the characteristics of **Big Science**, as it requires specific facilities. Neutron sources, (whether nuclear reactors for research or spallation sources), are beyond the reach of some countries due to their complexity and expense.

Research into neutron techniques in Spain began relatively recently. The first Spanish researchers to begin experiments did so in the 1970s. Although these researchers originally came from only a few research groups, mainly relating to materials science, over the years both the number of researchers and research groups and the number of scientific disciplines to which they belong (physics, chemistry, engineering, geology, biology, medicine and even archaeology and cultural heritage) have grown significantly.

It should also be highlighted that many Spanish researchers have written their doctoral theses and/or carried out post-doctoral work at these large facilities, and even work there as permanent scientists. This gives an idea of the huge development of this field in Spain over the last three decades.

Public bodies, particularly the government ministries responsible for research and science at various times, have been sensitive to this fact, and both funding and the number of research projects relating to neutron techniques have grown continually in recent years. Spain has also been involved in the European neutron source (Institut Laue Langevin (ILL), Grenoble, France), as an associated country, for more than 20 years, and was the first country besides the three founding

countries (France, the UK and Germany) to become part of this major facility. More recently, Spain has also begun to participate in a similar way in the English spallation source (ISIS, Didcot).

Finally, we would like to stress that most Spanish users of these techniques are associated with the Spanish Society for Neutron Techniques (Sociedad Española de Técnicas Neutrónicas, SETN), a body with over 200 members. SETN is also part of the European Neutron Scattering Association (ENSA), the body that represents neutron technique researchers in Europe.

Finding out more about the status of research in this field is particularly relevant at the moment, as Spain has applied for Bilbao to be the location of the European Spallation Source (ESS). In recent decades, Europe has been the worldwide leader in neutron science research, thanks to its facilities (ILL and LLB in France, ISIS in the UK, HMI and FRM II in Germany, SINQ in Switzerland). However, the new spallation sources in the USA (SNS, Oak Ridge) and Japan (JSNS, within the J-PARC), which have recently accepted their first users, together with the growing demand for neutron beam time by the European scientific community, support the case for opening a new facility: the ESS. The ESS will allow the promotion of research in various disciplines, with different applications. Some background information is listed in the bibliography **[1]**.

[1] For more details on the history of research into neutron techniques in Spain, please consult the Spanish Journal of Physics (of the Royal Spanish Society for Physics, [Real Sociedad Española de Física, RSEF]), Vol. 22, issue 4, pp. 21-31 (2008).

Most Spanish users of these techniques are integrated in the Spanish Society for Neutron Techniques (SETN), a body with over 200 members.

3 AIM

The aim of this document is to show the evolution of the use of neutron techniques within the Spanish scientific community via its scientific output.

This work is based on publications from the period 1970-2006 which are included in the international database **Web of Science** (WoS), with particular emphasis on aspects relating to collaboration between different research groups in Spain, as well as their collaboration with groups in other countries.

This gives rise to a number of questions: how has the discipline developed in recent years, in terms of the number of scientists, number of publications, and impact? Have its centres of activity increased in number? Is there a more diverse range of subjects within research topics? Does this discipline have the characteristics of big science? What is the status of the Spanish scientific community in the international context of this discipline?

A I M

{ The aim of this document is to show the evolution of the use of neutron techniques within the Spanish scientific community via its scientific output.

METHODS 4

Spanish scientific output on neutron techniques was obtained by identifying all documents in the WoS which featured any term derived from the lexeme ***neutron*** in the fields ***title***, ***keywords*** or ***abstract***, and the word ***Spain*** in the field ***affiliation***. Scientific output by Spanish researchers from institutions abroad was also taken into account. Searches were limited to documents published between 1970 and 2006. After documents were downloaded, they were reviewed in order to refine the search and rule out those which were irrelevant to the discipline being analysed.

This study analyses quantitative and semi-qualitative indicators based on international scientific publications, with the aim of obtaining as complete an overview as possible of the evolution of Spanish research into neutron techniques over the last thirty years.

a) Output indicators

NUMBER OF PUBLICATIONS

INDEX OF ACTIVITY

This analyses the degree to which a region or sector specialises in research into neutron techniques. It is calculated as the ratio between the contribution of a region or sector to the number of publications on neutron techniques with Spanish co-authors and the contribution of the region or sector to the Spanish output as a whole.

The JCR (Journal Citation Reports) classification of journals into disciplines is used to study trends in the thematic profile of activities. This groups journals into eight major areas.

b) Impact indicators

JOURNAL IMPACT FACTOR

Used as an indicator of the prestige of the journals in which the Spanish community publishes. The Journals' impact factor the year in which documents are published (JCR) is taken into account.

A frequent researcher in the field is one who has co-authored 5 or more documents in the last 15 years.

PERCENTAGE OF DOCUMENTS IN FIRST-QUARTILE JOURNALS

This includes the percentage of documents published in the 25% of journals with the highest impact factor within each discipline.

NUMBER OF CITATIONS PER DOCUMENT

This is an indicator of the repercussions the document has had within the scientific community in the field. The number of citations is analysed using various fixed citation windows (1, 2, 3 and 4 years), and a variable citation window, i.e. including all citations obtained for the documents from their date of publication to the downloading date.

c)

Indicators of collaboration, using several variables to analyse collaboration between authors and institutions:

COLLABORATION RATES: TOTAL, NATIONAL AND INTERNATIONAL

CO-AUTHORSHIP INDEX, OR NUMBER OF AUTHORS PER DOCUMENT

ANALYSIS OF COLLABORATION NETWORKS (USING UCINET)

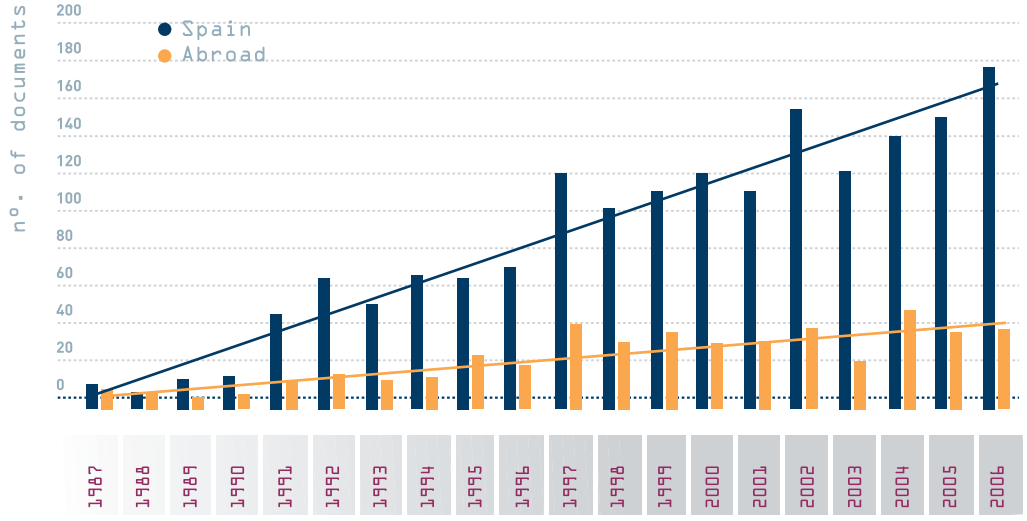
The evolution of output and impact is analysed using the indicators listed above. To evaluate the **Big Science** characteristics of the discipline and the integration of the Spanish researchers into the international scientific community, collaboration in the area, particularly collaboration with other countries and the presence of Spanish researchers in institutions abroad are studied.

The following criterion was adopted to quantify the size of a scientific community (in this case, the Spanish community which uses neutron techniques): ***"A frequent researcher in the field is one who has co-authored 5 or more documents identified according to the selection criteria stated above, in the last 15 years."*** This criterion allows us to compare the sizes of a given scientific community in different countries objectively, and to analyse their evolution development over time.

5 THE EVOLUTION OF SCIENTIFIC OUTPUT

Spanish scientific output in the field of neutron techniques between 1977 and 2006 comprised of 1687 documents (this figure increases to 2122 if we also consider documents in which Spanish researchers, not belonging to Spanish institutions, participated).

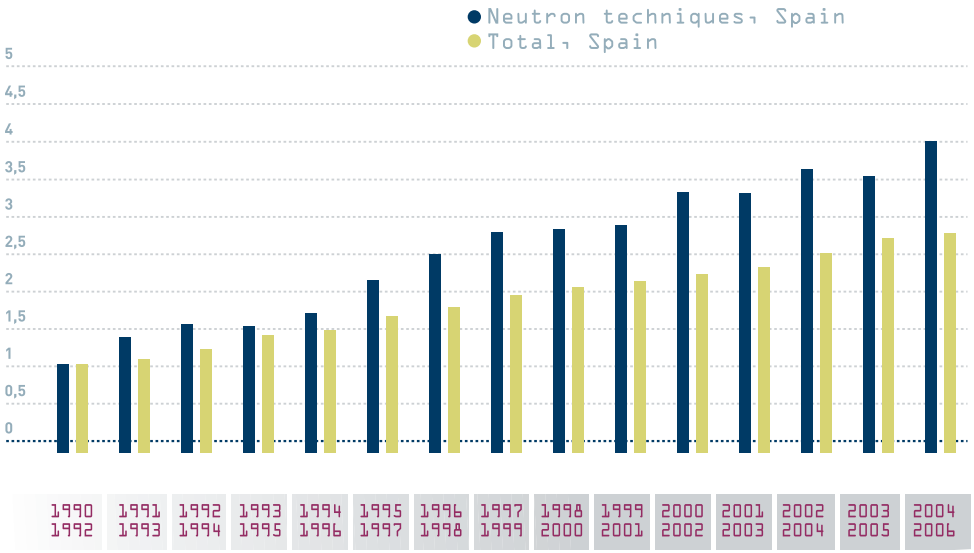
Up to 1990, output is sporadic and irregular (33 documents + 24 documents by Spanish researchers abroad), with a major increase after 1991 being observed (Figure 1). The output of Spanish researchers abroad (post-docs, researchers who have settled abroad, sabbaticals, etc.) is close to 20% of the total output for this period.



