

ELECTRONIC PAPERS FROM THE RESEARCH LANDSCAPE PROJECT

Series Editor: Ulf Sandström

2000:11

REPORT TO THE SERF COMMITTEE OF EURATOM (MACRO TASK S1)

**The Global Scale of Fusion
Fusion Research Labs and Opinions in Comparative Perspective**

Docent Ulf Sandström, PhD Mats Benner & M Sc Henrik Sandén

With contributions from:

PhD-student Martin Meyer, Science Policy Research Unit, Sussex University

Prof. Olle Persson, Umeå University, Sweden

N.B! No Appendices in this Version.

Swedish Institute for Studies in Education and Research

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Chapter 1: Introduction

1.1 Fusion as a Large Technical System

A research activity concerned with Thermonuclear Fusion by magnetically confined plasmas has been going on for three decades. The energy crisis of the 1970s was a driving force for increased budgets for fusion related research. The main objective of the European fusion program is to develop fusion reactors based on the DT (deuterium and tritium) reaction for power production. In comparison with other energy sources, the fuel supply for fusion is practically inexhaustible and the process is supposed to have minimal impact on the environment. Thus, fusion is seen as one of the very few acceptable long-term solutions for power production.

In political discussions about energy it is often put forward that energy supply will be a critical factor for economic growth in less developed countries in the 21st century, and that a more even distribution of energy could become a major determinant of global political stability. Fusion as a never-ending source of energy is, of course, often mentioned when these matters are discussed. However, the development cost of fusion energy is high and the scientific challenge is great. These circumstances lead some politicians and scientists to argue that fusion is not a viable source of energy.

The core science of fusion energy is plasma science, the study of the ionized states of matter. Plasma science is central in the development of fusion as an energy source. Plasma science is a fundamental scientific discipline with a significant impact on a wide range of national political objectives. Thus, fusion science and technology should not be treated as an isolated science policy issue. Instead, it has to be seen in the overall organization and political perspective of the fusion area.

Experimental fusion reactors are large and complex systems. They are complex not only in technical terms. The social and organisational preconditions behind fusion research are also quite complicated. The proposed International Thermonuclear Experimental Reactor (ITER) is a good illustration. A deeper understanding of issues of governance and the perceptions by policy makers and research directors (research leaders) is significant to the final objective of developing this energy source. The long lead times in fusion – the effort has been going on for several decades and will have to go on for several more decades – pose challenging questions about the coherence of a complex effort over several generations. Also, the increasingly international character of the programme adds challenges of planning and management.

1.2 World-wide Scale of Fusion Research

Our contribution will focus on the European scale of fusion research. Fusion energy is, however, truly an international and global effort.¹ The reason for this is simple enough: high developmental costs. International collaboration has therefore involved Japan, the United States, the European Union and the Russian Federation. In the United States, as well as in other countries, it is acknowledged that fusion science and technology is an international effort with a number of *partners*.

Efforts are focused on most aspects of fusion: its scientific base and technology development, as well as engineering design necessary to construct a long-pulse burning plasma experiment, i.e. the ITER program. The primary aim of ITER is to demonstrate the feasibility of fusion by achieving controlled ignition and extended burn of the fusion fuel. During 1998 the ITER program is engaged in the conduct of the Engineering Design Activities (EDA) to produce a comprehensive design of ITER and the technology necessary for the construction of a reactor. The objective of ITER is to demonstrate self-sustaining fusion delivering about 1500 MW in 1000-second pulses and tritium breeding. The high costs (about US\$ 9 billion) makes collaboration on the international level necessary. At the same time international collaboration complicates decisions on financing. An illustration to this is the decision by the United States to withdraw from the ITER project in late 1998.

The EURATOM fusion program as well as the current ITER project and its large-scale efforts of collaboration is at the centre of our analysis. It is crucial to look at the research efforts from a longer-term perspective to understand the dynamics of fusion research. Thus, we will start with the scattered national efforts 20-30 years ago and end with the present "globalization". The EURATOM collaboration is important in this respect.

The European fusion programme involves approximately 2000 professional staff from basic and applied research centres in different institutional settings: annual expenditure for both research institutes and universities lies at abt. 500 MECU, of which 225 MECU is funded from the Community budget.² The Joint European Torus (JET) was started in 1983 and will probably continue until ITER is established. One of the main points is that JET "has demonstrated how Member States can contribute efficiently in a joint effort towards a common goal", says the Barabaschi Report in its Findings and Recommendations.³

The European Community Fusion Programme has developed a strategy for the evolution of fusion research (see figure 4.6 below). The strategy is implemented through three parallel approaches, which are supposed to be of importance when constructing the Demonstration Reactor, DEMO. This device will be the first within the programme to produce significant amount of electricity and will exceed ITER. The development path towards DEMO starts with

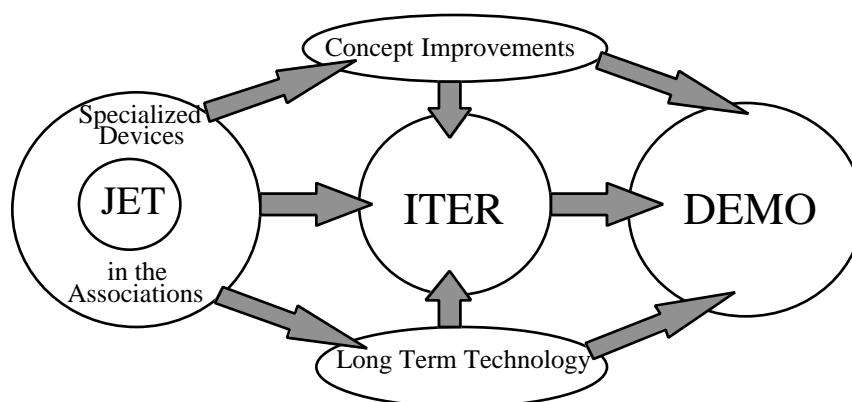
¹Fusion Energy Sciences Advisory Committee Report.

²Barabaschi Report (1996)

³Ibid. p. 16.

the experimental research at JET, which thereby provide support for the experimental research at Next Step, that is, ITER. Thus, the next device is named DEMO, which is going to be the first device that correctly can be labelled "fusion power plant". At the phase between JET and DEMO there are two more approaches besides ITER. The first approach is focusing on *concept improvements*, which refers to the improvement and development of the Tokamak concept as well as the development of the Stellarator and the Reversed Field Pinch, RFP. The primary aim of this approach is to increase the operational flexibility and reduce the complexity of the future device. The second approach is focusing on *long term technology* development, which aims to improve environmental conditions, safety and economic viability, etc.

Figure 1. The Development Path towards DEMO (from European Commission)



Source: Barabaschi Report 1996, p. 22

The European programme on fusion is a co-operation between national activities organised in Associations with the Commission. Each activity has a formula of cost sharing at different rates. According to the Barabaschi Report, the Associations "are the backbones of the Programme: they constitute a dynamic source of scientific and technological knowledge and a guarantee for the Programme's continuity and European cohesion". (p. 16) At the same time the evaluators found that the value of the Association's work could be further "enhanced by an even greater co-ordination of their activities in certain areas, for example through 'clustering' around specific themes and by intensifying their co-operation with industry". (p. 17)

The Barabaschi Evaluation Report of 1996 also places the ITER project in a political context: "The political significance of the ITER initiative should not be overlooked. The Board shares the view that the great challenges to mankind have an increasingly global dimension and will have to be faced through similarly global approaches. *ITER represents the first example* for the joint

construction of a large world facility, and is therefore *a pathfinder for future world-scale research initiatives.*” (p 22, our Italics)

1.2.1 Questions for Research

The aim of our project is to describe and analyse the relationship between national and international aspects in fusion research. Our analytical starting point is that the international programme is should satisfy two somewhat conflicting targets, coherence/endurance and flexibility.

Among and between different research groups one finds a variety of institutional set-ups, cultures and styles that affect collaboration. The political orientation toward international program is also influenced by structural differences such as different political orientations, different energy production and distribution systems, regulations, etc. Thus it is important to conduct comparative studies of different research collectives as well as different national associations involved in the fusion programme.

As a starting point we chose the following research questions:

1. Attitudes:

- What are the particular national political motives for participating in the international research collaboration?
- What are the attitudes among researchers and research directors towards the management of the fusion programme?
- What are the attitudes towards politicians among participants in the fusion programme?
- How is the integration of fusion physics in the physics community in general?

2. Co-ordination and Collaboration:

- What are the differences in organisational and institutional set-ups for the nationally organised research and how do they affect the conditions for co-ordinating different research groups on different levels?
- How does the division of labour function between researchers/research groups on the international and/or national level?
- What are the specific national patterns of collaborations between researchers and engineers and how do they affect the international framework of collaboration and co-operation?

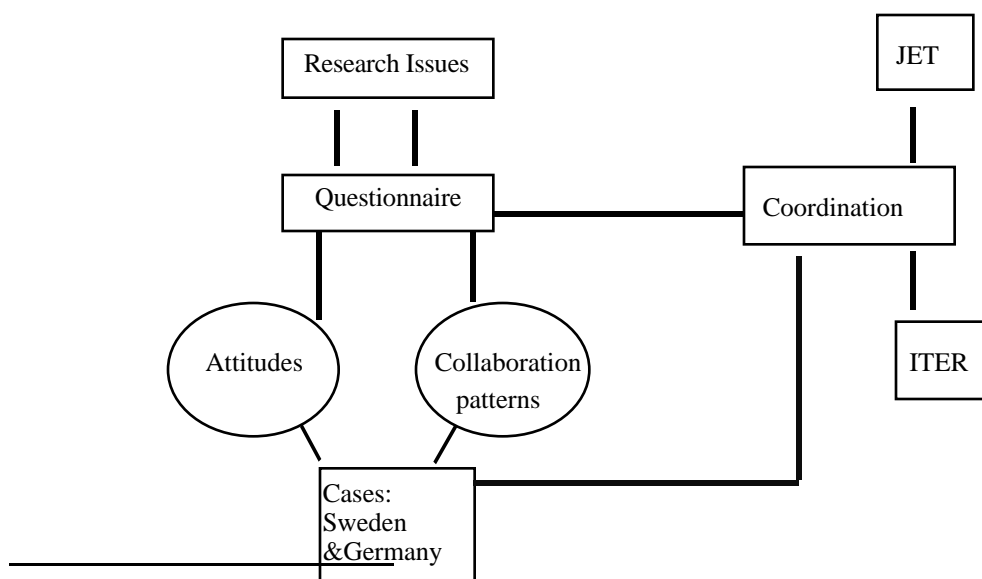
The outline of our study is the following: First we discuss research the major themes in the theoretical debates of studies of big science. In that section we also discuss methodologies for the studies that are undertaken. Secondly, we give some general information about the fusion programme in Europe as a background for a study of attitudes towards different aspects of the fusion programme among fusion research leaders and directors. The study is built on questionnaires sent out to Research Units (RU) in Europe. Thirdly we present a case study of the Swedish association in Europe. The initial aim was to present a systematic comparison between two cases, but this became impossible due to problems getting access to written sources on the

German Associations. We have restricted ourselves to use simple and general information on the German case as an illustration to some of the themes that are developed in the second part, and will to a large extent rely on our material from the Swedish case when discussing collaboration, steering and politics of fusion.⁴

The countries chosen were not considered to be opposites, but different in many important respects. Empirical data on the national level were thought to contribute to the analysis also of the questionnaire data. This goal has not been achieved in a way that was intended. The results from the Swedish case are conclusive and more in-depth, but the German study is fragmented and a necessary validation of certain observed patterns has not been obtained.

In order to test the hypothesis and investigate the research issues, as they were stated in the preceding section, one need to generate certain kinds of information. This kind of information will be of a qualitative as well as a quantitative kind. Some issues are concerned with attitudes, co-ordination and collaboration patterns. These issues have both the qualitative and the quantitative side. Collaboration patterns can be followed up for instance in case studies as well as one can measure collaboration patterns by means of bibliometric analyses. Thus our research design employs a multitude of methods. **Figure 1** gives an overview. *The questionnaire*, which has been carried out, will give information about attitudes and collaboration patterns; so will *the case study* focusing on Sweden. The idea of the research design presented here is that the variances in attitudes towards aspects of collaboration and co-ordination are functions of dimensional and categorical variables. These variables will be outlined in the following section.

Figure 1



⁴ The Swedish Association was very helpful and made it easy to implement the study. The authors of this report especially would like to thank Gunnar Leman, Lars Gidefelt and Gunnar Öquist from NFR for their co-operation.

1.3 Materials and methods

Our general method has been to gather information through a number of independent sources, that is we have implemented a triangulation method which brings together materials and data from at least four different sources. In the Swedish case study we have had the opportunity to test different databases and materials for research; Germany had, for different reasons, to be left largely as an illustration. In these aspects it is a pilot project for future efforts in the specific area "research on fusion research".

In the Swedish case study we had the opportunity to use the following types of material:

- (i) Bibliometrics (INSPEC database);
- (ii) Research Council project database (NFR);
- (iii) Material from the Questionnaire;
- (iv) Documents from the Swedish Association (NFR);
- (v) Interviews with research group leaders.

(i) Bibliometrics

Bibliometrics is a research tool that can be used for finding out the level of activity, the level of impact and the types of collaboration at the national and international arenas. The first use mentioned are of fundamental importance for the case studies. Bibliometric data have given a hint about where to start, which people to contact and where to look when searching for activities in the field of fusion. Bibliometrics also makes it possible to measure activities on the country level, which makes it easy to find out strong fields of research of a specific country. Level of impact is also of importance when studying these types of questions, but in this report we have found it irrelevant. However, time and resources did not permit the correction and validation of data that would be necessary for such an exercise.

Instead the study has concentrated on using bibliometrics as a tool for studies of collaboration, especially on the national level. It has used the database INSPEC which covers a long time-span (at least from 1980) and has a good coverage of technology as well as science, in fields relevant to fusion. A drawback is that INSPEC only gives information on first author addresses, but using the on-line service it has been possible to pick out information from the database on publishing activities during the 1990s for a special study of Swedish collaboration patterns. Unfortunately it was not possible to conduct the same investigations for the German case. But the main function

of the bibliometrical work has been to map the activities, including the level of each activity, in each country.

(ii) Research Council project database (NFR)

The Swedish Association NFR (The Swedish Natural Science Council) has a project database of its own that is built up by data on each project that applies to the council for money. In this data base there is general information about the projects, mostly economical and administrative. No scientific information is collected, except research field and project title. But data also from other fields of research are available so it has been possible to compare fusion to other areas when it comes to the success rates for project proposals (new projects and prolonged projects separately), the average project budget funded, the average time length of projects and the extent of budget cuts for projects in fusion.

(iii) Material from the Questionnaire

The questionnaire will be more thoroughly discussed in chapter 3. Here it should be mentioned that data from the questionnaire has been used as a validation instrument when it comes to publishing activities and economy on the research group level. The questionnaire was distributed to 185 fusion research leaders in Europe and its main focus is on the researchers attitudes on questions related to ITER, EURATOM, future research challenges, relations to politicians and to other physicists (inward, outward and international dimension).

(iv) Documents from the Swedish Association (NFR)

Minutes from meetings in the fusion committee of the NFR, the CCFP and the JET Committee.

(v) Interviews with research group leaders.

Research leaders or principal investigators at NFR. Research administrators at NFR, other physicists in the NFR committee for physics. In total, 11 interviews were made.

The German case study is mainly conducted from material of the above mentioned type (iv) and (v). It has to be underlined that, for several reasons, the access to sources of type (iv) has been quite limited.

1.4 Fusion as a System

Fusion, as section 1 illustrates, can be understood as large and complex system. Systems are characterised by a high number of interrelationships of system-actors. For the fusion system the actors are, for instance, plasma physicists and other researchers at fusion research facilities. These actors often draw a line between themselves and political actors influencing their work. This aspect of relationships between actors in the fusion system and the political system constitutes

the outward dimension of our research. In this respect one has to consider links to other systems as well, for example, the relationship between fusion researchers and scientists in other fields. These linkages can have some effects on the fusion system. In particular, fusion is a research effort of increasingly international character.⁵ This adds particular challenges of understanding and management. Therefore we also introduce the international dimension in our research design.

1.5 Dimensions of the System Fusion

The inward dimension deals with actions and activities of actors inside the fusion system. Attitudes, collaboration patterns within the research efforts and its co-ordination are affected by a number of factors, such as the organisation and structure of research units, the organisation and structure of the Association and/or dispersed organisation of research efforts. One example to illustrate the choice of aspects given here: The structural organisation of Associations in Europe vary as far as the integration of industrial collaboration in the Association structures concerned. This might effect attitudes towards industry, fusion research collaboration as well as it will influence the collaboration patterns of scientists with industry.

The outward dimension deals with issues and activities that are not carried out by actors directly involved in the fusion research efforts. Examples for actors of that kind are political actors, actors in industry and/or other physicists, engineers who are not directly involved in every day research development in fusion, but who have a view of ongoing activities and have an opportunity to exert some influence on the fusion system.

The international dimension plays a special role in our research. This is illustrated by our focus on the ITER collaboration and also the relationship of the EURATOM Association towards Brussels as well as the ITER project. Therefore we are looking at different patterns of collaboration on the research level within the international dimension. Other issues are:

- EURATOM and how it has effected collaboration patterns
- ITER and how it has effected collaboration
- ITER and how it might effect collaboration

⁵ The U.S decided late in 1998 to withdraw from the ITER collaboration. The effects from this action have not been seen yet and it might result in decreased, not increased, internationalisation of fusion research. Due to its recent nature this circumstance is, unfortunately, not covered thoroughly in this report.