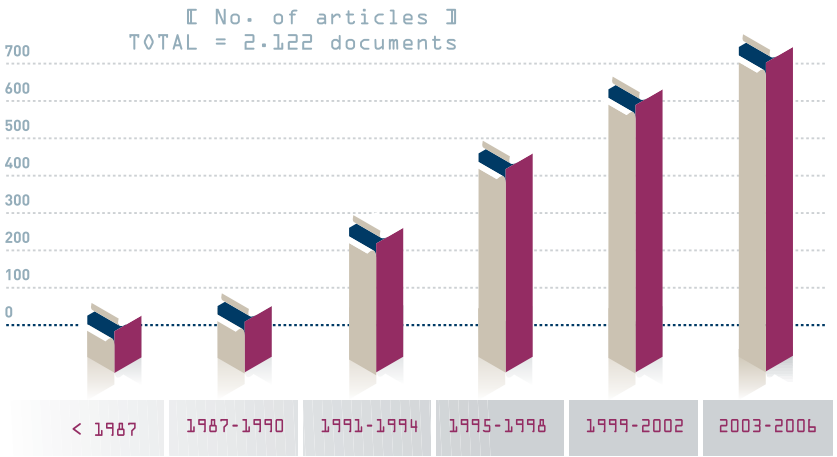
1.

Figure 1.
Evolution of Spanish scientific output in the field of neutron techniques.

The relative growth of publications on neutron techniques is greater than that of Spanish output as a whole in the WoS (Figure 2a). Output in the field of neutron techniques increases fourfold between the three years from 1990 to 1992 and the three years from 2004 to 2006, while Spanish scientific output as a whole increases by a factor slightly under 3.



2.a



2.b

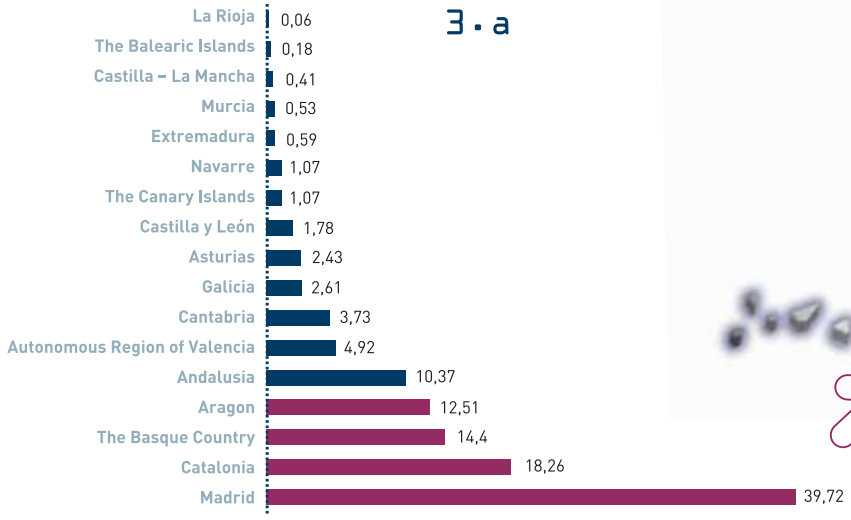
Figure 2.
2.a) Index of variation in the number of Spanish documents on neutron techniques and in all disciplines (baseline = 1990-92). 2.b) Development of the total number of documents over four-year periods.

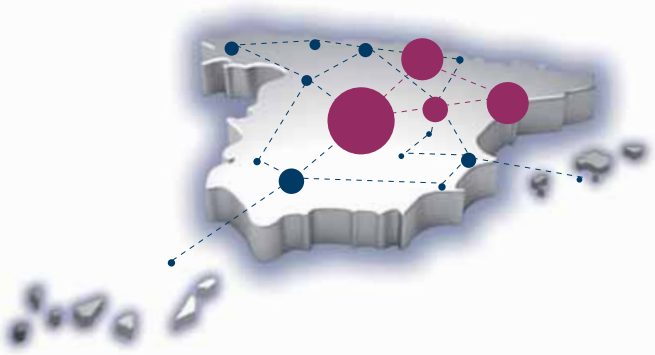
Spanish scientific output, in the field of neutron techniques, between 1977 and 2006 comprised of 2122 documents.

It is worth noting that over 57% of the output for the whole period was carried out in the 7 years from 2000 to 2006 alone. The distribution of output by region between 1970 and 2006 is shown in Figure 3. It should be highlighted that output is significantly concentrated in the Autonomous Community of Madrid.

Three other regions (the Basque Country, Aragon and Cantabria) also stand out significantly in the field. Their relative contribution to the subject is 2-3.5 times greater than that of the country's ***output*** as a whole.

If we turn to the institutional sectors and analyse the authors affiliation, we find that 69% of the documents list a Spanish university, 36% list one of the Scientific Research Council Centres (Consejo Superior de Investigaciones Científicas, CSIC), and 19% list mixed institutions (CSIC/University). This last group shows the highest degree of specialisation, as its proportional contribution to the subject is four times greater than that corresponding to Spain's output as a whole.





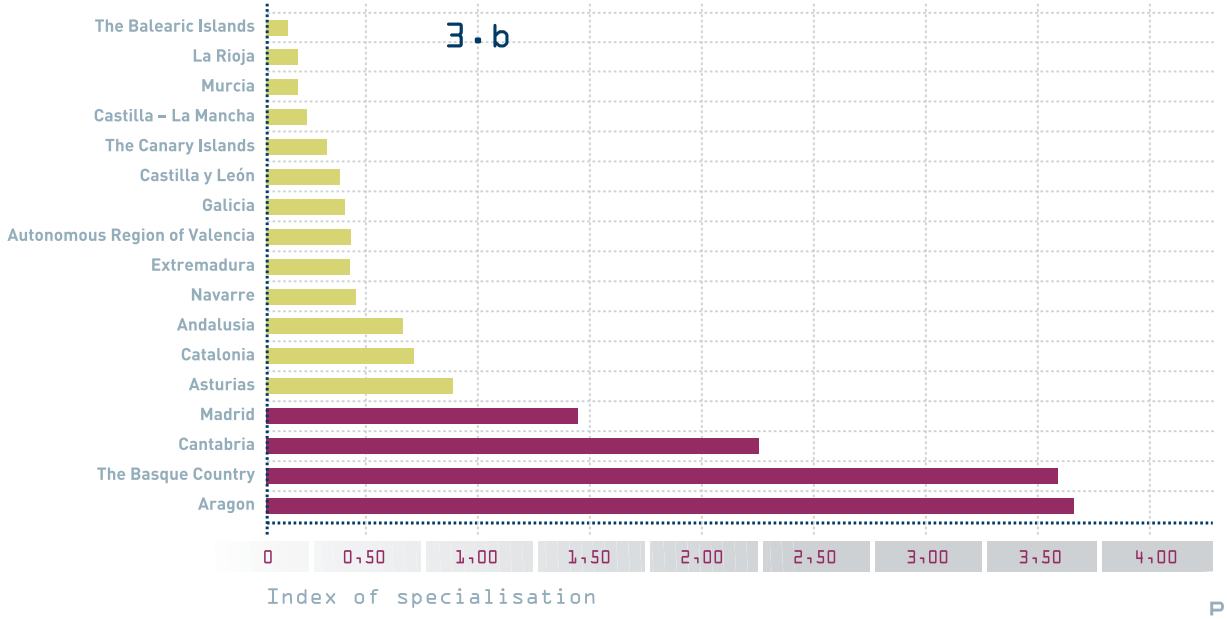


Figure 3.
3.a) Percentage of total of output by Autonomous Communities (WoS 1970-2006). 3.b) Index of specialisation of each Autonomous Communities (WoS 2003-2006).

6 CENTRES OF ACTIVITY: INSTITUTIONS & RESEARCHERS

The increase in output over time has been accompanied by a significant increase in the number of Spanish institutions which have published one or more documents relating to this discipline. This figure has increased from 40 (for 1991-1994) to 109 (for 2003-2006). It should be noted that output is generally concentrated in a small number of institutions, so that 50% of output corresponds to 5 institutions in the first of these periods, and to 11 in the second. Be that as it may, 33 of the 40 identified in the first period are still active in the last period studied, indicating that more than 80% of the institutions involved in the first years have now consolidated their status in the field. The institutions with the highest output in the period studied

include two CSIC institutions (the Madrid Institute of Materials Science and the Materials Science Institute of Aragon) and two university faculties (the Chemistry Faculty of the Unversidad Complutense of Madrid, and the Science & Technology Faculty of the University of the Basque Country).

Over the years, there has been a spectacular increase in the number of ***frequent researchers*** in the area (co-authors of 5 or more articles), which increases from 2 before 1990 to over 200 in 2006. Figure 4 shows the change in the number of 'frequent researchers in the field' over five-year periods. This information shows that the increase in output is due both to greater productivity on the part of researchers and a larger number of active researchers.