1.6 A Matrix for Analysis

After having outlined the three different dimensions of our research, we developed a concept for analysis where the influencing variables are integrated within a matrix. The rows contain behavioural patterns of interest to us. They are structured as described above. The columns describe a number of categories. The idea is that a certain behavioural pattern is characterised and dominated by one or more influencing variables (C_1 - C_n). The influencing variables are based on findings from interviews and will be implemented in our analysis of the questionnaire sent out to research leaders in Europe.

Categories Dimensions	C_1	...	C_n
Inward		...	
Outward		...	
International		...	

1.7 Categories for Analysis

The aim of our research project is manifold: we intend to test a taxonomy or categorisation of large technical fusion research efforts. From this we analyse patterns of attitudes in different research units. We also try to put these results into a discussion about different collaboration patterns. We use the research unit (RU) as our level of analysis. This can be justified by our impression that despite the very strong and very important international dimension, the international co-ordination of research in the field of fusion, the national mode of carrying out actual research is still prevailing the international. However, in a number of countries - for instance Germany - one can have a more detailed look at a number of different research efforts, which are materialised in different Associations to EURATOM.

Our research started from the hypothesis that mainly four categories could be used to describe and understand the behaviour row pattern of research units. These categories were *age, size, orientation and institutional setting*. Age with the characteristic old, middle aged and young; size with features like small, medium and large; orientation distinguishing between a technological, experimental and theoretical orientation and institutional setting split in two: universities or institutes. During our work we experienced a number of specific problems of finding a way to operationalise these categories on the basis of information available. In section 3.2 we therefore discuss *pro primo*, these difficulties and *pro secundo*, a number of other categories that has

evolved out of background variables (e.g. dynamics of labs, productivity of staff) used in the questionnaire. These new categories are not considered as validated results from our work, but, instead, as examples of what type of tools can be used in socio-economic research on fusion and the kind of analysis that might come out of it.

We have used policy documents to identify the official motives and arrangements in fusion-related research. Research of this kind must also reflect the predicaments in the respective country. Therefore we have interviewed key-actors to access their experience and viewpoints in relation to collaboration and co-operation in a project of this magnitude. In order to reflect the different attitudes that are held in countries and in different types of research units we have conducted a survey with questions on attitudes towards certain aspects of the European Fusion Programme. Finally, quantitative bibliometric methods have been used to analyse collaboration patterns, which in turn underpin the analysis in our case study of Sweden.

1.8 Theoretical Considerations

Fusion research and large reactors has been studied by several scholars in history of science and in social studies of science and technology (STS). As our focus in this report to a large extent is directed towards examining different routes or lines of investigation that can be useful in socio-economic studies of fusion research, we have chosen not to generate hypothesis from that type of literature, but instead, we have gone through different type of materials and other sources with the explicit aim of putting them together just to illustrate potential uses.

Before going further into the overall theoretical context of our studies it is necessary to say a few words about the existing literature on fusion science and technology. In the area of science history considerable efforts has been made by Joan Lisa Bromberg in her studies of "the invention of a new energy source". The book *Fusion* (1983) follows the history of fusion research in detail up to the end of the 1970s. In the article "TFTR: The Anatomy of a Programme Decision" (1982) she closely describes the rivalry between two Tokamak laboratories and the struggle for increased funding before the commissioning of the Tokamak Fusion Test Reactor in the U.S. Brombergs studies reveals the co-evolution of science *and* politics: "The first thing to note is that the politics were not injected by groups, like government administrators or congressional committees, outside the programme. *The political considerations were, rather, internalized by the scientist because of their concern to preserve and promote their programme* in as Washington environment marked by fierce competition for resources, and by pressure for results on a time scale set by the short intervals between federal elections."⁶ If lessons from Brombergs study could be transformed to European circumstances, especially fusion research and technology, it probably would have to underline the co-evolutionary nature of the whole business. The levels that have to work together are many more in European efforts, and with the inclusion of ITER it is even more complicated.

⁶ Bromberg (1982) p. 577 (our italics)

Strategies used by researchers in collaboration with administrators and politicians are studied by Gingras and Trépanier (1993) in a study of the construction of the Tokamak de Varennes in Canada. Mainly it is a study of a dispute over research agendas during the 1970s and the general aim is to understand why it ended in an unexpected way: ” (The case) thus illustrates how transformations in governmental priorities are the unexpected results of conflicting trends and interests among the many agents involved in the decision process”.⁷ In sum, the authors underline what Bromberg found in her study, but they bring the theoretical discussion a bit further using concepts from the French science and innovation theory (e.g. Latour).

The character of knowledge interests in many historical studies are centered on an event, be that a decision to start a programme or to shut down a reactor. The event-led story telling that is common in these studies does not coincide with our general aim as we are more interested in 1) the actual organisation and co-ordination of the programme on different levels and 2) the effects on the research performance from the global character of the effort. For example; we will ask how these things are viewed from the researchers (project leaders, research units leaders) perspective.

From this follows that we have an interest in organisational aspects of research and below (section 1.7.1) the reader will find our interpretation of the fusion project as such, i.e., as a complicated long term project with different actors influencing the process. As will be presented in this chapter, the ITER-project can be described in terms of *big science*, or *megascience*. In the following discussion the concepts *big science* and *megascience* will be used as equivalent terms. The reason for this is that over the past decades ”big” science has gradually turned into megascience, i.e., ”big” science has become ”bigger”.

1.7.1 Megascience and Politics

Since the beginning of this century the development of scientific research has changed dramatically. Scientific research today often involves political and economic aspects to a large extent, which as a result has transformed the role of the researcher. Scientific instruments are becoming increasingly complex, long termed and expensive, and the financing has to be legitimised by different actors in several countries. In order to create a better understanding of these kind of large scale projects, we use the concept of *megascience*. In short, the concept refers to a large, long-term project, which devours a very large amount of money and is therefore financially depended on governmental funding. However, the concept is more complex than this. The OECD Megascience Forum has defined megascience as ”...a project that addresses a set of scientific problems of such significance, scope and complexity as to require an unusually large-scale collaborative effort, along with the facilities, instruments, human resources, and logistic support

⁷ Gingras & Trepanier (1993) p. 9

needed to carry it out.”⁸ Also, the Forum presents three elements of importance when identifying a megascience project:

- the amount of funding required
- the unique character of the installation
- the nature of the programme⁹

The first element, the amount of funding required, can be discussed since the cost of these projects constantly has increased during the last decades. It might therefore be difficult to find a universal measure to determine how much funding a project must consume before rightfully being entitled megascience. The Forum does not present any explicit price tag for megascience projects, but refers to other authors who have defined megascience as projects in excess of \$1 billion (based on the total cost throughout the life). Regarding the next element, the Forum emphasises the character of the installation. This implies a discussion on the uniqueness of the installation, meaning that a megascience project cannot be duplicated, owing to its size and cost. Moreover, a duplication of this kind of project would merely reproduce the former results and the benefit will therefore be questioned. Finally, a programme can be either fixed or distributed in its experimental sites. This has to do with the facilities of the project, and in the former case the project requires an expensive complex central facility. The LEP facility (Large Electron Positron storage ring) in Geneva represents an example of fixed sited projects. Distributed projects do not require a central facility, although they do require a substantial central co-ordination. This kind of project is represented by, for example, climate or ocean observation programmes (World Climate Research Programme, WCRP, International Geosphere Biosphere Programme, IGBP, etc.)¹⁰

Although the proposed criteria is not useful as a universal definition of megascience, it does provide a basis for examination. Thus, in our report this definition is merely used as an explaining interpretation of the field of megascience.

Big science was an unknown phenomenon until the W.W.II. The phrase itself was not coined until the 1960s. According to E.K. Hicks and W. van Rossum, large-scale governmental support was initially often a way to express national chauvinism. It was also justified in terms of its military value. The classic example of a large-scale military project is *The Manhattan Project*, the US effort to produce an atomic bomb during World War II. Big science projects in the military sector involved large interdisciplinary teams of engineers and scientists, and industry, which played a central role. The governmental direction and funding were essential to the subsistence of the actual project, and government became structurally involved as the main financier.

⁸ OECD (1993) Megascience and its Background, THE MEGASCIENCE FORUM, p 52.

⁹ The OECD Megascience Forum, (1995), p 50.

¹⁰ The OECD Megascience Forum, (1995), p 66f

Consequently, scientific efforts on large-scale project became dependent on governmental support, thereby losing some of its former autonomy.¹¹

W.D. Kay discusses the problem of political legitimacy in his article *Democracy and Super Technologies*.¹² According to his observations, these kind of large-scale technologies often tend to be described in superlatives by the proponents. One might even say it is difficult to detect any sharp boundary between factual and rhetorical arguments.¹³ For example, the Apollo moon landing was described as "the most important event since Creation." Similarly, proponents of fusion have described the development of fusion power as equivalent to the discovery of fire. These statements are intended to achieve public acceptance to legitimate large and long-term costs. However, the enterprise of gaining public support can be hazardous in case of setbacks (delay, breakdowns, etc.): the public is prone to interpret these problems as total failures. This follows from the enormously high expectations, and the public often does not have patience or the trust to overlook the more or less natural setbacks of a scientific project. For the proponents, e.g. the scientists, this situation is difficult to handle; it is necessary to gain public and political acceptance, yet unrealistic expectations and offering promises that have little chance of being fulfilled under the stipulated budget can rapidly overthrow this support. The former public enthusiasm over the scientific project might then fade away, and the common feeling of witnessing an important historic process changes into a feeling witnessing and financing a costly fiasco. As a result, the willingness to maintain the financial support is reduced or even relinquished.¹⁴

In the early years of fusion science (1950s and 1960s), fusion researchers claimed that a viable fusion reactor could be constructed within the near future (20-50 years). Slowly, it became apparent that this promise could not be fulfilled; the researchers had run into serious difficulties on several fields, and the fusion power problem appeared to be more complicated than assumed. The consequence was a delay that most likely did hurt the cause of fusion research. One member of the research community discusses the danger of promising to much, and emphasises the importance of responsibility when selling the research to other actors of the society: "*The externalized cost of overselling science is no different from the cost of pollution: We leave it to the next generation of scientists to clean up the mess when we create expectations of science that may not be realized.*"¹⁵ Today, when the common belief in the fusion community is that a viable reactor will not be erected until 50 years from now, fusion researchers have to work hard to restore the public trust in their field.

¹¹ E.K. Hicks, W. van Rossum. Policy Development and Big Science, p. 1ff.

¹² W.D. Kay. "Democracy and Super Technologies" in SCIENCE, TECHNOLOGIES & HUMAN VALUES, Vol. 19 No 2, Spring 1994.

¹³ See The OECD Megascience Forum, (1995), p 66 ff.

¹⁴ W.D. Kay. "Democracy and Super Technologies" in SCIENCE, TECHNOLOGIES & HUMAN VALUES, Vol. 19 No 2, Spring 1994, p 135-140.

¹⁵ Kumar Patel. "Big Science vs. Small Science - or No Science?" in AMERICAN SCIENTIST, Vol. 82, No. 1 Jan-Feb 1994, p. 2.

A megascience project, based on international collaboration, usually have a legal framework for defining the conditions for the collaboration. This is necessary in order to guarantee sufficient long-term commitment from the national actors. Politicians are facing other problems when dealing with long term projects. Normally, politicians have two major motives in their work: first, they are striving to execute politics in conformity with their, and their party's, conviction. Second, they wish to be re-elected. However, a long term, large-scale project is a complex arrangement, and its character does not easily harmonise with the democratic political system. Instead, its role in the political decision making process is complicating the situation for the political actors. The decision to support a development of such a project cannot be based on an assumption of instant or close benefit, rather, the gain will not be observed until many years from now. In other words, the political actors lack incentives to allocate large resources to long-term projects when the observable profit lies 50 years in the future. As a result of this, politicians tend to find it more attractive to invest money and political prestige in short or medium-term projects. This is of course most apparent when the proposed long-term project involves a certain amount of risk of failure.

In the publication by *The Megascience Forum* (1995), aspects of megascience and its relationship with national decision-making processes are extensively discussed. Projects of magnitude, based on international co-operation, involves a complex decision-making process. The process is interactive and must respond to changes in the scientific, technical and financial situation:

Owing to internationalisation, decision making no longer proceeds in a linear way from a general project outline through to the submission of the financial decision to the responsible authorities; it is much more interactive, with scientific, technical and financial opportunities discussed and assessed together. Hence, the process involves gradually adjusting scientific priorities and primary fields of interest as well as refining the supporting arguments and financial procedures.

This also explains why such discussions take a long time and why the agreements are so fragile. Full consensus cannot be reached over a few weeks, and many steps must be taken before reaching a consensus to which all the partners can subscribe. Furthermore, neglect a single link in the chain of responsible bodies is sometimes enough to cause an unexpected refusal and block the whole operation.¹⁶

Since a megascience project involves many different actors (political actors, scientific actors, national actors, funding agencies, etc), it is hard to reach to a rapid consensus in the operation.¹⁷ The decision-making process for megascience is therefore complex and protracted.

¹⁶ The OECD Megascience Forum, (1995), p 85.

¹⁷ The OECD Megascience Forum, (1995), p 85.

1.7.1.1 Illustration: Political and Scientific Perspectives on the ITER project

The ITER project is a somewhat unique model for international research collaboration in science and technology. From European point of view, ITER will be the successor to JET, and the project forms a financial and geographical enlargement of the former research effort. The four parties co-operating in the field of fusion research (EU, Japan, Russia and USA) are involved in a complex system of co-ordination and collaboration. Canada and Kazakhstan have also joined the project by association with EURATOM and Russia, leading to a further increase in number of actors. This large-scale collaborative effort intends to facilitate and expedite the evolution of a commercially viable fusion reactor, which thereby requires a clear and consistent strategy. The mutual sharing of resources and expertise provides a basis for more efficient R&D in the field of fusion. When studying the components of the ITER-project, it soon becomes clear that the concept of megascience is eminently accurate in the analysis of the aggregate phenomenon. The ITER project is an international scientific experiment, aiming to produce valuable information in the search for commercially viable fusion power. It undoubtedly fulfils the criteria (or model) for a megascience project stipulated by the Forum (see section 1.7.1 above):

Required funding: The cost for the ITER construction, including the cost for management, engineering, and R&D will be around 7.5 BECU and the operation will cost around 400 MECU per year.¹⁸ The device, when in operation, will be running for approximately 20 years.

Unique character of the installation: The experimental reactor forms an important phase in the strategic development of the future Demonstration reactor, DEMO. It will generate information and experimental results, which will be fundamental in the development path towards DEMO. When erected, it would be meaningless to construct a second identical reactor, since this device merely would duplicate the information supplied by the former. Also, with reference to the discussion on funding above, a second ITER is not feasible due to the huge required costs. In this sense, the experimental reactor is clearly unique to its character.

The nature of the programme: The ITER project aims to develop and build an experimental reactor, and the device will require a ground at 40 hectare or more. The construction will be huge and it will engage approximately 500 researchers and engineers during management and operation.¹⁹ In other words, it constitutes a prime example of a fixed-sited megascience project. The decision where to place the actual reactor has not been settled, and remains a subject of discussion. *In summary:* According to the proposed definition above, the arrangement of the ITER project very much corresponds with the concept of megascience.

Political and societal commitment: As seen in the foregoing investigation, the realisation of the experiment is, by most members of the fusion research community, considered to be an important indication of political and societal commitment to future fusion research. Political support is crucial for a project of this magnitude, and the political actors therefore have a strong, although

¹⁸ Barabaschi Report, p 78.

¹⁹ Anders Karlqvist, Förläggning i Sverige av den internationella fusionsforskningsanläggningen ITER, 1994, p. 20f.

implicit, voice in the design process. In correspondence with the discussion above, the fusion researchers must ongoing convince other actors of the value of the project. This means that the researchers find themselves in a difficult position, since they – apart from performing regular research – must engage in substantive policy work. This is probably not only an unaccustomed task for the researchers, but these policy issues are also both time consuming and disturbing; instead of concentrating on scientific matters, they must from time to time struggle to maintain financial and political support. To conclude, lobbying is important in order to maintain a steady level of support for a long period of time.

In the mid 1990s fusion researchers in Sweden established a committee, The Fusion Research Committee (FFK), which, among other things, is dealing with policy issues of this lobbying kind. The members of the committee meets four times a year, where they, among other things, discuss different moves to keep the politicians and the public favourable to fusion research. The committee also puts effort in answering sceptical and opposing articles on the field of fusion. However, it is important to point out that FFK also deals with other questions; its primarily task is to advise NFR on fusion related issues and matters connected with the Swedish participation in the European Fusion Programme.

Undoubtedly, the construction of ITER implies more aspects than discussions on technological and scientific issues. There are several actors involved in the process, although they are not necessarily sharing a mutual understanding on matters of priority, and sometimes they even disagree on the idea of fusion. The most important group in the process, besides the fusion researchers, is the public, or to be more precise, it's elected representatives. As mentioned in section 5.1, experiments defined as megascience have an indisputable democratic problem hidden in its process. The construction of ITER and the development path towards an electricity producing reactor is scheduled to take 50 years, and maybe more. It is therefore to be considered as a long-term project, which is likely to have problems to operate smoothly in a democratic system. The decision makers, i.e. the political actors within the different states, cannot guarantee financial support for more than a few years in a row, while the project, on the other hand, is depending on steady, continuous funding. In other words, participation in megascience project is always vulnerable to changes in the opinion, and the proponents must therefore repeatedly struggle to ensure the survival of the project. This problem is briefly illustrated by the comments made by some of the researchers: for instance, the current large supply of oil on the world market has lowered the price on this energy resource, hence the opinion in favour of fusion power has decreased.

As presented above, long term projects, as for example ITER, might have difficulties to prosper soundly in a regular democracy. The system of democratic decision-making, based on regular elections, creates grounds for short-sighted policy. It should be stressed that the concept of short-sightedness in this context refers to the situation embodied in the democratic system (i.e., repeated elections which threatens to replace any government), and not to the policy of the parties or the political actors. The ITER project has problems fitting the dynamic political system, and the participating countries do not necessary share goals and ambitions concerning fusion research. Hence, the internationalisation of fusion research is creating a complicated

decision-making process, which could diminish the advantage of a common effort. This tendency is illustrated by the findings from the attitudes section in the questionnaire, where 71.4 percent of the respondents believes that the management of ITER will be problematic due to complex international relations (see chapter 4).

Regarding the complexity of international relations on the ITER research project, there are some hesitations to be found on the national level outside Europe. In recent years, the discussion has often focused on the costs of building a facility of this magnitude. For example, the problem of financing was clearly exposed in 1997 when USA, as one of the participants of the ITER collaboration, decided to cut the Department of Energy's fusion research programme from \$225 million to \$175 million. According to the proposal, most of the \$50 million cut will be taken from the US contribution of \$55 million to ITER. The US participation in the ITER collaboration is thereby questioned, at least in its current form.²⁰ The reduction of the ITER expenses was partly motivated by the argument that the confinement solution of the proposed reactor can be questioned. It is said that although the Tokamak is not a bad concept for confinement, more emphasis should be made on developing alternative confinement solutions. Therefore, a sub-panel of the Presidents' Council of Advisors on Science and Technology (PCAST) proposed that ITER should be scaled down from an estimated cost of \$10 billion to \$4 billion. This would result in the construction of a smaller, less ambiguous experimental reactor, in favour of other lines of research.²¹ This scepticism towards the design of ITER has clearly affected the European fusion researchers' attitudes on international collaboration and relations. Although the researchers are concerned over this situation, they are determined to overcome the obstacles that will occur in the future, as well as the present difficulties.

The problems of megascience discussed above might lead to the conclusion that long term projects like ITER are doomed to collapse under an unfavourable political system, large expenses and the different actors' variety of interest. And projects have indeed been dismantled before: It was a shock for the American physicists when the Congress decided to halt the building of the Superconduction Super Collider, SCC. This project differs from the ITER project in the fact that the former was a national project, while the latter is based on international collaboration. However, it is not at all true that international large-scale projects are predestined to face a future relinquishment. The winding up of a country's membership of ITER is regulated by a legal framework, which aims to secure a common long-term commitment. One reason for believing in a project like ITER is probably due to its international character. Although this might seem as an illogical reasoning with reference to the discussion above, it is plausible that the formalisation of international collaboration is settling the endeavour. To withdraw from an international collaboration effort, such as ITER, the actual national actor must be very determined, since this action would severely hurt the common research effort. This knowledge prevents an individual state from any causal defection, rather it has a tendency to remain loyal to its associate colleagues. In this context, formal international collaboration is crucial to the existence of the project.

²⁰ US budget plans jeopardize role in ITER, in *NATURE*, vol. 388, 10 July 1997, p. 110.

²¹ Cuts raise questions over future of fusion, in *NATURE*, vol. 377 19 October 1995, p. 567.

However, recently the US decided to withdraw from the ITER collaboration. This is a clear setback to ITER itself and it is obvious that the European researchers are very bothered by this fact. It is still unclear how the new situation will affect the process and the structure of the remaining actors' collaboration on large-scale fusion research. One scenario is that the ITER project, as we see it today, will collapse for the benefit of local or regional fusion research substitutes. Thus it is possible that Japan and EURATOM construct separate experimental reactors and that the internationalisation (or globalisation) of fusion research is halted.

1.7.2 Research Collaboration: A discussion

Before entering the field of fusion research in Europe and case studies on Germany and Sweden, it is important to clarify how the concept of collaboration is being used in the forthcoming sections. In the field of Big Science the concept is utterly present, although it is sometimes uncertain what is the meaning of collaboration. In addition, it is important to discuss how one can measure collaborative activity and how to categorise different types of collaboration. Collaborative activity can be observed on various levels and the mode of measuring involves different kinds of difficulties, depending on chosen method.

The common method of analysing collaboration is to investigate the frequency of co-authorship between different levels of individuals, groups, institutions or countries. Articles authored by more than one member of the categories mentioned above implicate a collaborative activity, and by using citation indexes this is easily and inexpensively pinpointed. As shown by for instance J. Sylvian Katz and Ben R. Martin (1997), this method holds a few problems, which must be considered before analysing the bibliometric findings. It is necessary to keep in mind that authorship and collaboration may sometimes diverge. For example, if two collaborating parts decide to publish their results separately, a bibliometric search will be inadequate. In this case it is impossible to find any trace of the preceding collaboration. Similarly, two non-collaborating parts might decide to publish their results together, which thereby give us a misleading indication of collaboration.

Initially, it might be necessary to specify what we mean by collaboration, i.e.: which activity should be seen as collaborative, and which should not? Katz and Martin try to distinguish collaborators from other researchers by suggesting a few criteria. According to them, collaborators will normally include the following:

1. those who work together on the research project throughout its duration or for a large part of it, or who make frequent or substantial contribution:
2. those whose names or posts appear in the original research proposal:
3. those responsible for one or more of the main elements of research (e.g. the experimental design, construction of research equipment, execution of the experiment, analysis and

interpretation of the data writing up the results in a paper).²²

It might also include

4. those responsible for a key step (e.g., the original idea or hypothesis, the theoretical interpretation): the original project proposer and/or fund raiser, even if his or her main contribution subsequently is to the management of the research (i.e., as team leader) rather than research per se.²³

Finally, J.S. Katz and B.R. Martin present a few examples of activities performed by non-collaborators, i.e. people/groups that are excluded from the groups of collaborators:

5. those who make only an occasional or relatively minor contribution to a piece of research:
6. those not seen as, or treated as, 'proper' researchers (e.g., technicians, research assistants).²⁴

Katz and Martin admit there are several exceptions to almost all of the mentioned criteria, and they conclude that research collaboration has "a very 'fuzzy' or ill-defined border."²⁵ The demarcation depends on social convention and can vary across e.g. institutions, countries and time. To sum up, the definition of a collaborative activity is somewhat loose, and this fact is important to remember when analysing the material. For our project these suggested criteria have been something of a guideline when examining collaboration pattern within the fusion community. As the definition is indistinct, the findings and categorisations of collaboration are interpretations based on available information.

J.S. Katz and B.R. Martin also make a distinction between different levels of collaboration, using the prefixes *intra* and *inter*. The prefix *intra* refers to collaborative activities between parts belonging to the same group/institution/country etc., while *inter* refers to collaborative activities between parts outside the given frame (group/institution/country etc.). For example, collaboration between individuals or groups in the same department would be called *intra-department*, while collaboration between departments in the same institution would be called *inter-department*. This distinction is often more complicated than it might seem; if two groups collaborate within a department they are performing an inter-group collaboration, but their activity can also be labelled intra-department collaboration.

Again, the distinctions of J.S. Katz and B.R. Martin are imprecise. Thus, their attempt to clarify different levels of collaboration might not be as elucidating as it would appear. For our project, this leads to the conclusion that the proposed distinction between different levels of collaboration

²² Katz-JS & Martin-BR., "What Is Research Collaboration?", in RESEARCH POLICY, 1997, Vol. 26, Iss 1, p. 7

²³ Ibid.

²⁴ Ibid.

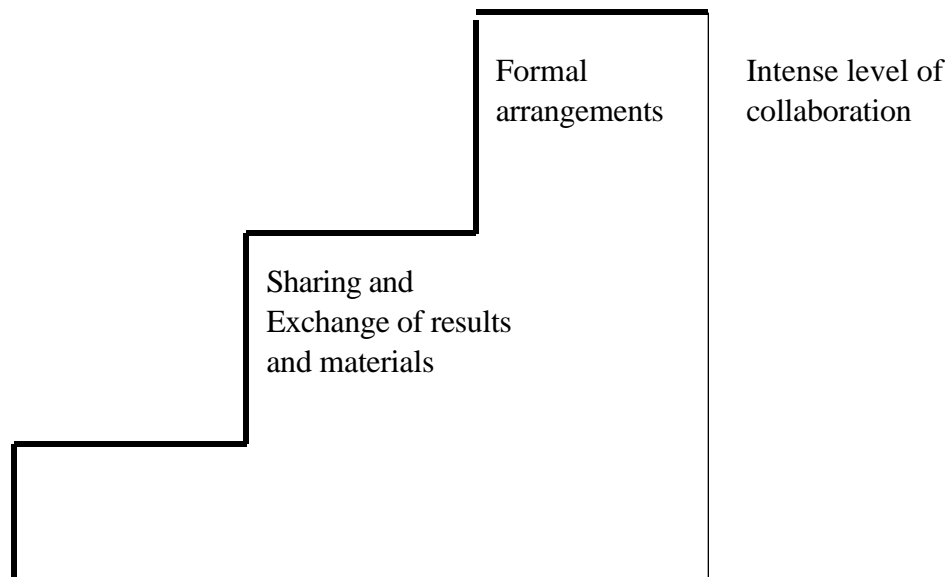
²⁵ Ibid., p. 8.

is unnecessary. The categorisation is important when investigating the concept of collaboration, but as we are primarily interested in inter-group collaboration, the additional levels are subordinate. When investigating the collaborative behaviour of a researcher, we ignore his status as an actor on a strictly individual level. Instead, our main focus is the research group, and the individual researchers are mainly interesting in aggregate form, i.e., as a member of a group. In other words, the aim is to identify each group's external (or *inter-group*) collaboration, leaving their "regular" internal (or *intra-group*) collaboration aside. The concept of collaboration would therefore refer to one group's collaborative contacts with other groups on a national or international level.

J.S. Katz and B.R. Martin have tried to purify the concept of collaboration in order to rule out activities that are invalid to the analysis. Inspired by their discussion, we have constructed a model which aims to explain the development process of collaboration between individual researchers or research groups. The model illustrates different levels of collaboration and how it can be graduated in a comprehensible form. Here, the collaboration process originates when two groups/researchers, or more, get together to communicate. We use the concept *communicative exchange* to describe this level. It includes a general exchange of information: either interaction face-to-face, by regular mail or electronic communication channels. This constitutes a very low level of collaboration and at this level the possibility of common publications is precluded. At the next step the exercise is extended to include the *sharing and exchange of results and materials*. This includes exchange of data and sharing of experimental devices. Jointly publications occur at this level, but only as an exception. At the highest level we find *formal arrangements and publications*, which refers to the sharing of economic responsibilities and epistemological principles. Here, common publications are the normal routine and the involved researchers regard themselves as collaborators. The model also includes a diversification between collaboration based merely on *input*, and collaboration based on *output*. In this context 'input' refers to the exchange of comments and ideas, while 'output' refers to common development of a product, e.g. an article.

Figure 2:

Collaboration: A Conceptual Model



Communicative
exchange

Low level of
collaboration

Input

Output

The model distributes collaborative activities into different levels, which intends to facilitate the forthcoming discussion collaboration. In our analysis, ‘collaboration’ will refer to activities on the highest step of the stairs (*formal arrangement*). The model can also be used to illustrate the maturation of a joint idea to the collaborative development of a certain product. Obviously, the model supplies a rather strained and simplified description over concept, why it should be understood as a conceptual guideline and not a summary of the contents in the concept.

The discussed definition and methodological approach does not give a precise verification of existing collaborative activities, but it illuminates a few important aspects of analysing research collaboration. First, it illustrates the importance of theorising the concept. In some cases the existence or absence of collaborative activities can be hard to detect because of an unclear understanding of the complicated concept. Second, it demonstrates some of the pitfalls and problems in measuring collaboration.

In some cases it is necessary to make a distinction between formal and informal collaboration. While formal collaborative activities are directed, supervised and supported by a central authority (e.g. a government), informal activities are not. In the latter case, the collaboration is mainly directed by the individual researchers own preferences on desired partners. Informal collaboration is not arranged in terms of an agreement (as in the formal case), and can change its form rather rapidly.

In order to detect and measure collaborative activities and collaboration patterns, we have carried out a bibliometric study of co-authored articles in the *INSPEC* database. As discussed above, *output* is fundamental for our understanding of collaboration, thus a bibliometric study helps us identify patterns of collaboration through published articles. This method is supported by information from interviews and questionnaires, which provides a subjective understanding of the leading researchers.

Chapter 2: EURATOM Associations²⁶

Before discussing the findings from the questionnaire, it is necessary to introduce the Associations to the reader. Thus, in this chapter a few facts regarding each Association are presented, mainly based on the report Fusion Programme Evaluation 1996 (Barabaschi Report). For a more thorough presentation over Associations it is recommended to explore the Barabaschi Report, considering the concentrated facts given here.

The Association EURATOM-Belgian State (Brussels and Mol) contributes to the improvement and application of Ion Cyclotron Resonance Heating (ICRH) to present experiments and ITER and the investigation of high confinement regimes. The Association undertakes work in close collaboration with Association EURATOM-KFA on TEXTOR 94 (see this Association below, and Table 2.2). In may 1996 this collaboration was extended to the Association EURATOM-FOM through the creation of the Trilateral Euregio Cluster (TEC). Extended theoretical activities relate to heating issues and the fundamental theory of transport.

The Association EURATOM CEA (Cadarache) is operating a large Tokamak, TORE SUPRA, and is an important contributor to fusion technology. In collaboration with the Associations EURATOM-IPP and -DCU, it is the European lead laboratory for the development of negative ion-based neutral beam injectors for ITER.

The Association EURATOM-Ciemat (Madrid) exploits a small Tokamak and a special type of stellarator, TJ-I, and TJ-IU, essentially for fundamental fusion physics. It also undertakes technology work on the characterisation of window materials for heating and diagnostic systems on ITER. The Association collaborates with the Association EURATOM-IST on a reflectory system of ITER.

The Association of EURATOM-DCU (Dublin and Cork) has a programme mainly oriented towards diagnostic contributions on COMPASS, TCV, ASDEX-Upgrade, JET and RFX, and on some theoretical aspects of fusion physics.

The Association of EURATOM-ENEA (Frascati, Milan and Padova) explores the high field, high density Tokamak line on FTU which has a circular plasma cross-section. With respect to ITER, studies of confinement and investigation of radio-wave heating and current drive (together with CNR-Milan) are the main goals. In fusion theory, activities relate especially to the modelling and effects of fast alpha particles in a fusion plasma. On RFX (CNR, Padova) the physics of the reversed field pinch is explored supported under an international collaboration. The Association

²⁶Source for this Chapter is the Barabaschi Report 1996.

also has a large programme in fusion technology, and undertakes a keep in touch activity on inertial confinement fusion.

Within its collaboration with TEC (see the Association of EURATOM-Belgian State) the **Association of EURATOM-FOM** is specialised in the study of transport in particular with a light scattering diagnostic of very high spatial resolution. The activities undertaken on the small Tokamak RTP is being transferred to TEXTOR 94. The Association does work in fusion technology, and develops a multi-megawatt Free Electron Maser as a tunable source for plasma heating and current drive.

The Association of EURATOM-FZK (Karlsruhe) is a key contributor in fusion technology and has a large superconductor testing facility (TOSKA) and a tritium laboratory. In plasma engineering, developments, in collaboration with industry and other Associations (EURATOM-CEA, FOM, Swiss confederation) on electron heating sources for ITER and for devices in the Associations (TORE SUPRA, TCV, W7-X) are undertaken.

The Association of EURATOM-IPP (Garching, Greifswald and Berlin) has been pioneering the development of the poloidal divertor. It operates, as its main experimental activity, the divertor Tokamak ASDEX-Upgrade, which has been employed for ITER-oriented testing of divertor concepts at high power fluxes. IPP is conducting two large-scale experiments at Garching; the already mentioned ASDEX Upgrade Tokamak, and the WENDELSTEIN 7-AS stellarator. A successor to the W7-AS stellarator experiment, WENDELSTEIN 7-X, is under preparation. A strong modelling and theoretical effort both in Tokamak and stellarator physics and reactor studies accompany the experimental work. The Association has numerous and extensive collaboration with other Associations and universities inside Europe as well as outside (IEA Implementing Agreements). It undertakes a keep in touch activity on inertial confinement fusion.

The Association of EURATOM-IST (Lisbon) is operating a small Tokamak, ISSTOK, and a strong participation in diagnostics and the related scientific evaluation has been established in the programmes on several larger devices, e.g. JET and ASDEX-Upgrade.

The Association of EURATOM-KFA (Jülich) in collaboration with its TEC partners, is executing a programme on plasma wall interaction, heating and transport and confinement studies on TEXTOR 94. KFA's contribution is mainly focused on edge plasma and plasma wall physics, and collaborates in the framework of an IEA Implementing Agreement.

The Association of EURATOM-NFR (Stockholm, Göteborg, Uppsala and Studsvik) with its EXTRAP T2 device, has an experimental programme on the reversed field pinch and collaborates with the RFX group at Padova, as well as with groups in Japan and the USA (IEA Implementing Agreement on reversed field pinches). Essential contributions are provided in diagnostics, particularly neutron diagnostics, and in theory and modelling. Fusion technology is another important activity in the Association.

The Association of EURATOM-ÖAW (Vienna, Innsbruck, Graz) addresses experimental, theoretical modelling and diagnostic aspects of edge plasma physics, turbulence, etc., as well as technology work on superconductors and materials.