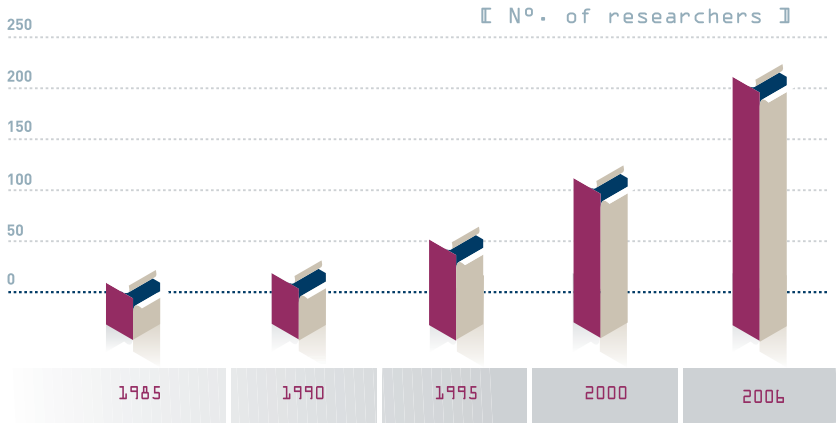


Figure 4. Evolution of the number of neutron technique researchers over five-year periods, following the established criterion of co-authorship of 5 or more documents (WoS, 1970-2006).

7 THE IMPACT AND QUALITY OF SPANISH RESEARCH USING NEUTRON TECHNIQUES

The trend detected is that the prestige of journals where articles are published is increasing as well as the number of citations received by publications over time (see Figure 5). This demonstrates the increasing quality of Spanish research into neutron techniques.

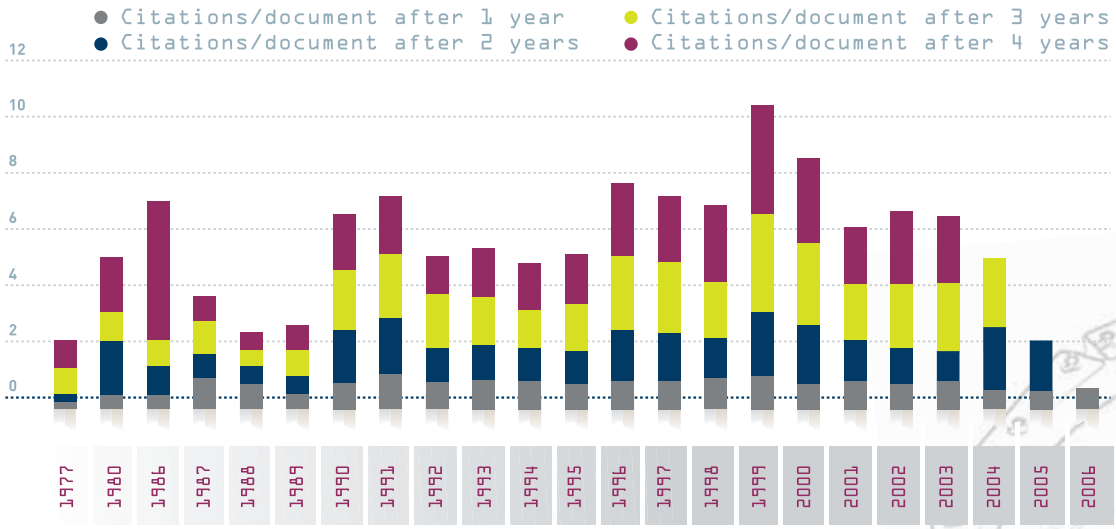
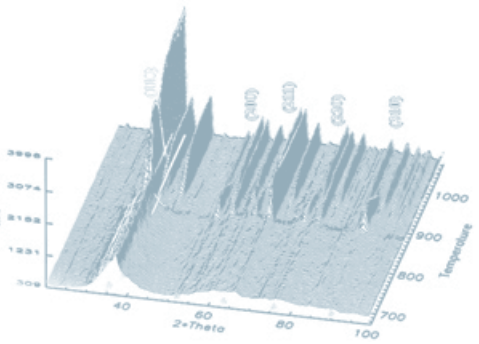
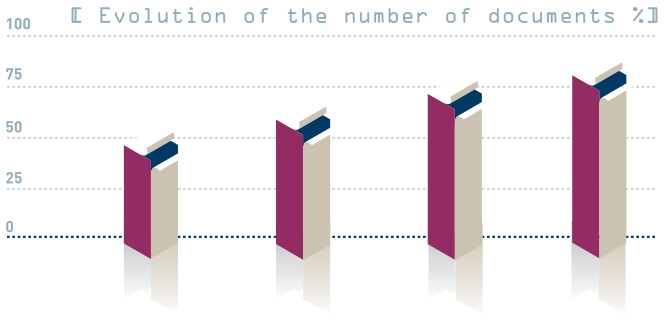


Figure 5. Development of the number of citations per document using citation windows of 1, 2, 3 and 4 years after publication.



The year-on-year evolution of the proportion of documents in first-quartile (Q1) journals (i.e. published in the 25% of journals with the highest impact factor within each discipline) is shown in Table 1. It is important to highlight the gradual increase in this proportion, which rises to almost 80% in the last period examined.

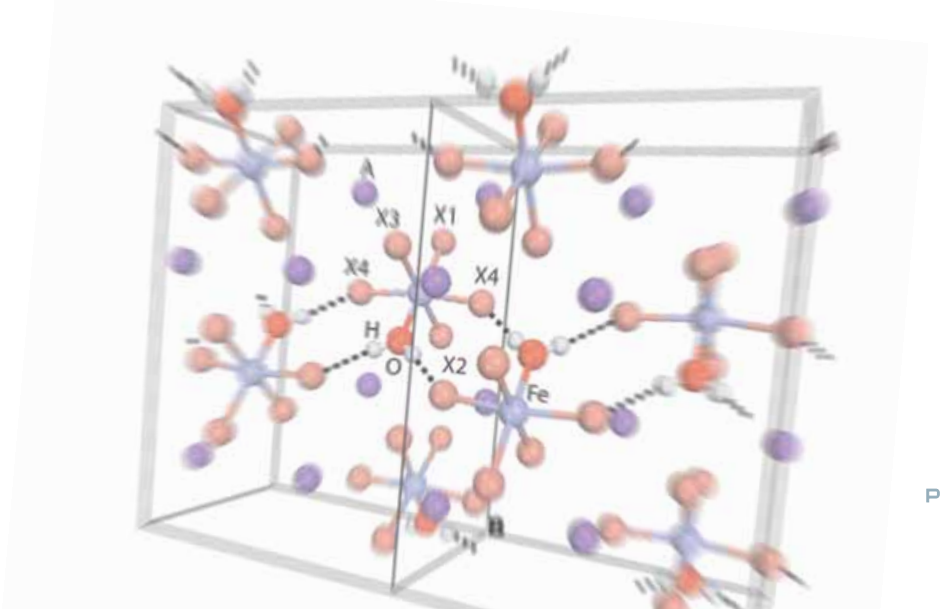
Table 1. Year-on-year evolutionof the total number of documents and citable items, and the percentage of these in Q1 journals (WoS 1991-2006).

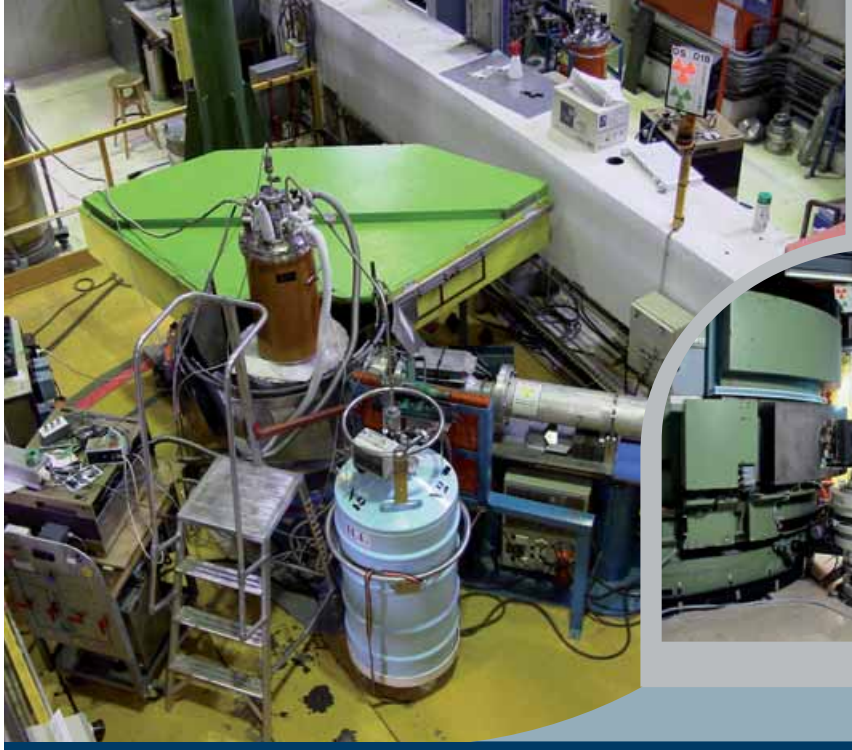


	1991-1994	1995-98	1999-02	2003-06
Nº. of docs	157	354	495	470
Nº. of docs, Q1	72	194	359	368
% of docs, Q1	45,86	54,80	72,53	78,30

NB: Nº. of docs, Q1 = Number of documents in first-quartile (Q1) journals (the 25% of journals with the highest impact factor within each discipline). The number of Q1 documents was calculated on the basis of journals' JCR classifications within their disciplines for the year in which documents were published (1997-2006), or for 1997 (for 1990-1996, as the JCR classifications for these years were not available).