The Association of EURATOM-RISØ (Roskilde) is developing laser diagnostics for fluctuation studies in fusion plasmas for application on W7-AS. RISØ has developed pellet injectors for fusion devices and does essential contributions to the technology programme.

The Association EURATOM-Swiss Confederation (Lausanne and Villigen) execute research for improving confinement and efficient use of magnetic energy. Also, the Association does substantial effort on computational plasma physics and code development. It collaborates mainly with EURATOM-CEA and -FZK on the development of electron cyclotron heating sources for TORE SUPRA and TCV.

The Association EURATOM-TEKES (Helsinki and Tampere) collaborates with JET and IPP on heating and current drive. Fusion technology work is devoted to aspects of ITER remote handling systems, water hydraulics and materials.

The Association EURATOM-UKAEA (Culham) does experimental work on the COMPASS Tokamak in an ITER like configuration, and participation in work on JET is a main activity. The Association has been a prime mover in work on fusion safety, environmental and economic studies, and is engaged in theoretical work on a variety of aspects. UKAEA collaborates with JET and ASDEX-Upgrade on physics scaling experiments.

At the **Joint Research Centre** (Ispra, Petten) work is undertaken for selecting and characterising materials for ITER, improving tritium-related knowledge and technology for operational and environmental safety, etc.

University groups contribute through their national associations as well as, in close collaboration with JET and several Associations. Greek groups participate in diagnostics and theoretical work.

Also, **international collaboration** is an important element in the activities of the Programme. Key contributors in the field of Tokamaks are USA, Japan and Russia.

2.1 FUSION ASSOCIATION BUDGETS

Associate	Country	Annual Expenditure Mio ECU*
Max-Planck Institut für Plasmaphysik (IPP)	Germany	78
Commissariat à l'Energie Atomique (CEA)	France	65
Ente per le Nuove Tecnologie, l'Energia e l'Ambiente (ENEA)	Italy	63
Forschungszentrum Jülich GmbH (KFA)	Germany	24
Forschungszentrum Karlsruhe GmbH (FZK)	Germany	22
Swiss Confederation	Switzerland	19
Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT)	Spain	18
United Kingdom Atomic Energy Authority (UKAEA)	United Kingdom	16
Stichting voor Fundamenteel Onderzoek der Materie (FOM)	The Netherlands	11
Swedish Natural Science Research Council (NFR)	Sweden	9
L'Etat Belge (EB)	Belgium	7
Risø National Laboratory (RISØ)	Denmark	3
Instituto Superior Técnico (IST)	Portugal	3
Technology Development Centre Finland (TEKES)	Finland	2
TOTAL		340

* Estimated 1996 expenditure, excluding expenditure under the NET Agreement

Source: Community Fusion Programme - Input Documents for the 1996 Evaluation Board, DG XII Fusion Programme, May 1996.

2.2 FUSION ASSOCIATION DEVICES

DEVICE	ASSOCIATION EURATOM
Tokamaks	
TORE SUPRA	CEA (Cadarache)
ASDEX-Upgrade	IPP (Garching)
FTU	ENEA (Frascati)
TCV	Switzerland, CRPP (Lausanne)
TEXTOR-94	KFA (Jülich)
COMPASS-D	UKAEA (Culham)
START	UKAEA (Culham)
MAST	UKAEA (Culham)
RTP	FOM (Nieuwegein)
ISTTOK	IST (Lisbon)
Reversed Field Pinches	
RFX	ENEA (Padova)
EXTRAP-T2	NFR (Stockholm)
Stellarators	
Wendelstein 7-AS	IPP (Garching)
TJ-II	CIEMAT (Madrid)
TJ-1U	CIEMAT (Madrid)
Wendelstein 7-X	IPP (Greifswald)

Chapter 3:

Questionnaire analysis: Background Variables on Labs in the European Fusion Programme

3.1 Introduction

The questionnaire includes different groups of questions, that is, identification, trajectory of the lab, resources, activities and attitudes. As mentioned above, the main focus is on the researchers attitudes on questions related to ITER, EURATOM, and future research challenges, relations to politicians and to other physicists (inward, outward and international dimension). Before presenting the findings from the statistical material, it is necessary to discuss some of the background details on the questionnaire and procedure of analysis.²⁷

In order to locate *fusion research leaders*, a request was sent to Heads of Research Units within European Fusion Programme, asking for names and working addresses of relevant persons. Presumably, we did not receive information on all fusion research leaders and the findings are therefore not applicable for the entire population. In total 185 questionnaires were distributed, but the number of replies did not exceed 97 (i.e., 53 %). The answers were not equally balanced in terms of national belonging, in fact some countries are not represented at all (France and Greece). Nor are the associations equally represented; for example, only 10 percent of the Jülich (Germany) researchers responded. Further, since some of the Associations are comparatively small in terms of staff (here: fusion research leaders), the numbers calculated as a percentage have a good chance of being misleading when the response rate is less than 100 percent. Therefore we have chosen to neglect a few Research Units (RU:s) which are either too small to be of real significance to us (Switzerland, Spain, Luxembourg, Portugal), or where the response is too low to allow a statistical treatment. Respondents from these units do not appear in comparative analysis based on *nation* or *RU* other than in aggregated form.

When analysing attitudes on basis of orientation, we ignore two respondents since they either represent a researcher involved in SERF actions or a person representing the Ministry in the country. Altogether, this lead to the conclusion that the findings based on the questionnaire are not as statistically reliable as one would hope for. Another consequence from the small sample is that it is not possible to go far in detailed analysis in specified groupings. This is very obvious when we are dealing with country/RU as an independent variable. Not more than six countries

²⁷ A number of the background questions are, of course, fusion related, but for many of the questions we relied on a questionnaire done by Philippe Laredo at CSI Ecole de Mines de Paris. That work, in which Sandström was one of the partners, is yet to be finished.

have a number of responses that makes it meaningful to show figures by country (see table 3.1 below).

The number of sent in questionnaires from each country are shown in table 3.1:

TABLE 3.1 RESPONSES BY COUNTRY

Country/RU	Send out	Response	Resp. rate (%)
Austria	17	12	70,5
Belgium	11	9	82,0
D-garching	32	8	25,0
D-jülich	20	3	15,0
D-karlsruhe	14	12	85,5
Denmark	2	2	100,0
Finland	6	4	66,5
France	4	0	0
Greece	1	0	0
Ireland	5	4	80,0
Italy	26	15	57,5
Luxembourg	1	1	100,0
Netherlands	12	6	50,0
Portugal	5	2	40,0
Spain	5	1	20,0
Sweden	13	9	69,0
Switzerland	3	2	66,5
UK	8	7	87,5
Total	185	97	52,5

3.1.1 Structure of Questions and Attitudes

As discussed earlier, our preliminary focus is on the researcher's attitudes towards certain statements. In order to perform a systematic analysis of the attitudes we have ordered the statements used in the questionnaire in five different groups. In this categorisation the groups are also discussed in terms of inward, outward and international dimension, as presented in the part I. **First**, the perceived obstacles and endangerment for fusion research is discussed and analysed. This includes questions on political and scientific perspectives on fusion research, as well as aspects on future problems. **Second**, a few attitudes on collaboration is scrutinised. In this context, the attention is on EURATOM and the international dimension of collaborative research efforts. **Third**, the analysis concentrate on issues regarding power and influences of the field, stressing the role and position of the political actors. **Forth**, the attitudes towards the general research directions is analysed. This section discusses how the fusion researchers accept the programmes' priorities and stipulated research efforts. **Finally**, the analysis includes a section on the fusion researchers perceived relation between fusion and other physics. The "group-dimension relation" is illustrated in the table below (table 3.2). The questions can be found in Appendix I.

TABLE 3.2 SYSTEMATIC ARRANGEMENT OF QUESTIONS ON ATTITUDES

	Group 1	Group 2	Group 3	Group 4	Group 5
Inward				1, 3, 4, 9, 21, 22	
Outward	5, 6, 10, 11, 23		2, 12, 13, 14, 15, 16, 17, 18		7, 8, 24
International		19, 20,			

NB! Numbers in rows refer to number in the attitude section of the questionnaire (see Appendix I)

Group 1: Perceived Obstacles and Endangerment for Fusion research

Group 2: Collaboration on World and European level

Group 3: Actors of Power and Consistency of Influence

Group 4: Research Directions

Group 5: Fusion and the Physicists Community

Unmistakably, the presented groups above are not independent between themselves, rather, they tend to intersect on several aspects. The categorisation is however simplifying the procedure of analysis and defines questions of interest.

3.2 Independent variables

Country was chosen as the first background variable. This variable has already been described above in table 3.1.

3.2.1 Orientation of Lab or Research Group

One of our major ambitions has been to arrive at a valid classification of research units and respondents according to their orientation (technological, experimental or theoretical). In the questionnaire there is a question where the respondent is asked to classify the activities of the own research group (we called them research labs in the questionnaire). We used the following categories: Fusion physics (theoretical or experimental), Underlying technology and Diagnostics. Besides this we also have a question asking for keywords as descriptors of activities. From this we managed to classify our respondents in different groups, but we were not satisfied with this. We also had a material that were based on answers about the main journals where each respondent usually published articles. This gave us additional information that was used as a validation of information as it was possible to compare the keywords received from each respondent with

descriptors used in the INSPEC database for journals. This procedure gave us the result that is presented in table 3.3.

TABLE 3.3 RESPONDENTS BY ORIENTATION

ORIENTATION	
Experimental	34
Technological	39
Theoretical	22
Other	2 ²⁸
Sum	97

We also initiated a more general validation of this operation as we had the opportunity to use the INSPEC database. Through the classification used in that database we thought it would be possible to receive at least a broad picture of the different activities in each research unit/association/country (see table 3.4 after this section). To this end we analysed papers in the INSPEC database from 1995 to 1998 (September), in all 1107 articles as no conference proceedings were included, i.e. we only used refereed articles in journals. In table 3.4. these articles are distributed to each country or association. Germany is, if all associations and other fusion related institutions are put together, the country with the highest figure of published articles during this period. Countries like Italy, France, UK, Sweden, Holland, Switzerland, Spain and Belgium all have more than 20 articles why it might be a doable task to analyse articles according to orientation. This is done in the Appendix IV where a general classification is done of the journals that have been mentioned by our respondents.

TABLE 3.4. FUSION ARTICLES 1996–1998 (SEPT.) BY ASSOCIATION.

No of articles				
Country/Assoc.	1996	1997	1998	Total
Italy	64	79	36	183
France	38	94	31	163
UK	33	77	50	163
D-Garching	40	72	42	155
D-Jülich	19	50	28	98
D-Karlsruhe	19	16	5	40
Germany(other)	31	55	29	115
Sweden	4	29	8	41
Netherlands	11	12	13	37
Switzerland	6	8	10	26
Spain	6	13	4	23

²⁸ Here 'Other' refers to two respondents which could not be classified as member of any of the stipulated orientations. One of the respondent belongs to the ministry, the other is directly related to SERF.

Belgium	3	7	11	22
Poland	4	6	6	16
Portugal	1	7	4	13
Finland	2	5	4	11
Denmark	1	7	2	10
Austria	4	0	2	6
Total	286	537	285	1107

TABLE 3.5 ORIENTATION (ARTICLES) AND COUNTRY (PER CENT) 1995–1998 FROM THE INSPEC DATABASE.

Country	General %	Practical %	Theoretical %	Experimental %	Total
Italy		20	31	48	99
France		27	32	39	98
UK		29	38	30	97
D-Garching		18	37	43	98
D-Jülich		18	43	39	100
De-Karlsruhe		16	23	58	97
Germany (other)		11	32	55	98
Sweden		12	51	37	100
Netherlands		19	43	38	100
Switzerland		15	33	52	100
Spain	4	13	30	52	99
Belgium	23		36	38	97
Portugal		54	8	38	100
Finland			36	64	100
Denmark	10		30	60	100
Austria			50	50	100
Total	2	20	35	42	99

Note: the calculation does not include smaller categories like bibliographies and such.

Table 3.5 gives a general impression of the activities going on, but if we want a thorough and more in-depth study of each country we probably will have to include all type of papers published from each country. This method gives us an overview and even if it cannot be used as a methodological validation of our own classification of each research unit leader it proves to underpin it. There are interesting patterns and differences between countries. Most of the published articles are of course in experimental and theoretical areas, and the method used underestimate the activities in the technological (practical) fields of research. To a large extent it seems as if the bibliometric descriptors are unable to distinguish between technological and experimental activities. This we can tell from the classification of activities at Karlsruhe compared to other German associations. The former are to a large extent technology oriented, while the

others are more experimental. Jülich, Sweden and Austria have most of their publishing activities in theoretical areas.

3.2.2 Age of Lab or Research Group

This variable has been organised in three different classes: (1) research groups (labs) started during the 1950s and the 1960s (according to the respondent's view). This group are called *Old*; (2) Research groups (labs) started during the period 1970–1988 (*Medium* aged); (3) Research groups (labs) that were stated after 1988 (*Young*). The numerical results are exposed in table 3.6. The reader should observe that the classification is based on data given by the respondents themselves. We have no information about the actual start of each research unit. Instead we wanted information that was close to the research leader and the impression of "age" that they had themselves. In consequence, inside of an "old" Research Unit there might be newly set up groups that will be classified as young in our analysis. From this follows that we have one problem interpreting our data: does the respondents refer to the own group or lab or do they refer to the Research Unit? In this case we would argue that it does not matter as too much as it is also interesting to analyse respondents from where they put their identities not from where they belong in a formal classification of organisations.

TABLE 3.6. AGE OF RESEARCH LABS OR RESEARCH GROUPS

AGE*	
Old	46
Medium	26
Young	16
Sum	88

*Missing value: 9

3.2.3 Size of Research Lab or Research Group

This variable is grounded first and foremost on our data from each Association, i.e. figures presented in paragraph 2.1. We have categorised the associations in three classes: small, medium and large.

Small are those units that belong to associations with an annual budget less than 15 MECU.

Medium are units that belong to associations with an annual budget larger than 15 MECU but less than 50 MECU.

Large are units that belong to associations with an annual budget larger than 50 MECU.

From this categorisation and the data to which we had access (Input Documents for the Barabaschi Report from 1996) we get the pattern that is exposed in table 3.7. It is a huge disadvantage that we have not been able to receive any data from the European Fusion Programme itself. Information on distribution of funding for different objectives is restricted. This situation has clearly complicated the investigation, and as a consequence it has undermined our understanding of Associations and the European fusion programme. As a consequence with this we have had to rely on data from 1996 and data on a highly aggregated level.

TABLE 3.7 ASSOCIATION AND UNITS BY SIZE

COUNTRY/ Associate	SIZE		
	Small	Medium	Large
Austria	12		
Belgium	9		
Denmark	2		
Finland	4		
Germany-FZK		12	
Germany-IPP			8
Germany-KFA		3	
Ireland	4		
Italy			15
Netherlands	6		
Portugal	2		
Spain		1	
Sweden	9		
Switzerland		2	
United Kingdom		7	
Total	48	25	23

NB! Please note that this table does not include countries, which have not answered the questionnaire. The numbers indicate amount of answers from each country/Associate. Luxembourg is not represented in the table, but is present in the report in aggregated form.

Source: Community Fusion Programme - Input Documents for the 1996 Evaluation Board, DG XII Fusion Programme, May 1996.

We have also used an alternative strategy for the size variable. The results from this is exposed in table 3.8. There we have used economic data on lab budgets for the categorisation of respondents by size. In the questionnaire respondents were asked to specify the lab budget for 1997. That is, they were supposed to answer with their own research group in mind. We did not ask for figures about the whole Research Unit, but, obviously, in some cases this happened as the director responsible for the RU answered the questionnaire. We have used these data to classify each answer in three economy classes (see table 3.8). We find a pattern that goes pretty well with the results of table 3.7.

TABLE 3.8 COUNTRY BY ECONOMY CLASS (NB! MISSING VALUES NOT INCLUDED)

No. of Economy class	Economy class			
Country	A=<1 MECU	B=1-10 MECU	C= >10 MECU	Total
Austria	7	2	0	9
Belgium	3	6	0	9
D-garching	1	2	4	7
D-karlsruhe	3	5	2	10
Italy	1	9	4	14
Ireland	4	0	0	4
Netherlands	0	3	2	5
Sweden	5	1	0	6
Finland	3	1	0	4
UK	0	0	7	7
Total	27	29	19	75

Source: Questionnaire (Missing values 20)

TABLE 3.9 ORIENTATION BY ECONOMY CLASS

Orientation	A=<1 MECU	B=1-10 MECU	C= >10 MECU	Total
A Theoretical	12	4	4	20
B Experimental	7	13	7	27
C Technological	11	15	8	34
Total	30	32	19	81

Source: Questionnaire (Missing values 14)

In order to validate our data on size we present a cross tabulation between orientation and Economy class in table 3.9. It is apparent that we find a logical pattern in the table – theory orientation is to a large extent in the lowest economy class, while experimental "labs" shows quite the opposite pattern. The impression is that some of the respondents have answered not for a specific research group, but, instead, had the whole unit in mind when answering on these background data questions.

Thus, we have to use a calculation that takes this problem into account. Whether the respondent had the former or the latter definition of lab in mind does not matter as long as we correlate figures internally (in the questionnaire). Instead of absolute numbers of size we have to each for relative figures that can be produced from data about activities collected from the respondents answering about budgets, staff, publishing and so on. That type of relative figures goes beyond the quite static and aggregated data on association level.

Our move to relative variables are, also, motivated from other reasons. When we analyse attitudes it soon becomes apparent that variables unable to cover the dynamics over time give us only a small part of the picture. A person situated in a lab in permanent growth will probably have views that differ in many respects from people situated in labs in decline. In the questionnaire we included a questions where the respondents were supposed to describe the evolution of their lab (as judged by number of research staff) over the last 10 years (or since its establishment) (question seven in the trajectory section). The respondents could tick in on five different trajectories described in figures [no growth, decline, continuous growth, single increase, up and down, or give their own description in a small figure].²⁹ From this material we made three categories: Growth, No Growth and Decline. Numbers are shown in table 3.10.

TABLE 3.10 TRAJECTORIES OF RESEARCH LABS/GROUPS IN FUSION

Trajectory*	No.
Growth	30
No Growth	40
Decline	21
Total	91

* Missing values: 6. Source: Questionnaire

Obviously we would expect a lab in growth to have had some recruitment's during the last two years. We had a control question on that (question 11a and b in the trajectory section) and from what we have seen there are no problems regarding coherence in the answers from respondents.

What type of labs are growing and which does not? In table 3.11 are shown the figures from a cross-tabulation of Trajectory and Economy Class. Here figures are shown in numbers translated with an Index method. This method counts the observed value divided by the expected value. [The formula for the latter figure is like this: Column Sum x Row Sum /Total Sum]. In summary, the index method shows if the specific category is under- or over-represented in the material. We cannot see if the tendencies are significant or not, but we get a hint about where there are interesting relations to investigate further.

TABLE 3.11 NUMBER OF (INDEX METHOD) ECONOMY CLASS BY TRAJECTORY

No of Economy class	Economy class			Total
	A=<10 MSEK	B=10-100 MSEK	C= >100 MSEK	
1. Growth	1,211	0,944	0,770	1
2. No Growth	1,238	0,927	0,756	1

²⁹ This question was derived from the questionnaire developed by Philippe Laredo.

3. Decline	0,287	1,207	1,750	1
Total	1	1	1	1

Source: Questionnaire

From table 3.11 we learn that the largest labs are in decline and that the smallest are growing. If the medium sized labs are excluded and only the two extremes (small and large) are compared we receive highest possible significance, i.e. in 97 % of all cases we will probably find a difference between the two in the direction *that small sized labs are growing and large sized labs are declining* ($p > 0,02$, $\chi^2 = 8,63$ Df=2). Exactly the same pattern is revealed when Economy Class is compared to Age of research lab.

In our interpretation these figures and results are an indication of the fact that there are a number of new labs that have come into the European Fusion Programme due to the integration process in EU during the 1990s. That counts for countries like Finland, Ireland and Portugal, but as table 3.12 shows this explanation is far from complete.

TABLE 3.12 TRAJECTORIES OF RESEARCH LABS BY COUNTRY

Numbers of	Trajectory			Sum
	1. Growth	2. No Growth	3. Decline	
Country				
Austria	6	5	0	11
Belgium	6	3	0	9
Switzerland	2	0	0	2
D-garching	3	3	2	8
D-jülich	0	2	1	3
D-karlsruhe	3	5	3	11
Denmark	0	2	0	2
Spain	0	0	1	1
Italy	5	4	4	13
Ireland	2	2	0	4
Netherlands	0	1	5	6
Portugal	1	1	0	2
Sweden	0	7	1	8
Finland	2	2	0	4
UK	0	3	4	7
Sum	30	40	21	91

Source: Questionnaire. Missing values 6.

3.2.4 Institutional setting

To our knowledge there are no classification according to this variable available from the European Programme. Unfortunately we did not ask for information that could identify different institutional settings in our questionnaire. Initially we were told that several of the questions that we wanted to send out would be available directly from the head quarters of the Fusion Programme. (One reason for not having them in the questionnaire was that the respondents would turn it down as it would take too much time to put the figures together.) Later we learned that

Brussels was unable to send us any material due to the restricted nature of the material we wanted! In a short sentence: Catch 22!

The strategy for identifying the institutional setting of each respondent relies on the addresses of each questionnaire. First we tried to sort out those addresses that gave an indication of being formally an institution belonging to a university. Secondly, we categorised the others as institutes. The numbers of respondents are shown in table 3.13.

TABLE 3.13 INSTITUTIONAL SETTING BY RESPONDENT

Setting	No.
Institute	70
University	27
Sum	97

There is a significant difference ($p < 0,02$) between institute and university settings when related to Trajectory. Institutes are in the category decline, while university labs are over-represented in the growth category.

3.3 Dynamics of Labs

3.3.1 Personnel and Doctoral Students

Recruitment of new personnel, e.g. doctoral students, can be considered as one of many indicators of dynamics in labs. Of course, recruitment of permanent staff is a typical alternative way of growing or finding new research options in Research Institutes. As there are an interesting difference between research institutes and universities in this respect we have investigated further on this topic. It seems quite clear that institutes have a low number of new doctoral students over the past two years. In universities the picture is very much the other way around. When looking closer at the question (question 11a in the trajectory section) whether the lab has recruited permanent staff since 1995 we find that institutes have been more active than universities. The conclusion is simple – institutional setting gives ground for different strategies in recruitment.

Is there a tendency for old labs to stick to their personnel and for young to recruit? Table 3.14 shows that this is the case (also in this table we have used the Index Method to make it easier to see the over or under represented categories). In that table we have constructed a measure on doctoral recruitment called Doct./MECU. Data were divided in three classes:

High ($= < 1$ MECU per New Doct.)

Medium ($= 1$ MECU – < 10 MECU per New Doct.)

Low (> 10 MECU per New Doct.)

It is exactly what it says: the number of doctoral students recruited over the past three years divided by the annual budget in MECU (we used the figures given in the questionnaire). In the next tables, table 3.14 and 3.15, the dynamics are correlated to Economy Class. The pattern is the same: There is a weak tendency that young labs have a higher proportion of recruitment of doctoral students and that small sized and low budgetary units (labs) have a tendency to recruit new doctoral students. In correspondence to this, old units seem to have a hard time finding or recruiting doctoral students and large units/labs have the same problems. One intervening factor is orientation. Experimental labs have a high portion of personnel recruited, but they are lower when doctoral students are counted. Theoretical labs (normally small and in a university setting) shows very much the opposite behaviour.

Considering that there is no correlation at all – a zero-relation between recruitment of staff on the one hand and recruitment of doctoral students (Pearson $r = 0.22$) – we get the impression that the probability of finding dynamic labs is higher in smaller and younger, university-based settings than in other.

TABLE 3.14 AGE BY NUMBER OF DOCTORAL STUDENTS RECRUITED PER MECU.

No of Doct./MECU	Doct./MECU			
Age	A Low	B Medium	C High	Total
A Old	1,160	0,993	0,561	1
B Medium	0,816	0,951	1,690	1
C Young	0,816	1,109	1,183	1
Total	1	1	1	1

Source: Questionnaire

TABLE 3.15 ECONOMY CLASS BY NUMBER OF DOCTORAL STUDENTS RECRUITED PER MECU

No of Doct./MECU	Doct./MECU			
Economy Class	A Low	B Medium	C High	Total
A Low	0,269	1,178	2,525	1
B Medium	0,888	1,363	0,227	1
C High	2,285	0,126	0	1
Total	1	1	1	1

Source: Questionnaire

3.3.2 Productivity in Publishing and Lab Structure

The questionnaire also asked for estimated numbers of publications; a) articles in refereed journals, b) in conference proceedings and c) in lab reports. In the following analysis we have chosen to make a certain distinction between these categories instead of putting them all together. Each category of publication has been subject to a valuation, which gives us a weighted estimation of productivity. Number of articles in refereed journals is multiplied by three; publications in

conference proceedings is multiplied by two; and the number of publications in lab reports remains unchanged. The figure that we get from this operation is laid as the basis for two different productivity measures:

A. Productivity in relation to Lab Budget (Prod-Class Ec)

B Productivity in relation to Lab staff (Prod-Class Staff)

The correlation between these two measures are fairly low – Pearsons $r = 0.52$. One reason might be that there are many missing values for measure B, but we should, of course, not expect to find a correlation between such variables. Theoretically we have no indications that staff and budgets are correlated in fusion research. Large facilities comes in between as a co-variance factor. *As a consequence, we will prefer to use the staff related measure as we have better data.*

Our first finding is that no matter what measure used there is a highly significant difference ($p < 0,001$) in productivity between Economy Classes. Units/labs with a small budget have a high productivity and the large ones have a low productivity. This is confirmed also when the conventional variable "size" is used.

Surprisingly, we find an unexpected result when it comes to the "age" variable: Units classified as "young" have a relatively low productivity, few of them have high figures. The tendency for "old" labs are positive, but not to a significant extent. Among medium-aged labs there is an even distribution according to productivity classes.

"Trajectory" does not give a distinct pattern although declining labs tends to be in the category for low productivity labs. It can be noted that no growth labs have tendency for high productivity. A number of theoretical labs can be found in that category.

As small units often have a theoretical orientation we find a pattern where theoretical labs have a tendency for high productivity and Experimental vice versa. Technological labs are quite evenly distributed between productivity classes, but the tendency is that their productivity are in the lower end (see table 3.16). Also, we find a strong correlation between productivity and institutional setting. University-based labs have a distinct high value and institutes are seldom highly productive (see table 3.17).

TABLE 3.16 PRODUCTIVITY BY ORIENTATION(INDEX METHOD)

Prod-Class(staff)	Orientation			Total
	A Theory	B Experimental	C Technological	
A_Low	0,650	0,980	1,192	1
B_Medium	0,000	1,516	1,043	1
C_High	1,987	0,674	0,795	1
Total	1	1	1	1

Source: Questionnaire (Absolute numbers: 62)

TABLE 3. 17 PRODUCTIVITY BY INSTITUTIONAL SETTING (INDEX METHOD)

Prod-Class(staff)	Institutional setting		Total
	Institute	University	
A_Low	1,116	0,604	1
B_Medium	1,292	0,000	1
C_High	0,700	2,030	1
Total	1	1	1

Source: Questionnaire (Absolute numbers: 62)

The pattern then is almost the same as the one found for personnel and doctoral students. If our method for identifying productive labs are accepted we might conclude this section with a short summary: *Small, old and university-based labs tends to show good performance when performance is measured from publishing data.*³⁰

The following chapter will use these background variables for an analysis of the attitude section of the questionnaire.

³⁰ It is a pity that we lack information about costs for facilities. Such information might change the described pattern in several dimensions.

Chapter 4:

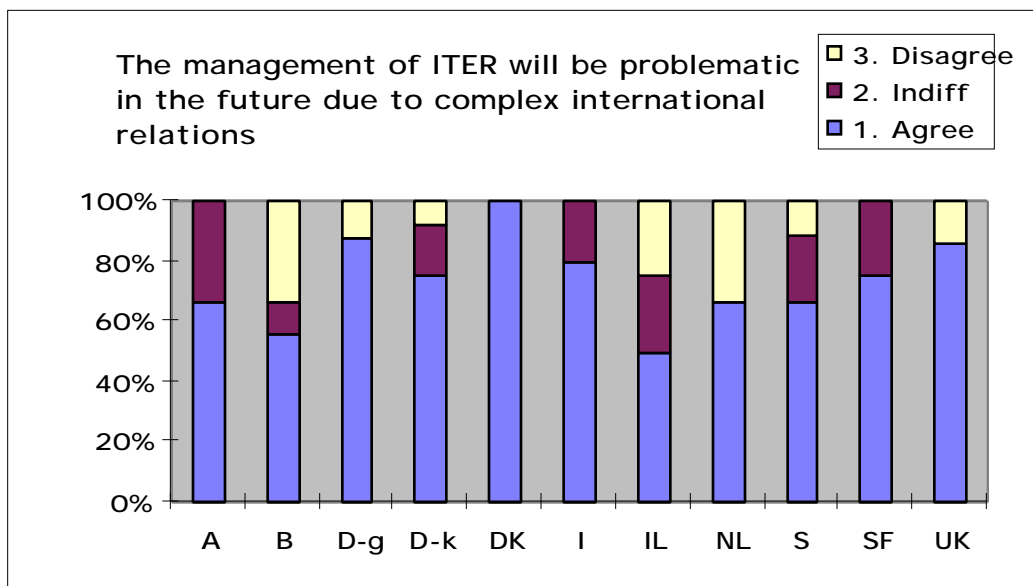
The Fusion Research System: An Analysis of Attitudes

4.1 Perceived Obstacles and Endangerment's for Fusion Research

Every scientific effort tend to include obstacles and difficulties caused by, for example, the complexity of the scientific field, decline in political commitment etc. These are problems that researchers often have to face when participating in large scale projects, and some of their concern was apprehended in the distributed questionnaire.

The fact that ITER is an international project, with a variety of different national and international actors influencing the process of construction, design and operation, is somewhat discouraging for the researchers. When asked if the fusion researchers believed the management of ITER will be problematic in the future due to complex international relations, a great majority of the respondents answered affirmatively (70.3%). Strong attitudes on this question can be found among research leaders in Garching, Karlsruhe, Denmark, Italy and the UK (see fig. 4.1.) Also, researchers working on technological issues or declining research labs agrees more strongly to the statement than other groups. Many mention the indecisive behaviour presented by the US partner, and some suggests that Europe and Japan should develop a stronger collaboration. Although expressing their fear that the project will be hampered by the complexity of international relations, the respondents are eager to point out that since JET has proved to be manageable, ITER will be too. This goal is very important and does not allow the participating actors to surrender, therefore, future problems must be overcome.

FIGURE 4.1



Further, the investigation shows that the fusion researchers within EURATOM find the realisation of the ITER project crucial to the research efforts on fusion in their home country. 82.6 percent of the respondents indicated that a decision against constructing ITER would endanger their national research efforts on fusion. The question indicates a strong relation between international support and national commitment to fusion research. There is no significant variance between groups of size or age of the institute/department, but it is possible to detect a modest diversification between different groups of orientation. While 91.2 percent of respondents within experimental orientation fear that the construction of ITER is closely related to the national research effort on fusion, 71.4 percent of the theory oriented respondents agree. Close to one fifth of the latter group strongly or mildly disagree to the statement, and the technology oriented researchers stand between these groups. The general findings illustrate how members of the European fusion research community perceive the consequences of giving up the project. According to their understanding, a decision against ITER would be a severe setback to fusion research itself, and would reduce the national efforts to fundamental research on fusion. The national programmes will have great difficulties in retaining the present funding, and might even lose it completely. As a result, a strong majority are convinced that a decision against ITER would imply a severe reduction in credibility for the vision of a practical implementation of fusion principles.

ITER is therefore not only a necessary step towards a commercially viable fusion reactor, but also a symbol of societal and international commitment on fusion research. It seems as if certain groups of the fusion researchers acknowledge that the decision on ITER is crucial to their field: A decision to continue with the ITER effort would mean a long-desired sign of commitment, while the negation would imply a decay in practical implemented fusion research, leaving only fundamental research efforts. Thereby is the field of fusion research standing at the crossroads, facing either future prosperity in effort, or possible decline.

Then again, a few argues that a decision against ITER probably would lead to the design of a reconstructed device, implying that a negative decision might not be devastating to the present fusion research. There is a tendency that respondents of technological orientation have more of confidence on this question. The new device might not be as ambitious and challenging as the former, since it is more than likely that such an experiment would receive less funding than the estimated cost of ITER. However, it would secure the presence of practical implemented fusion research.

The outcome of the decision on ITER is obviously by many perceived as fundamental to the development of their field. According to the overwhelming majority of the respondents, a serious threat to the construction of the ITER reactor can be found on political and economic grounds. No less than 90 percent agreed strongly or mildly to the statement: “It is likely that large scale fusion research projects will be hampered due to political and economic problems“. Their position indicate a rather strong feeling of insecurity towards the future of their ITER related work. Respondents expressed their worries over this matter, implying political short-sightedness: “Certainly the continuous finding of oil pushes in the future the severe necessity of power. But time runs.“ According to some research leaders, the uncertainty of political commitment also leads to problems in the recruitment of the next generation of researchers. They imply that the field of fusion is interesting to young people, but very few dare to make it a career because of the uncertain future. The continuing of the ITER project would therefore change this tendency, securing a long-term perspective on large-scale fusion research. This question indicates that there is mistrust towards the political community and we will come back to that later as it is one of our most interesting and most obvious results. Group leaders in fusion research has almost no, or very low, faith in actors from the political community (see below in section 4.4).

When asked whether they find it likely that large-scale fusion research projects will be hampered due to scientific and technological problems, the answer diverged. A majority (54%) strongly or mildly denied accuracy of the statement, thereby presenting a very confident position on the near evolution of large-scale fusion research. According to one researcher, scientific and technological problems are not a real issue, but an alibi for politicians. However, 36.5 percent of the respondents expresses the opposite opinion, saying that scientific and technological problems have a good chance of suppressing the progress. This might imply a worry for at least a partial defeat caused by the immediate problems within the field, i.e., it presents the uncertainty linked to actual construction of the reactor. When analysed more closely, there is a notable difference on the national level to be found. As illustrated in figure 4.2 (below), most researchers in Belgium and the Netherlands resist the statement, while the situation is the opposite in Austria, Italy and United Kingdom. In this context, it is important to make clear that the written comments on this question demonstrates a faith in ability to overcome mentioned problems: “We have to work hard“, one respondent wrote.