Almost **80% of articles** published today are published in first-quartile journals.





8 THEMATIC PROFILE OF RESEARCH USING NEUTRON TECHNIQUES

The distribution of documents by field (Table 2) shows that output is mainly concentrated in **physics** (58% of the total), **chemistry** (40%), and **engineering** and **technology** (23%). Other fields contribute only sporadically. Over time, research in chemistry increases significantly (from 27% in 1991-1994 to 48% in 2003-2006), while the proportion of physics research falls (70% of documents in 1991-1994 vs. 51% in 2003-2006) (Figure 6). In each field, articles on neutron techniques tend to be published in journals with a greater impact factor than the average for Spanish output as a whole.

Table 2. Thematic profile of activities by field.

Field	< 1987	1987 1990	1991 1994	1995 1998	1999 2002	2003 2006	Total	%
Physics	3	25	154	216	277	300	975	57,79
Chemistry	0	2	60	126	203	282	673	39,89
Engineering, Technology	1	10	42	64	134	134	385	22,82
Biomedicine	0	0	1	5	8	13	27	1,60
Others	0	0	2	4	4	6	16	0,96
Total	3	30	221	354	495	584	1.687	

NB: Fields are defined according to the JCR (2005) classification of disciplines in major areas. It should be stressed that the sum of the percentages is greater than 100%, as some journals are allocated to more than one subject area. Indicators relative to areas with a low number of documents are not calculated.

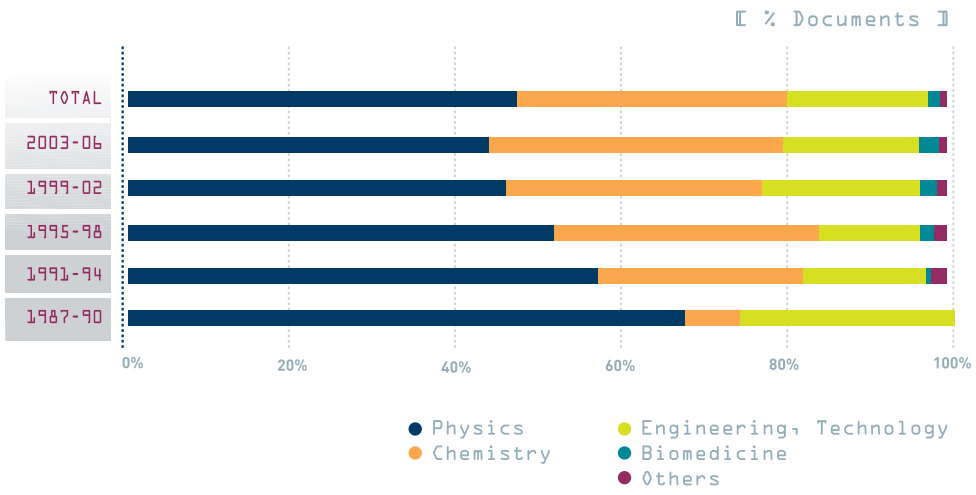


Figure 6. Development of thematic profile over time.

A more in-depth thematic analysis shows that output is distributed among 56 disciplines, with the following being the most significant in terms of the number of documents: ***solid state physics*** (34%), ***physical chemistry*** (24%), ***multidisciplinary materials science*** (19%), and ***inorganic and nuclear chemistry*** (13%). Over time, there is a decrease in the proportion corresponding to solid state physics, while the contribution of other disciplines increases (21 disciplines in 1991-1994 vs. 49 in 2003-2006). There is a positive evolution in all disciplines, some showing particularly outstanding growth, such as ***inorganic and nuclear chemistry*** (a 512% increase), ***physical chemistry*** (a 318% increase) and ***atomic, molecular and chemical physics*** (264%), all with growth figures above the average for the field.

{ Research using neutron techniques tends to be published in more prestigous journals than Spain's average scientific output in practically all disciplines.

If we examine the last seven years (2000-2006), we see in Figure 7 the eleven disciplines with the greatest output, along with their impact relative to the average for Spain in each discipline. Thus we see that research using neutron techniques tends to be published in more prestigious journals than Spain's average scientific output in practically all disciplines (RIF> 1), while it receives more citations than the Spanish average in six of the eleven disciplines (relative citations > 1). Particularly outstanding areas include polymers, for their high RIF, and multidisciplinary chemistry, for its high relative citation index.

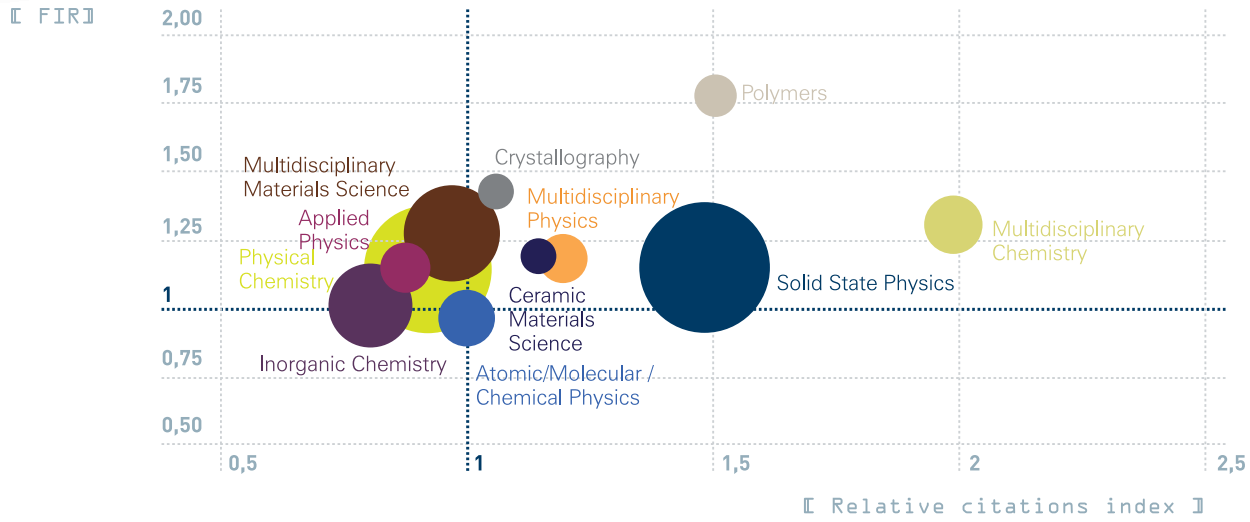


Figure 7. Main publication disciplines, with relative impacts and their relative citations indices (WoS 2000-2006).

9 GENERAL CHARACTERISTICS OF SCIENTIFIC COLLABORATION

The average number of authors per document has remained fairly stable at around 5 throughout the period examined, while the average number of institutions per document tends to grow, and is now approximately 3 (see Table 3).

Table 3. Development of collaboration on neutron techniques over time (WoS 1970-2006).

Year	< 1987	1987-90	1991-94	1995-98	1999-02	2003-06	Total
Nº. of authors / document	3,33	5,10	4,77	4,78	5,18	5,41	5,1
Nº. of institutions / document	2,67	2,57	2,36	2,46	3,06	3,09	2,8

Research into neutron techniques is characterised by high indices of collaboration, particularly international collaboration. This is shown clearly when we compare the collaboration profile of this field with that for Spain as a whole (Figure 8). For 2000-2006, less than 14% of documents were attributable to a single institution; this figure being 38% for Spanish output as a whole. The national collaboration rate is similar to that for Spain as a whole, but the high proportion of documents with international collaboration (75%), which is much higher than the proportion for Spanish scientific output as a whole (34%) is striking.**[2]**

[2] Gómez, I., Sancho, R., Bordons, M., Fernández, M.T., La I+D en España a través de publicaciones y patentes (R&D in Spain via Publications and Patents). In: Sebastián, J. and Muñoz, E., Eds. Radiografía de la investigación pública en España (An X-Ray of Public Research in Spain), pp. 275-302, New Library, Madrid, 2006.

Research using neutron techniques is characterised by **high indices of collaboration**, particularly international collaboration.

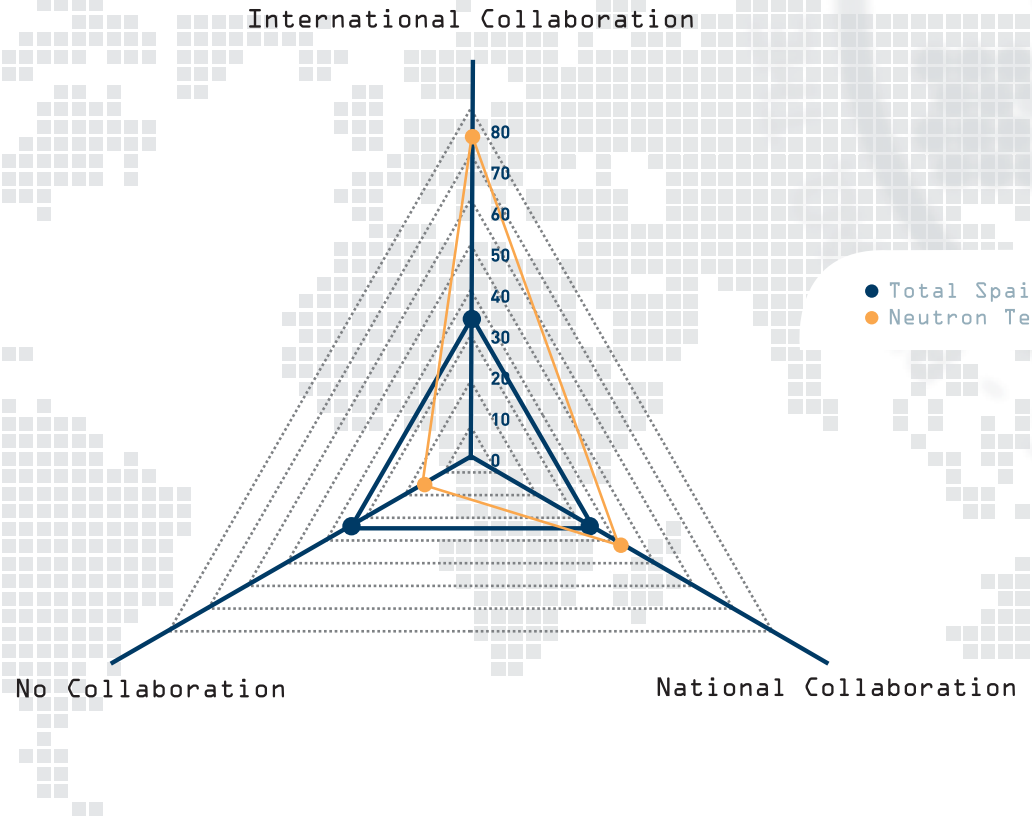


Figure 8. Collaboration profile of Spanish research using neutron techniques in comparison with Spanish scientific output as a whole (WoS 2000-2006).

Research with international collaboration has certain distinctive characteristics, such as higher numbers of authors and institutions per document, and greater orientation towards subjects within the domain of Physics. 60% of documents with international collaborations are published in journals dedicated to fields within physics, and almost half (49%) of documents are published in journals devoted to fields within chemistry.

10 DETAILS OF INTERNATIONAL COLLABORATION

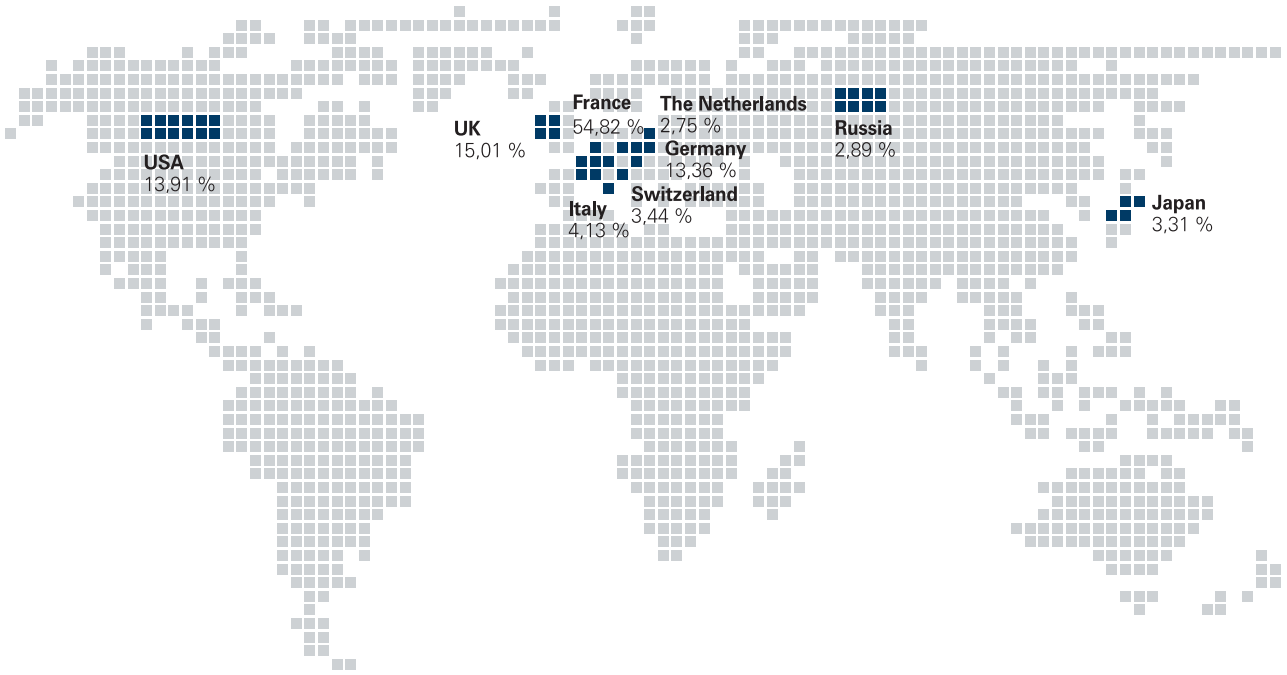
Collaboration with European Union countries is dominant (61%) throughout the period examined, although this percentage tends to fall slightly as links with other countries increase (e.g. links with the USA, which have risen from 7% to 10% in recent years).

Within the countries with which neutron technique researchers have collaborated on more than 10 documents in the most recent period (2000-2006), France´s position stands out with a frequency four times higher than that of the country in second place. France is involved in 55% of documents, while for Spanish science as a whole collaboration with France represents only 17%. The UK, on the other hand, which is the country that most collaborated with in Spanish science as a whole (27%), appears in only 15% of documents within the field of neutron techniques. This close relationship with France is explained by the fact that the first neutron source in which Spain became active was the ILL. Table 4 shows data for the countries which appear in 20 or more documents.

As is shown in Table 5, all the institutions with which Spain has collaborated on more than 10 documents in recent years have major facilities for research using neutron techniques. Particularly striking is the **high level of collaboration with the Institut Laue-Langevin (ILL) in Grenoble, which is involved in 36% of Spanish output on neutron techniques**. This is because, as mentioned above, Spain has been associated with the ILL for more than 20 years.

Table 4. Distribution by country of Spanish documents on neutron techniques carried out with international collaboration, and comparison with Spain's collaboration profile in all fields (WoS 2000-2006).

[Countries]	A Neutron techniques		B All fields in Spain	
	Nº. of docs	% int'l coll.	Nº. of docs	% int'l coll.
France	398	54,82	13.024	17,16
UK	109	15,01	20.799	27,41
USA	101	13,91	15.070	19,85
Germany	97	13,36	11.543	15,21
Italy	30	4,13	10.478	13,81
Switzerland	25	3,44	3.756	4,95
Japan	24	3,31	2.144	2,83
Russia	21	2,89	2.606	3,43
The Netherlands	20	2,75	5.210	6,87



The high level of international collaboration in the field is explained by the fact that a great deal of research is associated with foreign institutions with large facilities devoted to research using neutron techniques. Many publications, particularly in the fields closest to physics, are the result of work at these institutions or collaboration with researchers there. Even among documents with no manifested international collaboration (no foreign research institutions are mentioned in the authors' place of work information), links with foreign institutions have been found, in the form of references to experiments or use of data obtained at a foreign experimental facility. The importance of international collaboration is demonstrated by its presence in the small number of documents published before the 1990s, and by the fact that even after that date there are publications by Spanish researchers abroad, which suggests a high degree of dependence on large facilities at foreign institutions for research. In the last decade, 8 of every 10 publications by Spanish researchers have come from researchers located in Spain (6 of them with international collaboration), and 2 from researchers abroad.

Table 5. Foreign institutions with which Spanish researchers collaborate (only institutions with more than 10 documents collaborated on (WoS 2000-2006).

Institution	Country	% docs with int'l collaboration
Institut Max Von Laue Paul Langevin, ILL	France	36,36
CEA Saclay, Lab Leon Brillouin, LLB	France	4,96
ISIS-Rutherford Appleton Lab	UK	4,82
KFA Forschungszentrum Julich GmbH	Germany	3,99
Centro Atómico Bariloche	Argentina	3,03
Laboratorio Louis Neel, CNRS	France	2,48
Paul Scherrer Institut	Switzerland	2,34
Argonne National Laboratory	USA	2,20
Los Álamos National Laboratory	USA	1,93
Hahn Meitner Inst Berlin GmbH	Germany	1,65

It is interesting to note that Spanish researchers tend to collaborate with EU countries in 61% of their publications, and with the US in only 14%. This latter percentage is lower than that for other fields (20%).

Although other disciplines note greater impact for research carried out with international collaboration, our data do not show any significant differences in impact according to whether or not foreign institutions are involved in publications. There are significant differences in the numbers of institutions and authors: documents prepared with international collaboration tend to have higher numbers of both. Some authors claim that this favours greater impact, but in our case no clear trend is observed.

One possible explanation for this is that international collaboration is essential for research in this field, and is not limited to prestigious researchers or groups as sometimes happens in other disciplines. On the other hand, an earlier study in the field of physics also failed to show the greater impact expected for international collaboration **[3]**, stating that increased impact is directly related not to international collaboration, but to the ability to cooperate with "well-connected" agents. Neither should the greater impact expected and observed for publications by Spanish researchers in collaboration with US institutions be overlooked. This suggests an interest in developing these links, which are not as strong in this discipline as in other fields of research.