FIGURE 4.2

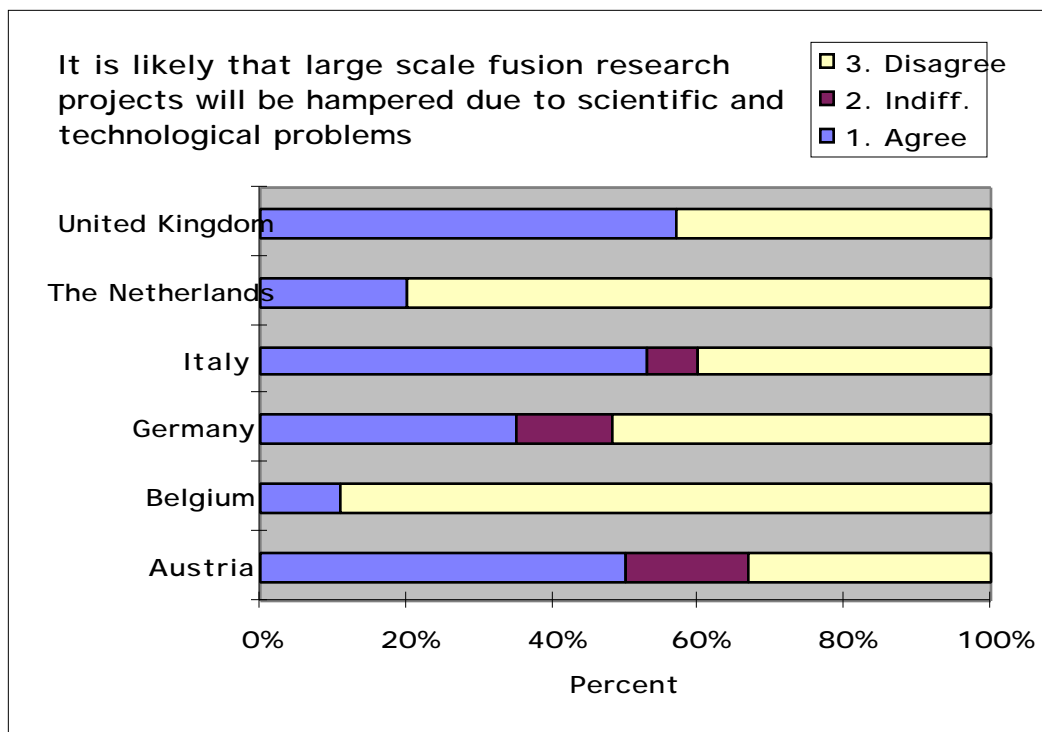


Figure 4.2 exposes a significant national variation regarding the perception of scientific and technological challenges within fusion research. The Belgian and the Dutch researchers seem to have a firm trust in the potential of current large scale fusion research projects, while, for example, the Italians and the British perceive critical difficulties within the field. The correlation on national belongings is to some extent a result of different national orientation of research (fusion physics or technological research). Research leaders with a technological orientation are more willing to agree with the statement and experimental and theoretical physicists disagree, but the variance is by no means significant (χ^2 test= 0,3). The smaller and younger research units seem to have a higher degree of faith in the fusion project.

The question might reveal a difference in tradition, but it is also possible that Austria, Italy and United Kingdom have faced certain problems in their research process. These problems do not necessary have to be based on the complexity of the field, but might emanate from perceived anomalies within the programme. This explanation is particularly plausible in the case of Italy, where the findings indicates a certain discord with the common programme on fusion. In order to verify or disqualify this assumption, a closer investigation of the actual countries needs to be executed, for example, an analysis of their historical background on the field of fusion research. The results from the questionnaire do not provide adequate information to explain the causes of national differences on opinions.

To sum up, the feeling insecurity is mostly caused by the irresolute position of the political actors and the difficulty in obtaining governmental funding to large scale projects like ITER. The scientific and technological aspects of the realisation of the project are either considered not to be

a critical issue, or are not as serious to disrupt the construction of a beneficial device. Consequently, the perceived threat against large scale fusion research is to be found outside the research itself, that is, external influences constitutes the main object of distress. As shown in the diagram above, researchers in Austria, Italy and United Kingdom are more worried over scientific and technological obstacles in fusion research than members of other nationalities.

The potential problem of recruiting the next generation of researchers was also dealt with in the questionnaire. The matter might be considered as an obstacle to fusion research in general, which thereby motivates a closer investigation. As many as three out of four agree to the statement saying that there is a problem in the recruitment of a younger generation of researchers. From country perspective, only Finland and Austria deviates from the general pattern. In the comments the respondents often refer to the scarcity of permanent appointments: “True! To have a permanent position becomes more difficult in the field of fusion. People prefer fields of physics with higher ‘job security’, like laser physics“ (Q89). The comments also suggest that the lack of political long term planning explains the recruitment problem. The uncertainty about the realisation of the ITER-reactor is another factor which probably affect the recruitment negatively, according to several researchers. Others point out that this is a frequent problem in the field of physics; it is difficult to find and attract young and talented researchers. Respondent’s orientation seem to be insignificant on this issue, but smaller units and young units tend to disqualify the statement that recruitment is a problem for fusion research. Also, respondents belonging to decreasing or stagnating labs (as measured by number of research staff) are more prone to agree on the recruitment problem. The discussed issue is also related to the question whether fusion researchers are having a problem convincing the physics community over the value of performing and funding fusion research. This is discussed in section 4.5.

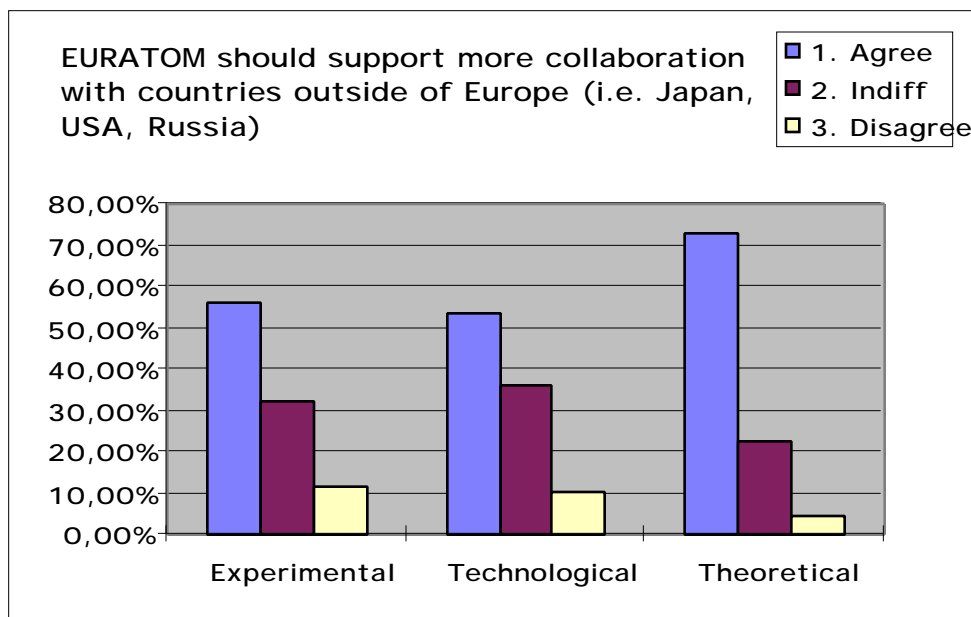
4.2 Collaboration on World and European Level

This section focuses on certain attitudes towards the operation of EURATOM. The European Fusion Programme is based on international collaboration, therefore, the question of collaboration will initially be discussed. The researchers were asked to comment the following statement: EURATOM should support more collaboration with countries within Europe. The reason for including this statement to the questionnaire, is to determine the researchers opinion on the current level of international collaborative activity. The outcome presents a clear statistical support for the statement (60.% agree, 32% indiff and 8% disagree), which thereby indicates a need for increased efforts on European collaboration. There are no differences with respect to age or size. Some proponents ask for easier procedures for exchange of scientific and technical staff, but apart from these few examples there are not many written comments exposing deficiency in the collaborative aspects of the programme. Less than ten percent strongly or mildly repudiate the statement, thus the amount of indifferent respondents is rather large percent. From a perspective of orientation, a minor variance can be observed; the technology oriented group tends to be very positive to enlarge the internal European collaboration (69.2% agree, 20.5% indiff and 10.3% disagree), while the group of theoretical researchers are mainly indifferent to the statement (45.5%

agree, 50% indiff and 4.6% disagree). Still, a large part of the latter group urge for increased European collaboration. All in all, it seems as if a majority of the researchers are dissatisfied with the EURATOM support on collaboration within Europe. However, it should be noted that “more collaboration“ generally must be considered as a good thing, which implies that researchers favourable attitudes on this matter need not necessary be an expression for criticism. This would explain why such a few respondents defined certain areas of discontentment. Instead, many expressed their satisfaction over the support on collaboration, implying that EURATOM is doing its best. According to some respondents, collaborative activities cannot be improved any further.

The second statement on this matter referred to EURATOM and collaboration with countries outside of Europe. The tendency is very much the same to the example above, and a majority (59%) feels that the mentioned collaboration should be increased. Again, quite a large group (31.6%) is indifferent to the statement of increased international collaboration. Slightly, there is a tendency among larger and old units not to agree on this statement, but not a statistically significant extent. There is also a tendency among researchers of theoretical orientation to be more supportive of the idea of increased international collaboration outside of Europe (see figure 4.3).

FIGURE 4.3



Obviously, researchers of theoretical orientation are rather satisfied with EURATOM:s support on collaboration within Europe, but feels that it should be strengthen on the international level. Researchers of technological orientation presents a slightly different position: it is more urgent to improve the internal European collaboration than to increase the support on other international collaboration. Still, the majority of each orientation would like increased collaboration on the international level.

The analysis of the findings from the last statement is similar to the former: Most fusion researchers welcome more of international collaboration, within as well as outside of Europe, but hardly blame EURATOM for the current situation of insufficient international collaboration. On the contrary, many support the efforts on collaboration made by EURATOM. In some cases, more collaboration is not desired; one researcher, opposing more support to international collaboration, expressed his indignation over the fact that countries outside Europe do not contribute an adequate share. As a consequence, collaboration with these countries should be reduced. But, it should be emphasised that many respondents are positive: “EURATOM is doing its best. If it had larger funds, it would support more collaboration. That obviously would be desirable (Q89).

4.3 Actors of Power and the Consistency of Influence

When studying attitudes within the fusion community, it soon becomes clear that the members of the community have a special relation to the political actors influencing their field. In general, they express scepticism towards politicians’ actions and motives regarding handling and development of the fusion research field. Also, they often feel that the politicians influencing the fusion community are ignorant; 56.8 percent mildly or strongly resisted the statement claiming the mentioned politicians were well informed. Only one fifth had a favourable attitude towards politicians’ level of understanding of the field of fusion. Especially in the UK lab leaders had a negative opinion on this matter. There are no significant variances between different groups of orientation, but it is obvious that the medium sized labs and the labs with a long tradition have negative attitudes towards, and maybe negative experiences of, political actors.

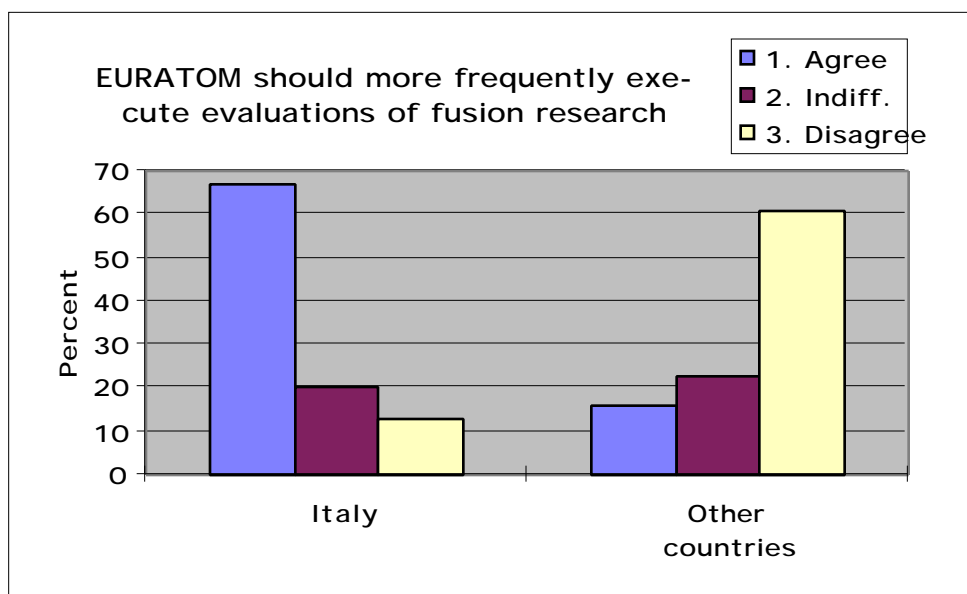
To some extent researchers blame themselves for not sufficiently explaining the importance of fusion research to the political actors. 90.7 percent of the respondents think experts in fusion should put more emphasis on this matter: “After 50 years of battling, it is important to convince the political actors that ours is not the battle of Sisyphus“. In other words, even though practical implemented fusion research have a long term perspective, it should not be seen as a never-ending story. The researchers recognise a steady progress and the final goal appear to be visible, although it might not be within immediate reach. Accordingly, the research effort of constructing a viable fusion power reactor is therefore not a waiting in vain. Another opinion is that information should be transferred to the public in general and that this is the most important issue for the future: “Manifestly true, the biggest fault in the fusion community“ (Q60 UK). Others view the opinion that politicians does not listen to reasonable argument anyway (Q68 Germany).

In correspondence with the discussion above, most researchers (86.6%) argue that the political actors have difficulties appreciating benefits of large scale, long term research on fusion. In the eyes of the researchers, the politicians are primarily interested in short-term solutions. As two respondents puts it: “Politicians have a horizon that stretches out till the next election”. and “Fusion is too long term for the political community” (Q146 NL). Since the accomplishment of a burning plasma is considered to be almost crucial to fusion research in the near future, a large-scale device will be needed. To the researchers, it stands clear that large-scale projects are unpopular in

the political community and that the political determination fluctuate over time. Only in Holland we find researchers who disagree to this statement. It also seems as if the newly established labs and the smaller ones have a tendency to be in favour of politicians in this respect. Our findings seem perfectly logical as these units have come into the EURATOM lately and appreciate the funds that have become available.

The fusion researcher's activities are dependent on a long-term perspective and they do not appreciate the idea of being judged on short-term basis. From the overall analysis, it is apparent that the members of the fusion community are somewhat frustrated over this fact: "I believe that it is most important to convince politicians that it is urgent to consolidate present knowledge in a "burning plasma" sized next step. Its success will change human on its long-term energy future definitely (as will its failure). WE HAVE TO KNOW SOON IF WE COULD DO IT OR NOT!!!" (Q 13) The indecisive signals from the political actors clearly generate an uneasy feeling among several of the members of the fusion research community. From their point of view, experts ought to have a stronger voice in long term policy decision making. 69.8 percent of the respondents share this request for more power over their field, although some merely stresses a desire to have more of the politicians attention. The general opinion is that the politicians should present a wide guideline and thereafter leave the implementation and structuring of programmes to the experts. Obviously, this is not working satisfactorily today and the fusion researchers want more influence over their research field. Not surprisingly, 50 percent of the Dutch researchers oppose the statement as these respondents seem to have a more positive attitudes towards politicians. The same is true, but with lower figures, with reference to Jülich and Finland. Technological researchers are slightly more positive to the statement than other groups. The large units have a tendency for more technocratic opinions, but these attitudes are also to be found in the newly established laboratories. This is perfectly consequent with the former attitude (need to explain fusion) if we interpret this as a perceived need for more of "political" activity from the researchers side.

The question of modes of evaluation is also important in this context, since it has a rather strong influence on the research process and the legitimisation towards the political and scientific community. The respondents have a rather mixed opinion on their position towards the amount of evaluations performed by the EURATOM. 22.7 percent are indifferent on the statement that EURATOM should more frequently execute evaluations of fusion research, while 23.7 percent believe this, at least to some extent, would be preferable. To an exceptional rate Italian respondents agree to this statement (66.7 %) see figure 4.3. But, the absolute majority of respondents (53.6 %) disagree. Fusion researchers are not in favour of more frequent evaluations and a few of the respondents also question the competence of the evaluators, implying that more evaluations are acceptable on conditions that they are performed by qualified people. There is little significant variance between different groups of orientation, although researchers of technological orientation are slightly less negative to the idea of increased numbers of evaluations. Instead, there is a significant tendency for larger labs to agree on the need for more frequent evaluations.