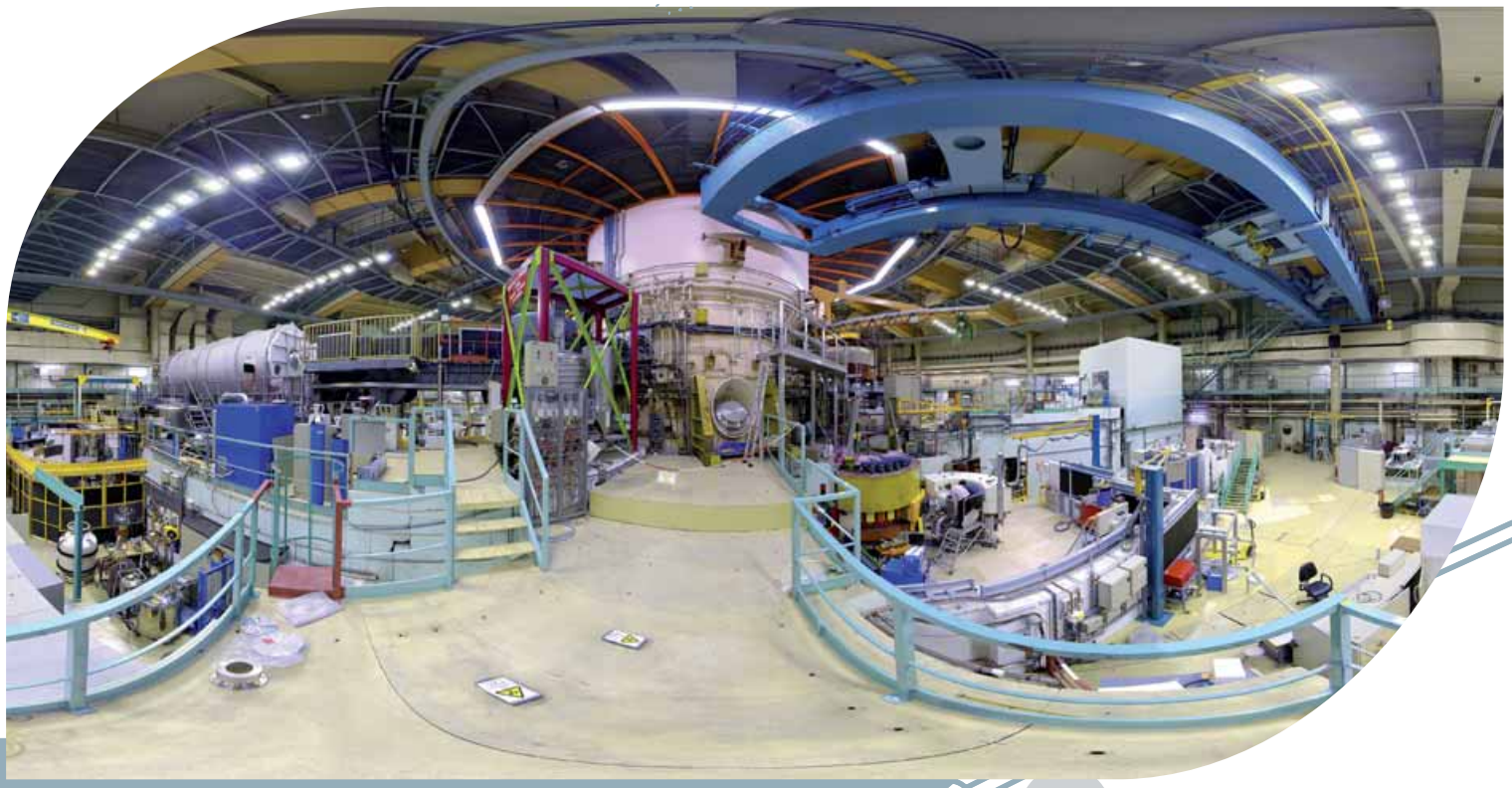
[3] MA, N. AND GUAN, J. C., An Exploratory Study on Collaboration Profiles of Chinese Publications in Molecular Biology, Scientometrics, Dec. 2005; 65(3):343-355; VAN RAAN, A. F. J., The Influence of International Collaboration on the impact of Research Results: Some Simple Mathematical Considerations Concerning the Role of Self-Citations, Scientometrics, Jul. 1998-31 Aug 1998; 42(3):423-428.

11 THE DEVELOPMENT OF COLLABORATION NETWORKS BETWEEN INSTITUTIONS

Given the importance of collaboration between institutions in the field, only 17% of documents were attributable to a single institution between 1970 and 2006. This percentage falls to 13% if only the period 2000-2006 is considered. This is studied by analysing social networks and their development from the beginning to the end of the period examined.

The number of nodes in the network almost trebled between the two periods analysed (1991-1994 and 2003-2006), but network structure remains very similar: in both periods, the network had 58% of its nodes connected, and two components. The main component, centred very clearly on the ILL, includes 71% of the connected nodes in the first period, and 95% of the connected nodes in the second period: although the size of the network increases, it remains centred on the ILL, perhaps becoming even more so.

There are few links between Spanish institutions, although they do tend to increase over time. Almost all Spanish institutions within the main component for the first period maintain a similar intensity of collaboration in more recent years. The following institutions are important in both periods: the Material Science Institute of Madrid,



the Chemistry Faculty of the Universidad Complutense of Madrid, the Institute for Material Structure and the Material Science Institute of Aragón. In the second period a clique appears, consisting of the Chemistry Faculty of the University of the Basque Country, the Donostia International Physics Center and the Materials Physics Dept. (CSIC/University of the Basque Country) in San Sebastián. These, along with the Forschungszentrum Jülich, are closely interconnected.

Regarding the positions of nodes within the network, if we consider only the main component it is striking how central the ILL is for the various parameters examined (degree, proximity and mediation), as it is the node with the highest values in both periods. Next in importance is the Material Science Institute of Madrid, which maintains a high degree of centrality over time according to the indicators used (see Figure 9).

The network remains centralised in the second period. The degree of centrality and proximity of the main nodes of the network tend to fall slightly, while their mediation increases due to the appearance of new institutions operating closer to the edge of the network.

The network is centred very clearly on the ILL, to which 95% of the nodes are connected.

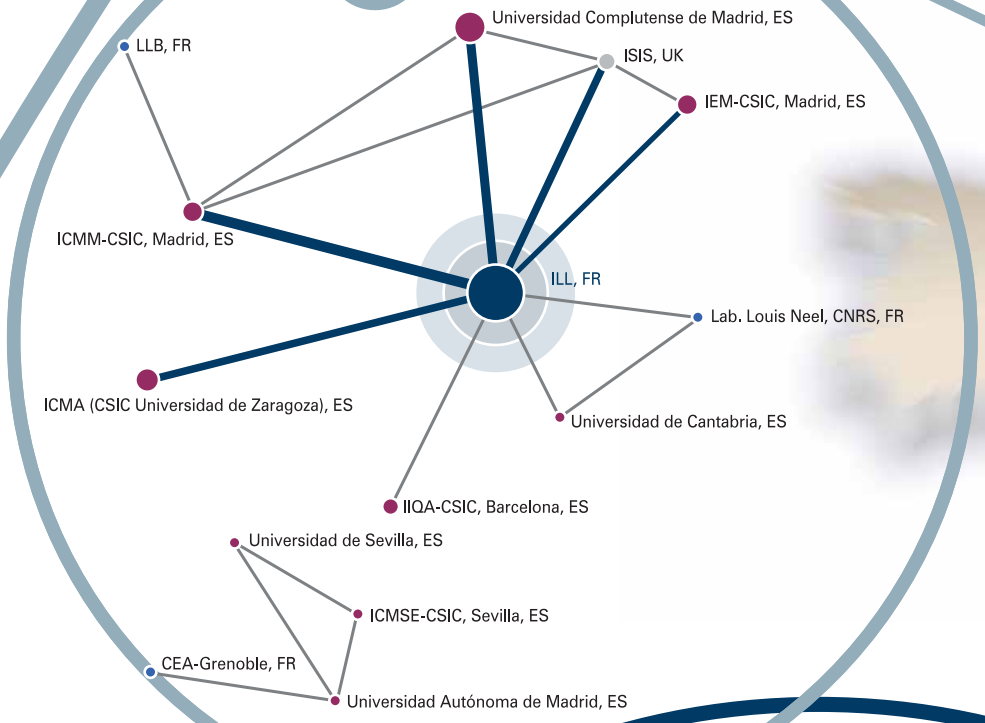
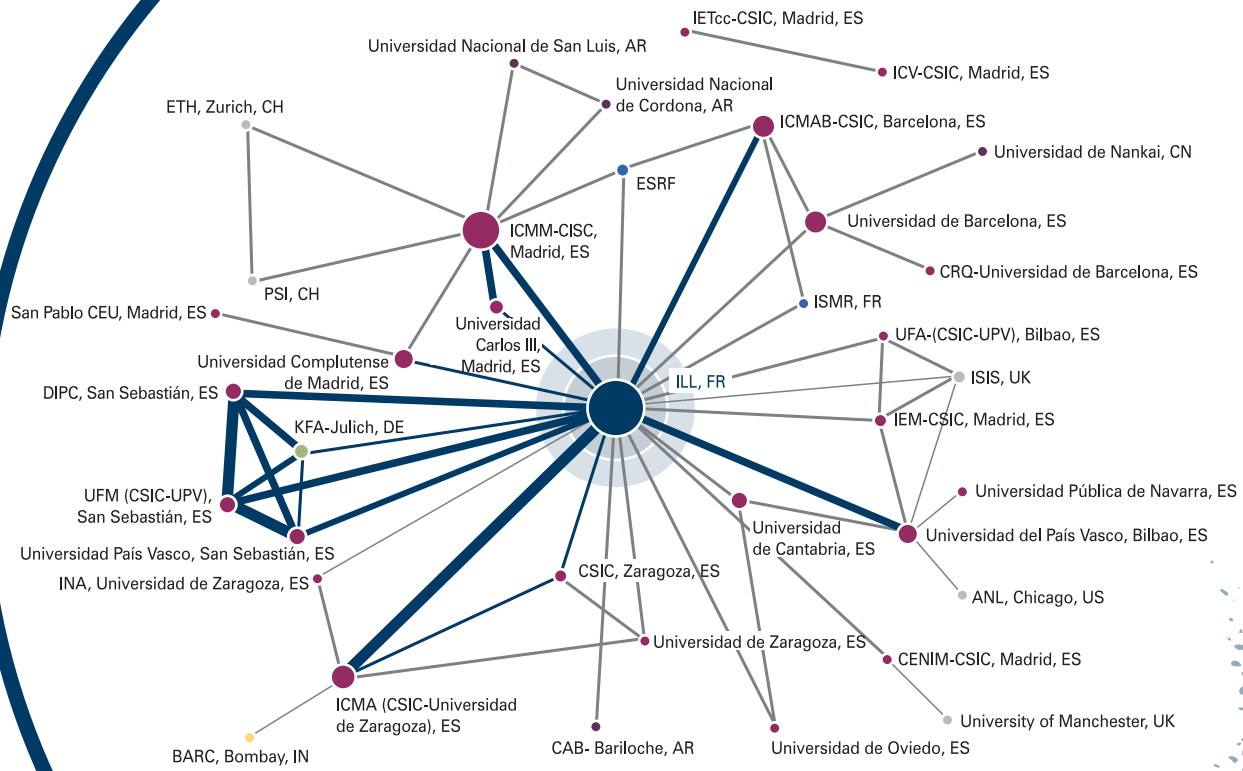


Figure 9. Development of the collaboration between institutions network (only institutions with more than 4 documents collaborated on).

1991-1994

2003-2006



In order to display the collaboration networks between Spanish institutions more clearly, the ILL has been removed from Figure 10. This shows the appearance of other components, which show a tendency to group together centres which are close together geographically and have links with institutions abroad. However, only in exceptional cases do they have intense collaboration links (see Figure 9).

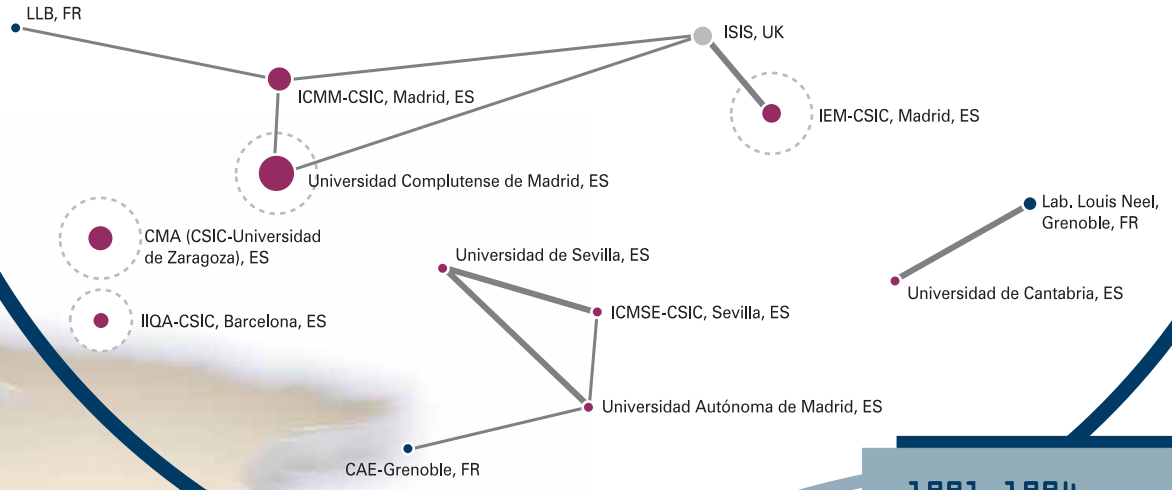
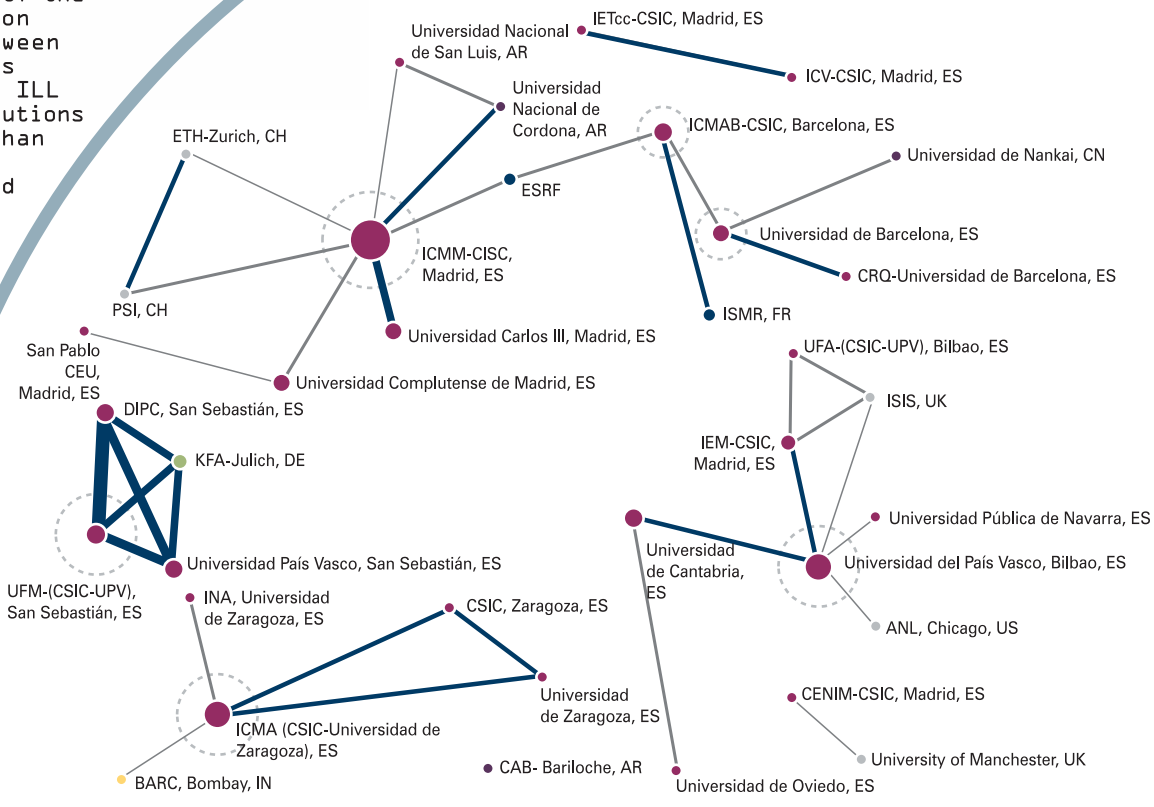


Figure 10. Development of the collaboration network between institutions without the ILL (only institutions with more than 4 documents collaborated on).



12 SPAIN IN A GLOBAL CONTEXT

Spain's position in the worldwide ranking is 8th, with a high average number of citations per document.

In order to illustrate the changes in Spain's relative position in the global context, a general search for documents was carried out, restricted to those which contained the terms "neutron AND (scattering OR diffraction OR reflect* OR echo OR polari*)" in the title. Three four-year periods (1983-1986, 1993-1996 and 2003-2006) were selected. In the first period, 1983-1986, Spanish scientists appear in only 0.5% of documents, and Spain ranks 25th among the countries with the highest output. In the second period, 1993-1996, Spain has made spectacular progress: Spanish contributions are present in more than 2.5% of global output, and it has climbed to no. 12 in the ranking. In the most recent period, 2003-2006, Spanish scientists appear as co-authors in more than 5.5% of all publications. Spain's current position in the worldwide ranking is 8th.

It should also be noted that the average number of citations received per document is above the worldwide average in the last two of these three periods. In the last period studied, Spain is also among the 6 countries with the highest citation per document coefficient, among the 20 countries with the highest output.