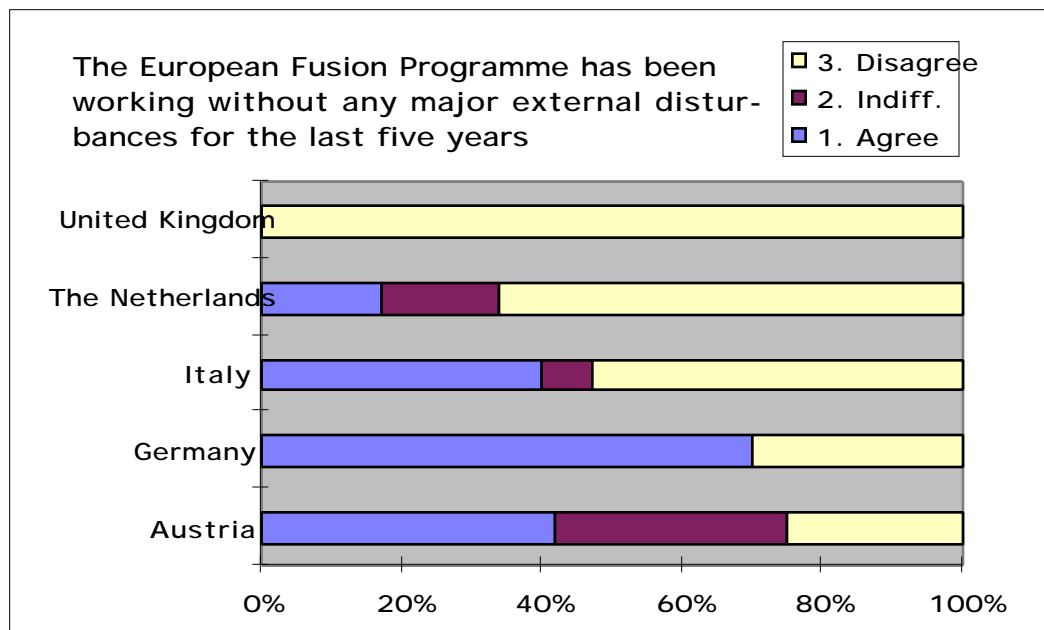
Furthermore, we find a dispersed pattern of attitudes towards the composition of the evaluation teams. 44.3 percent of the respondents strongly or mildly support the statement claiming that there is a need for more evaluators from outside of the fusion research community, while 25.8 percent strongly or mildly resist. The former group welcome external evaluators, at least to a moderate sense, and expresses a need for an increased amount of impartial people in the evaluation teams. The latter group seems to think that there are enough outside people in the evaluation teams and stresses the importance of having a sufficient amount of experts on fusion in these teams. Some of the researchers indicate this is not always the case. Again, we find differences between countries; respondents from Belgium, Holland, Italy and Sweden are in favour of external reviewers. The statement does not expose a difference in opinion between groups of orientation, although technologists are indifferent to a large extent. Neither size nor age makes any difference in attitudes. It should be noted that not a few respondents pointed out that almost all evaluators already comes form outside of the fusion community. At the same time we have to consider this type of opinion: “Outsiders are easier to fool! Important is the vision, overall qualities and openness!” (Q172 CH).

Moreover, the actual purpose of the evaluations will be discussed. The questionnaire includes the following statement: The outcomes of most evaluations are more focused on legitimising the whole research effort as such, rather than on its actual performance. 45.8 percent of the respondents strongly or mildly agree to this statement, while 21.9 percent have the opposite opinion. It is therefore a fact that many respondents feel that at least some of the evaluations have been based on ambiguous motives, although the subject are seldom penetrated any further. However, one of the respondents commented that this type of legitimising evaluations are important when evaluating long term endeavour, which implies that these kind of projects need to be regularly legitimised in order to maintain its political and economic support. Although the Italian respondents are in favour of more frequent evaluations they also have the opinion that

most evaluations, hitherto, have had primary legitimising effect. People from old units and newly established labs are more willing to accept this statement. Certainly, some respondents feel that evaluations can be a way to gain public and political acceptance towards national fusion research and the European fusion programme. This corresponds with the theoretical discussion on how to maintain the political support towards megascience project (see section 1.7.1). From this point of view, evaluations can be seen as policy actions, which can illuminate the common fusion research effort and the final objective of fusion power.

In this context, the questionnaire also investigates the question on eventual occurrence of external disturbances. This issue is rather unsettled among the fusion researchers. Although 45.8 percent of the respondents have not observed any major external disturbances for the last five years, 43.6 percent claim they have. This is quite a large cleavage among researchers in the same field, and it vividly illustrates the political problems related to the research task. The perceived obstacles (as mentioned above) consists primarily of the uncertain evolution of the ITER-project, caused by a number of factors. To start with, some researchers find the American position towards international collaboration on fusion troublesome, meaning that its reluctance towards funding ITER threatens to knock over the common assignment. Some also claim that the programme is disturbed by the budgetary turmoil within the European parliament. These attitudes partly varies among groups of orientation; while the absolute majority (52.6%) of the technologists agree to the statement, the absolute majority (54.6%) of the experimental researchers oppose. However, the investigation also expose a rather great variance of position among different nationalities (see figure 4.5).

FIGURE 4.5



The diagram above illustrate the respondents statistical position in a few of the involved countries, and the national contrasts are very clear. While the German researchers are rather content with the external influences on the programme, the British are unhappy. We have to acknowledge the problems at JET during 1997-98 to understand the British opinion, but Holland, Italy also have high figures for those who do not agree with the proposed statement. Older labs, along with declining labs, seem to be more observant to this type of problems.

To conclude this section we can summarise our findings as follows: Many fusion researchers are frustrated with their current situation. They would like to strengthen their power over their field, thereby securing a long-term perspective on practical implementation of fusion research. This can be interpreted as technocratic tendencies among influential researchers in the field of fusion. In their eyes, the low level interest and lack of knowledge among political actors cause this situation. These actors' inability to offer a clear and persistent commitment has created a distrustful attitude from the researchers towards the politicians. Consequently, the SERF programme should develop projects that is able to analyse this cleavage between communities and one important object is to analyse opinions among politicians and policy advisors. Finally, when it comes to the question of evaluations, the attitudes are more diverse and difficult to interpret.

4.4 Research directions

In the following our discussion will focus on the attitudes towards a number of questions all of which circulate around issues of desired direction of fusion research efforts. The European fusion research community consists of a variety of groups, and it is hardly surprising that attitudes differ among lines of orientation.

The European Fusion Programme is mainly focused on physics and technology development related to ITER, and the activities at JET constitutes a phase in this task. The programme is based on European collaboration and a joint research effort, and must therefore be co-ordinated and balanced to operate efficiently. Programmes of this magnitude and character frequently face various types of complications, as a result of their overall configuration. In our study, we briefly examine the referred fusion researchers' attitudes of the programme. As a first step the researchers were asked to indicate their position on the internal situation of the programme: Has the programme worked without any major internal disturbances for the last five years? According to our investigation, the general belief among the fusion researchers is that the common programme has run rather smoothly from an internal perspective. 68.4 percent of the respondents held this belief, while only 19 percent had the opposite position. The written comments regarding negative aspects of the matter were often related to the British staff issue at JET, which obviously has caused an internal commotion. The staff problems have also been discussed in scientific journals, and although this issue is often mentioned in the written comments, the general attitude is that, for the present, the programme works without any major disturbances. We find that the UK research leaders are a bit more critical towards the internal management. Probably due to the problems at JET. Also the medium aged labs (1970–1987) are a bit more willing to agree with the statement.

The researchers were asked to declare their position on the following statement: *For the next five years the fusion projects should focus more on developing/improving new concepts.* Although there is a great deal of discord amongst the respondents, there is a clear tendency to welcome increased efforts on concept improvements. 57.7 percent of the respondents strongly or mildly agree to the statement, while 22.7 were of opposite opinion. This might expose a modest discontentment over the priorities set by the European Community Fusion Programme. Several researchers indicate a benevolent attitude towards developing and improving new concepts, but stresses the importance of constructing ITER. The ITER approach is therefore considered to be of higher value than to increase the efforts on different concepts. In their point of view, an increased effort on finding and improving new concept would be counter-productive, since it would imply reduced efforts on the other approaches. The gain that would be made on this kind of priority would implicitly harm the development of ITER and technology. It should be noted that quite a large group of the respondents, 19.6 percent, is indifferent to the statement. The interpretation of the figures in this example should therefore not be too venturesome. The attitudes are, however, to some extent correlated to origin of orientation. Technologists are more willing to support the idea of increased efforts on concept improvements. The medium sized RU:s distinctly approve such a direction of research in the future and the same pattern are found among newly established labs. The longer you have been in the area the more eager to finish the whole effort.

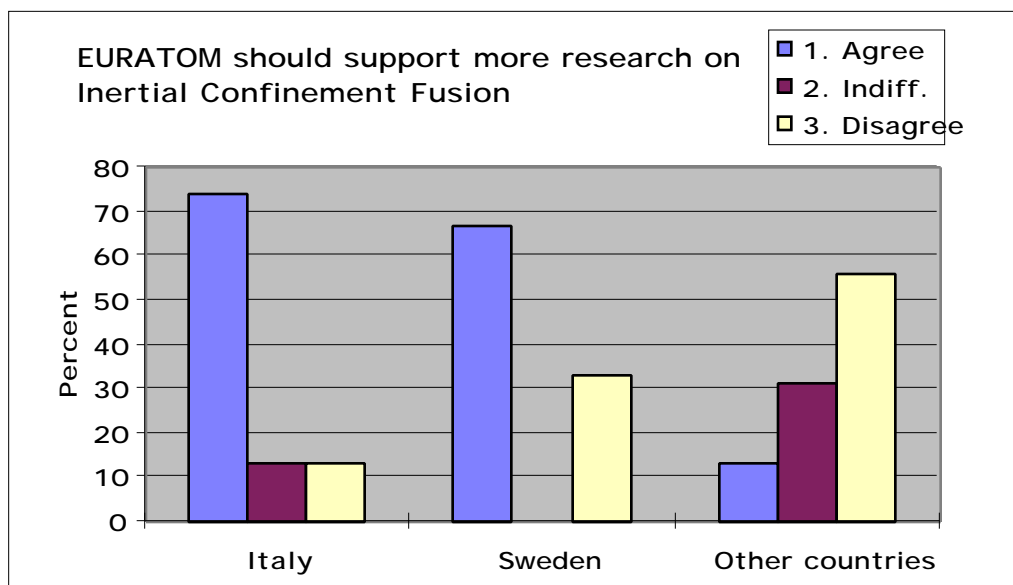
The general attitudes towards intensifying the concentration on technological issues are similar to the example above. The figures are very much the same, although the minority opposing a different priority is becoming greater. 58.3 percent of the respondents give a nod of assent to an increased endeavour on technological development, while the opposition slightly increases to 31.3 percent. The proponents often claim this field to be of increasing importance, stressing that wall materials will be the most critical issue in the future. They defend their position implying that the technology lacks the accurate maturity compared to the other fields. In this case, as in the former, there is a correlation related to orientation. The fusion physicists are not as eager to concentration on technological issues as the technological group (the former 31.8% and the latter 84.6 %). In fact, the 59 percent of the theorists disapprove more concentration on technological issues. This might not come as a surprise, since the allocation of resources very much can be described as a zero sum system, i.e. increased efforts on technological issues implies less money to theory oriented research. Experimental oriented researchers are dispersed in this issue: 45.5 percent welcomes the suggestion, while 45.5 percent disapprove.

In this context, the stipulated direction of research efforts will be discussed in more detail. The current prioritisation of the Tokamak concept is sometimes discussed and questioned in the international debate. Consequently, the questionnaire included statements regarding the research strategy on confinement, inquiring over the balance of EURATOM supporting research effort. Inertial Confinement Fusion, ICF, is an alternative approach to the Tokamak solution. According to the responses, there is not a wide support for increasing supportive efforts on ICF; only 27.1 percent advocates increased efforts on this field of confinement. A large group (47.9%) is explicitly negative to such an opening, while 25 percent remain indifferent. The arguments against more support on ICF are very often based on an antipathy towards this type of confinement

approach as it is closely connected to military research. From their point of view, some of the spin-offs from research on ICF have military relevance and the common programme should therefore not execute any substantive efforts on this field, at least for the moment: “*No mix with military research for any European wide programme*“, one researcher commented. In other words, ICF needs a ‘de-militarization’ before further exploration is acceptable.

There is no significant variance in opinion between different groups of orientation; the rate of agreement is higher among technological lab leaders. The same is true regarding size and age: the larger units have more of ICF-positive researchers and we will find them in medium aged labs. But, there is a clear national divergence to be found. Close to every associate member of EURATOM is statistically against more research effort on the ICF concept. The clear exceptions are Italy and Sweden, where 71 percent of the Italians and 67 percent of the Swedish respondents are positive to the idea. This is a sharp contrast to the other nations (see figure 4.6).

FIGURE 4.6

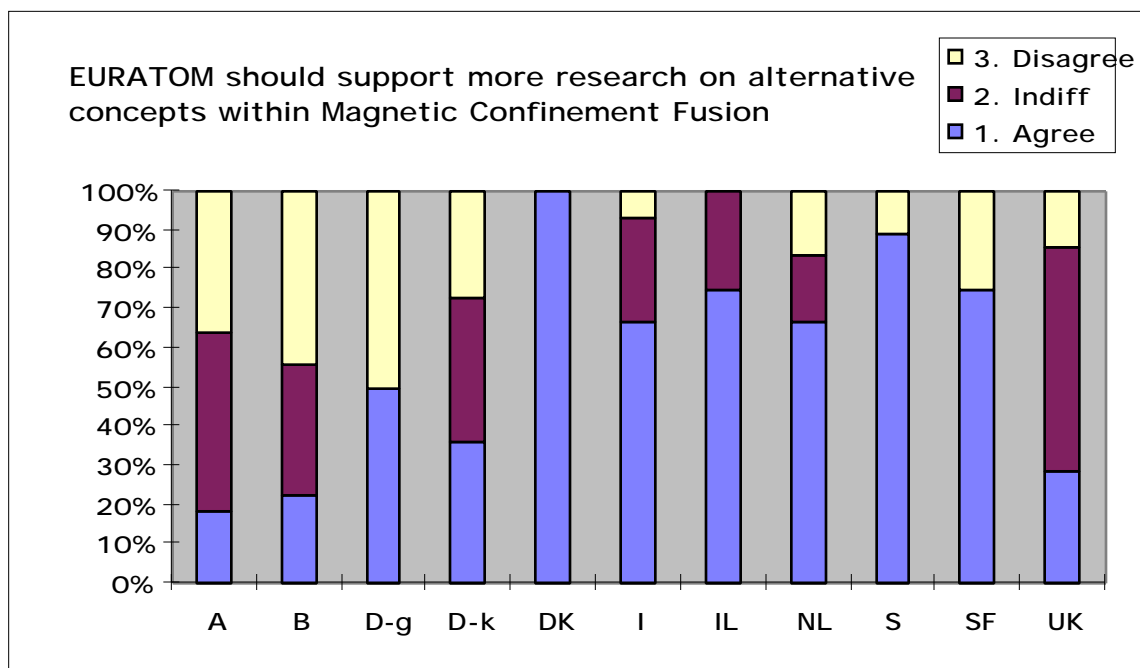


As shown by the figure, the Italian position on ICF (and to a lesser extent the Swedish position) can be described as an antithesis to other members of EURATOM. Hence, the findings expose an existent conflict on EURATOM research emphasis, and one Italian researcher finds it “...*totally arbitrary to ban it*“ (that is; research efforts on ICF). It should be noted that the Italian Association undertakes a keep in touch activity on inertial confinement fusion, which might explain some of the Italian respondent’s interest in ICF. The discussion over this issue is far from settled in the fusion community.

Along with the discussion on different concepts of confinement, is the question on alternative concepts within Magnetic Confinement Fusion, MCF. As in the ICF example above, this is a question on the balance of EURATOM supporting research effort. The respondents express mixed opinions on whether EURATOM should support more research on this matter (alternative concepts within MCF) or not. While 49.5 percent are either strongly or mildly in favour of such a change, 25 percent are indifferent and 25 percent negative to the idea. Thus, a change in priority

within MCF has a rather strong support, which implies a desire for further exploring before current concentration on the Tokamak concept. This attitude is not related to orientation, something that might surprise. Newly established research groups or labs have a quite strong tendency to agree on this. They are in favour of an open research in this respect, while the older have strong opinions in the other direction. Danish, Irish and Swedish respondents are typically open in this respect.

FIGURE 4.7



Still, present prioritisation of the Tokamak concept, and the general balance of the programme, seems to be supported by many researchers. As one researcher puts it: *It is a must to study alternative concepts, however, work on the Tokamak line should stay on the same level as now.* This opinion is probably quite common in the fusion research community, and the internal differences should not be overestimated. A rather large group is indifferent to the statement (25.3 %), and 49.5 percent of the respondents supports the idea of increasing efforts on alternative concepts within MCF. Our conclusion from this is that also this question is unsettled in the fusion community.

To conclude the discussion on priorities, it seems as if the researchers disagree on whether there is a sound balance between the three approaches in the development path towards DEMO, or not. Although ITER seems to be considered as the outmost important phase, there is a clear tendency to ask for increased efforts on the other approaches, especially among technological researchers. This tendency is particularly explicit in the case of the technology development, where some of the arguments are based on credibility; development of reactor technology is crucial in order to keep credibility for the fusion programme. However, a substantial number of researchers do not share this requested priority of technology, rather, they tend to find the development path

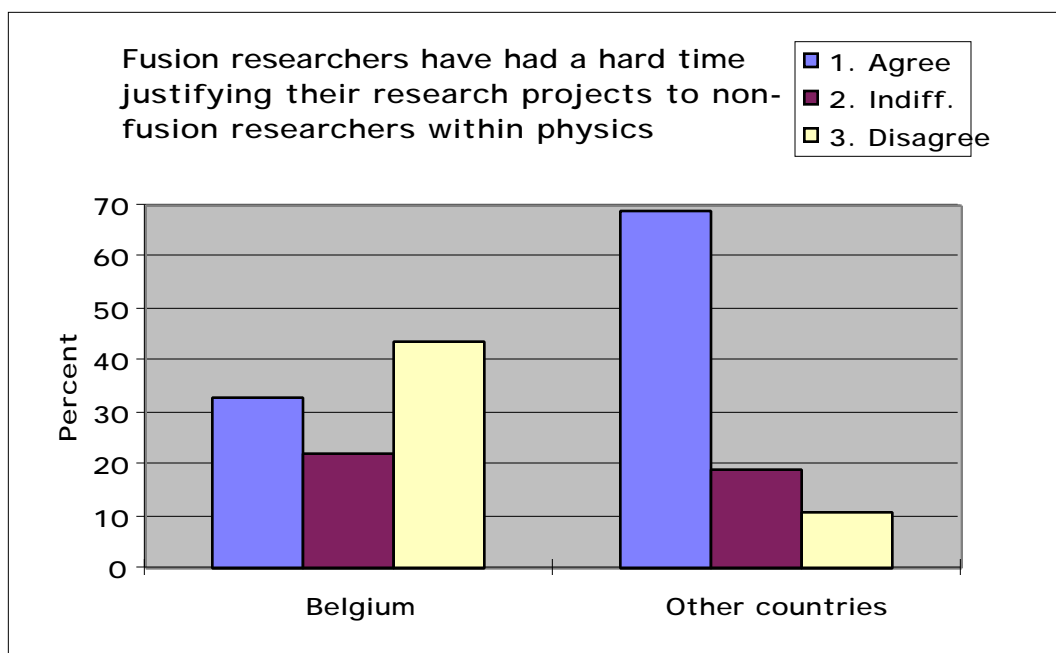
satisfying balanced. They often emphasise the next step approach, i.e., the construction of ITER, as the primary goal.