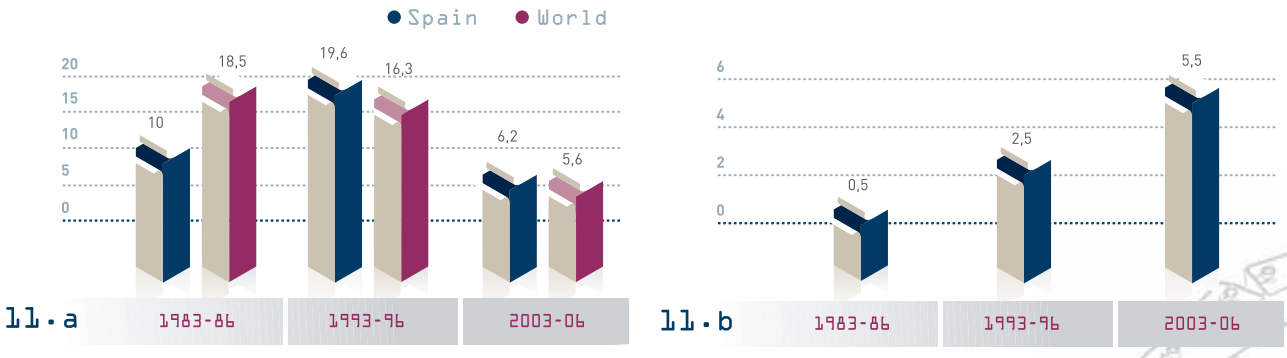


Figure 11. a) Impact of publications (number of citations per document) with Spanish co-authors on neutron techniques. The citation window runs from the date of publication to the present. b) Percentage of documents with Spanish co-authors.

13 CONCLUSIONS

SPANISH SOCIETY
FOR NEUTRON TECHNIQUES

Several findings indicate that research into neutron techniques in Spain is well established and enjoying major growth:

* **Major increase in the number of documents**, particularly from the beginning of the 1990s onwards. This increase is greater than that of Spanish scientific output as a whole in the same period. The soar in Spanish output occurs after 1987, when Spain became an associated scientific member of the Institut Max von Laue-Paul Langevin (ILL), an international point of reference in research using neutron techniques, and after the creation of the ***Users' Commission***, which acts as an advisory and consultancy body to the Spanish Government on this field, and the Spanish Society for Neutron Techniques, which currently has more than 250 members.

* **Increased output is significantly linked to the increase in scientific collaboration in the field**. National collaboration increases, contributing to the creation of networks within Spain, and especially to international collaboration, which is involved in almost 70% of documents. This facilitates the integration of Spanish researchers into the international scientific community.

* **Growth in the expected and observed impact of output**, which tends to be published in higher-prestige journals, and to receive more citations, over time.

* **A growing breadth of research subjects over time**. This favours the application of neutron techniques in the context of various disciplines and with various applications. There has been an increase in publications on chemistry, along with a relative decrease in fields within physics.

* **Increasing output of the most active institutions**, which tend to consolidate their position over the period examined, and the appearance of new institutions active in the field.

* **An increase in the number of active 'frequent scientist' authors** both in Spain and abroad. This is greater than the increase in the number of publications.
* **Output and impact data for Spain can be placed in the global context**. From the beginning of the 1980s onwards, Spain has climbed the ranking of countries with most output, and now ranks 8th. Spanish publications have greater impact than the worldwide average for the field.

France, which is present in more than half of Spanish publications with international collaboration, is Spain's main collaborator, thanks to the major facilities located there, particularly the ILL. The presence of Spanish researchers at the ILL has been promoted by the Spanish Government, and has allowed a separate group, ***Spanish Initiatives on Neutron Scattering*** (SpINS) **[4]**, to be created. A study of scientific collaboration networks of Spanish scientists in the field shows that they are clearly centred around the ILL, indicating particular dependency on the ILL for research. Over the years, new institutions have been incorporated into the network, increasing its size and the links between Spanish institutions, but the network remains centred around the ILL, which is its core.

The ***European Neutron Scattering Association*** (ENSA) **[5]**, which brings together the main national associations in this field Europe-wide and regularly organises various activities and conferences, should also be borne in mind. This is an association which promotes and supports research within the field, coordinates and develops new facilities and fosters links with industry and society, making it an undoubted factor for cohesion and integration between member countries, favouring the dominance of links between European countries over intercontinental links.

Despite significant dependence on particular facilities, our data suggest that there is also research in the field which is not clearly related to neutron sources located abroad, i.e. there is also ***Small Science*** within this discipline. Another striking fact is that if we examine the number of authors and institutions per document the size of research teams is not excessively large in comparison with other areas of physics. This is a **Big Science** in that it is dependent on large, costly facilities shared internationally, but if we look at co-authorship information it does not seem to require large teams for its experiments.

An examination of authors' output levels reveals a high proportion of occasional authors and a core of highly productive authors, with a

[4] **http://spins.unizar.es**

[5] **http://neutron.neutron-eu.net/**

high proportion of their output carried out in collaboration with foreign researchers. Do these researchers belong to the international social networks of the discipline? Their regular participation as speakers at the main conferences in the field would seem to suggest that they are. A quick consultation of the schedule of the main conferences held on this subject in recent years ***(European Conference on Neutron Scattering, International Conference on Neutron Scattering)*** reveals that Spanish researchers do attend these events, particularly European events, and that some are members of the scientific committees of European conferences, and scientific committees and experiment evaluation panels at the main European neutron sources, but rarely at their American equivalents (based on consultation of the last three events held: 2004, 2006 and 2008). A more detailed, rigorous study of the role of Spanish researchers in the international scientific community would require analysis of the citations received by their publications: are they cited by groups and researchers with prestige within their specialist areas? However, this analysis falls outside the aims of this work.

In summary, Spanish research in this field is closely linked to Spanish researchers' growing access to neutron sources in various countries around the world, which are the cores of research in the area. **A new spallation neutron source in Europe would undoubtedly stimulate competitive, quality scientific and technological research, and training for young scientists and technology specialists in the field. One argument in favour of locating this neutron source in Spain is that Spanish research into neutron techniques is currently enjoying major development and growth, in both quantitative and qualitative terms, with an impact well above the worldwide average, and a great deal of specialisation in the field in certain regions of Spain.**




Staff

Thirty years of Spanish research using neutron techniques: a well-established discipline

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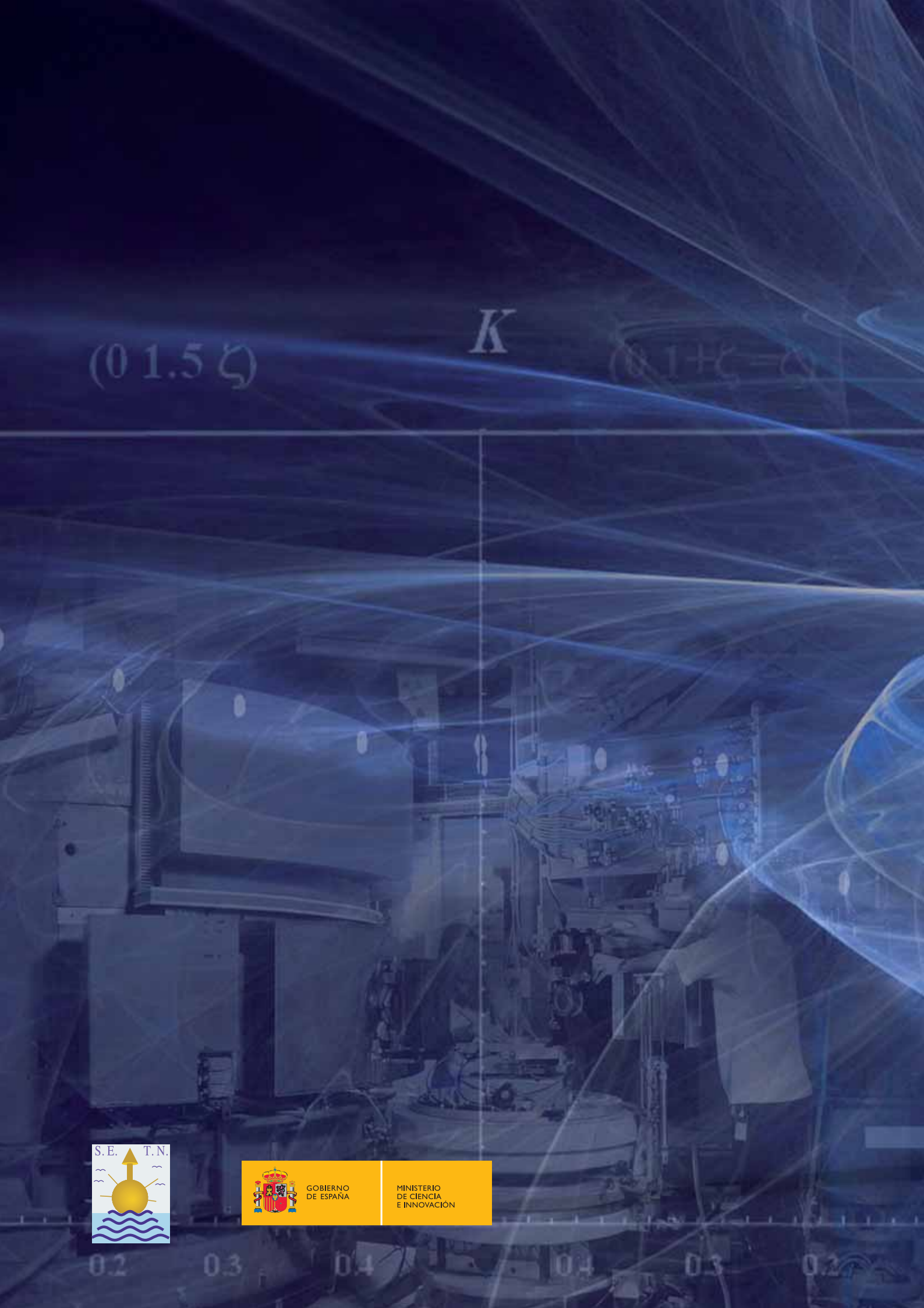
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