4.5 Fusion and the Physicists Community

The objective of the European research effort is the construction of a viable fusion reactor. As discussed earlier, this endeavour calls for a defined strategy and a focus on practical implemented fusion research. Doing this, there is a risk that physicists of other disciplines disapprove on the treatment of fusion research issues. In some cases, fundamental research and practical implemented research is looked upon as conflicting modes of activities. It is therefore interesting to study the fusion researchers' relation to outside physicists, asking how the former recognise their field in relation to other disciplines within physics.

Not very surprising, the fusion researchers denies the statement that the fusion programme has drawn funds away from more worthwhile physics research (85.6%). Not more than 4 percent of the respondents agree. The researchers often stresses the importance of their quest; the opportunity to develop a new viable energy source. This understanding of the situation motivates the present position of fusion research, and explain why the field of fusion have a legitimate right to receive current level of funding. However, a majority of the fusion researchers (66%) confess they have a hard time justifying their research projects to non-fusion researchers within physics. The comments sometimes refer to budget problems and other physicist's tendency to dismiss the fusion research progress as insufficient. The perceived problem of legitimisation of fusion research within the physics community is equally shared between the groups of orientation, and also rather equally shared between the different nations. Nevertheless, there is one exception; The Belgian researchers do not agree with their colleagues about this matter. Only one third of the Belgian respondents are positive to the statement, while 44 percent reject its correctness (see figure 4.8). In moderate terms we find a tendency for research leaders from newly established labs to agree that funds have been drawn from more urgent fields of physics.

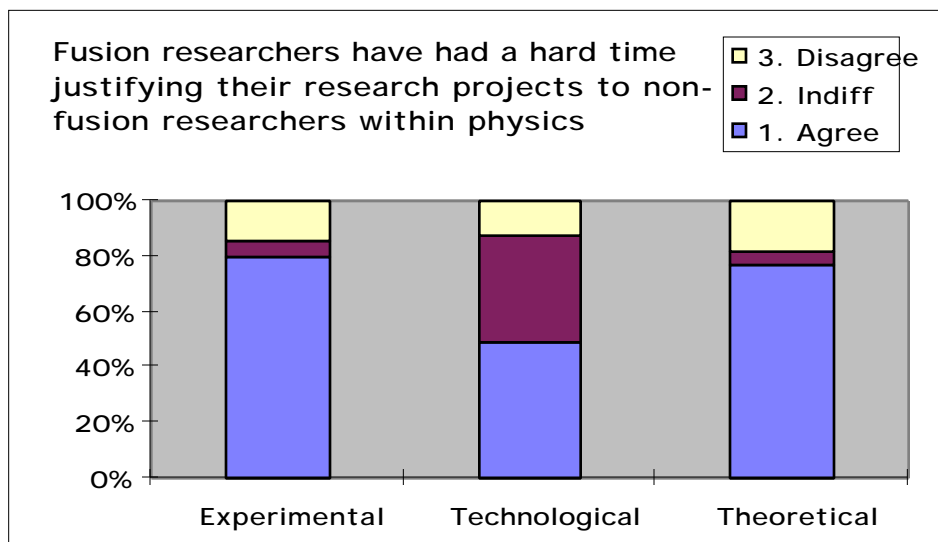
FIGURE 4.8



According to this investigation, many fusion researchers are troubled over the insufficient understanding from the other physicists. The Belgians, on the other hand, do not share this uneasiness to the same extent.

The general uneasy relation to non-fusion physics is also reflected in the responses to the statement: *It is most important in the near future to convince other physicists of the usefulness of the fusion research.* This is thought to be very important to the absolute majority of the respondents; no less than 78.3 percent confirm the correctness of the statement, while only 6.5 percent dispute it. These numbers are rather accurate when analysed from the perspective of RU, with one small exception; respondents from FOM (the Netherlands) do not feel as insecure in their relation to other physicists as members of other RU:s do. About 40 percent of Dutch respondents resist the importance of securing the support from other physicists. The majority of the Dutch respondents do agree on the statement (60%), but still the numbers reveal a divergence from the general path. Theory oriented respondents are extremely favourable to the statement: every single member of this group is concerned over their future relation to other physicists. This perception illustrates a significant justification problem among the researchers of theoretical orientation, and obviously this group feel beset, or at least misunderstood, by their colleagues within other field of physics. Respondents of technological orientation are less worried over this issue, although the majority (63.2%) stress the importance to overcome the perceived disbelief of other physicists. Almost one forth of this group indicate they remain indifferent to the statement. The third group of orientation, experimental researchers, places itself in-between the other groups in terms of attitudes (see figure 4.9 below). Surprisingly, there is a slight tendency among members of declining research labs (in terms of research staff) to be less disturbed over the future relation to other physicists. More than one out of four either disagree or remain indifferent towards the statement.

FIG 4.9



It can also be noted that old and large labs view this as a problem (70 % agree), but even higher agree rates comes from the newly started labs (Young agree 81 %). In conclusion we might say that a low level of institutionalisation (and integration into the fusion community) leads give ground for worries in this respect. A result that is far from unsuspected.

4.6 Productivity, Setting and Attitudes

From the collected questionnaire data it has become apparent that certain types of labs had a higher level of productivity (as defined in section 3.3.2), while other labs presented a comparably lower level of production. In this section we will study how attitudes relate to the productivity variable (production related to staff). There are some differences, which we will discuss briefly. The presentation will only give the major characteristics in the material.

The investigation shows that high producing respondents are more positive to the political actor's cognition of fusion research than medium- and low producing respondents. The tendency is that the higher level of productivity, the more willing are the respondents to believe the political actors influencing the field to be well informed. The findings expose how level of production seems to be related to the researchers understanding of this issue.

Regarding the question on more concentration on technological issues the tendency is rather clear and consequent; a higher level of productivity implies a greater reluctance in attitude towards the statement. Only 29 percent of the high producing group appreciate more effort on technological issues, while 42 percent oppose the idea. As much as 76 percent of the low producing group welcome more effort on technological issues, although this is more dependent of orientation than

production; members of technological orientation are over-represented in the low producing group.

As seen from the discussion above the production variable yields rather meagre results when it comes to explaining and revealing certain attitude patterns. Although there is a notable difference in production between the categories, they submit little or no new information for this specific part of the investigation. Likewise, ‘institutional setting’ as a variable of its own expose little or no difference in attitudes between university based researchers and institute based researchers. It is possible that this outcome is generated by the sometimes imprecise questions/statements in the attitude section, which might have caused the respondents to interpret them differently between themselves. Moreover, only a few statements focus on the question of steering and co-ordination of the European fusion programme. This situation is very much regretted since it has become apparent that this issue deserves more attention than given in this report. As will be discussed in the following section, it seems as if many fusion researchers are ‘politically correct’ in their view of the European fusion programme; they seldom express any critique on any section of the programme. The reason for this might be that the fusion community has been under substantial pressure for the last four years. Some political doubt and uncertainty in the international relations are likely to have affected many members of the fusion field. From this, it is logical if the fusion researchers’ survey behaviour indicate that everybody is of one mind about the future of fusion research and the development of the next large-scale project.

4.7 Further Analysis and Conclusions

When executing a factor analysis (or cluster analysis) on the collected questionnaire data, it is possible to detect certain patterns of attitudes. The method presents an opportunity to arrange groups of attitudes, which thereby helps us to explain a large part of the variance in the material. Structural patterns of combination of attitudes that might be difficult to discover by simple correlation methods becomes open for interpretation. The five largest clusters explain half of the variance, and two of the largest factors (factor 1 and 2, see table 4.1 below) presents approximately 15 percent of the total variance. In order to describe the clusters we use concepts that to some extent are taken from political science and political debate (see table 4.1 and figure 4.10). The concepts should not be understood too literal; their purpose is to indicate, rather than define, specific patterns of attitudes in the European fusion community.

TABLE 4.1 FACTOR ANALYSIS OF ATTITUDES

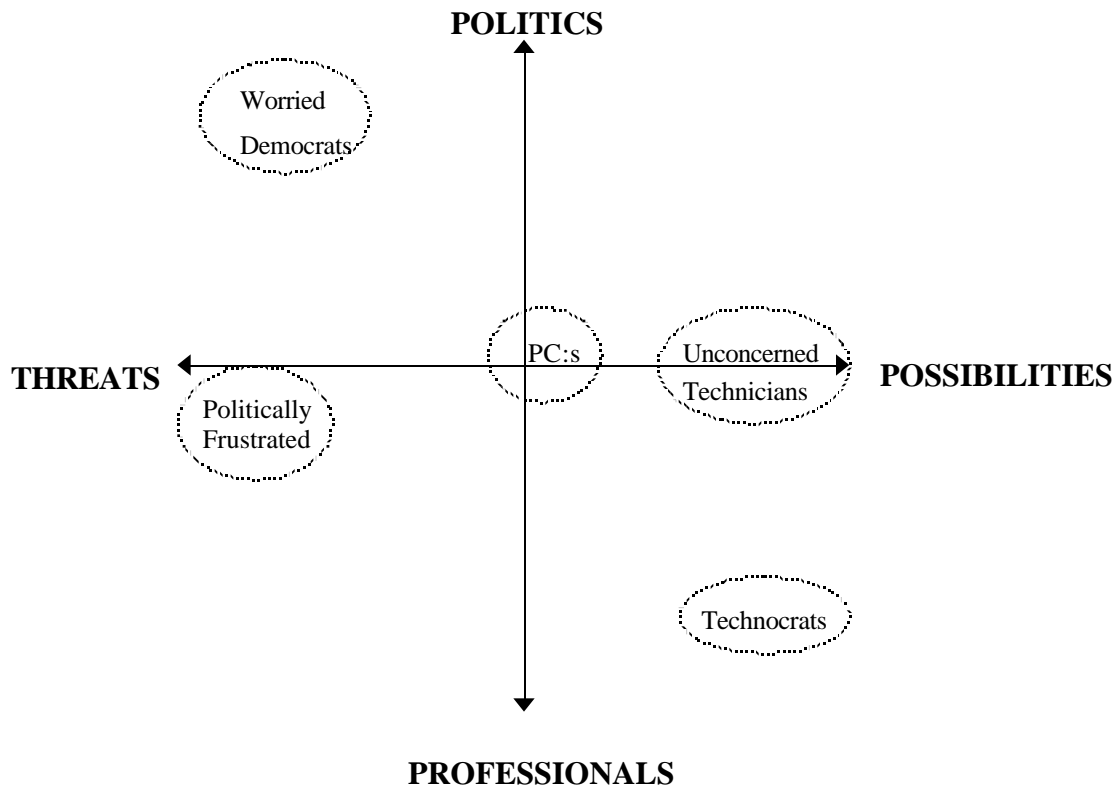
Factor One	PC:s (Political Correctness)
Factor Two	Politically Frustrated
Factor Three	Worried Democrats
Factor Four	Unconcerned Technicians
Factor Five	Technocrats

Political Correctness: The largest group, Factor One, represents attitudes that signal an resistance against taking position in any controversial issue. This group have a tendency to avoid taking sides in the discussion. According to them, the ITER programme will not be complicated due to complex international relations, and politicians do understand the benefits of large-scale and long-term research. The positions on these issues deviate rather sharply from the general belief. Moreover, they feel that evaluations are for the best of fusion, although there is no need for more of evaluations. The cluster reveals a certain tendency for a group of people to say ‘no’ to a number of controversial statements in the questionnaire. Their political view is indisputable correct, they do not accept the occurrence of any disturbances in the programme. In fact, one can almost say that they deny perceiving any problems at all. All in all this leads to the conclusion that they are PC (politically correct): When faced with controversial statements, they chose not to chose, i.e., they advocates the present situation and oppose any suggested changes. Consequently, they avoid all types of political problems.

Politically Frustrated: The next group holds a group of people who can be described as politically frustrated. In this group we find a number of persons who want to concentrate the research efforts on managing the technical problems at first-hand. They are explicitly negative towards statements concerning new concepts or alternative lines of research, e.g. ICF. From their point of view, the primary challenge is to solve the technical problems, hence putting more effort on other fields will merely slow down the process of developing a fusion reactor. They see most of the problems as emanating from the political sector, why they are quite critical towards politicians that does not appreciate long term research.

Worried Democrats: Members of Factor Three expresses a more confident position towards the political apparatus and democratic procedures. According to them, there has been no serious problems within the fusion programme when it comes internal as well as external factors. They are explicitly against a stronger voice for experts in fusion politics; hence they rather plead for a benevolent treatment by the political actors than increasing the power of the fusion researcher. Still, they are a bit worried over how complex international relations will affect the ITER collaboration, although they do not fear a national withdrawal from fusion in case of a negative decision on ITER. Another typical trait of this group is that they cannot see any motive for putting efforts on convincing other physicist’s about the benefits of fusion research. Also, they see political and economic problems as conceivable threats to large-scale fusion research projects. Naming this group ‘Worried Democrats’ might be provocative to some, since it would insinuate that members of other attitude groups are ‘non-Democrats’. However, in this context the labelling serves purely categorisation purposes and do not refer to political position of the individual researcher.

FIGURE 4. 10 ATTITUDES IN A TWO-DIMENSIONAL ANALYSIS



Unconcerned Technicians: The fourth group consists of cool and calm persons, who often are technicians. They are rather unconcerned over issues and problems that is related to recruitment of next generation of researchers, relation to other non-fusion physicists, etc. They are content with what is and would hardly want any changes at all. Not very surprising, they agree on the statement that the programme should concentrate on technical problems in the nearest future. In their point of view, most of what is left to solve are generally technical things. As in the case of the ‘Worried Democrats’, they see no need of convincing others about the benefits of fusion. Consequently, members of this group are self-confident and unconcerned over their future as fusion researchers.

Technocrats: Finally, the clustering of attitudes reveal a group in which the respondents are in agreement on the need for experts in fusion to have a stronger voice in long term policy making. Also, they feel that experts should put more emphasis on explaining the importance of fusion research to different political actors. The same is true regarding the need to convince other physicists about the benefits of fusion research. Obviously, members of this group have a desire to steer, explain and persuade the public and political actors, although they have a rather positive

attitude on the future process of fusion research. In a way, this group represents the antithesis of the 'Worried Democrats' discussed above.

Chapter 5: Case Studies of Sweden and Germany

5.1 Introduction to Case Studies

According to our analysis in chapter three Sweden could be characterised as an old, small and university-bases association, while Germany would be categorised as an old, large and institute-based. The cases represents two extremes when it comes to the productivity measures used in that chapter. As this information was not available before the selection of cases was it did not act as a rationale for the cases under study. Already here it should be underlined that our material has weaknesses that, by no means, makes it justified to generalise our findings from the questionnaire to the country level. The low response rate, especially from large countries, can act as illustration to the problems that follows such an ambition.

5.1.1 Fusion in Sweden and Germany: bibliometric analysis³¹

INSPEC-data shows that Germany is the third largest producer of articles and papers in research related to fusion. Sweden is ten times smaller than Germany. The proportions reflects the national budgets for fusion research. In table 4.1 we have distinguished between efforts directed towards theory on the one hand and experimental efforts on the other. While Germany has an equal distribution of activities it is apparent that Sweden has a relatively higher activity in theoretical research.

TABLE 5.1 WORLD, FUSION RESEARCH 1996—OCT 1998 (PERCENTAGE OF EACH CATEGORY)

Land	Total share %	Experimental share %	Theory share %
USA	30	22	27
Japan	18	23	14
Germany	11	12	12
Russia	8	10	8
Italy	5	6	5
UK	5	4	4
France	5	5	4
China	3	4	4
Sweden	1,2	1	2
Espana	1	1	1
Holland	0,5	1	1,5
Belgium	0,5	-	1
Sum %	100	100	100

Source: Inspec-database Online.

³¹ The bibliometric work is done by Olle Persson in collaboration with Ulf Sandström.

A closer look at Germany and Sweden reveals that the countries to a large extent are alike. There is, though, a difference in profile regarding the extent of theoretical activities. Sweden is markedly more involved in that type of research, but otherwise the countries have quite the same distribution of activities (see table 5.2).

TABLE 5.2 PROFILES OF FUSION RESEARCH IN GERMANY AND SWEDEN

Profile	Germany (%)	Sweden(%)
Theoretical	25	43
Experimental	33	29
Practical	15	11
Application	3	0
Trans (pract-exp-theor)	7	7
Other or unclassified	17	10
Total	100	100

Source: INSPEC database (1996–1998)

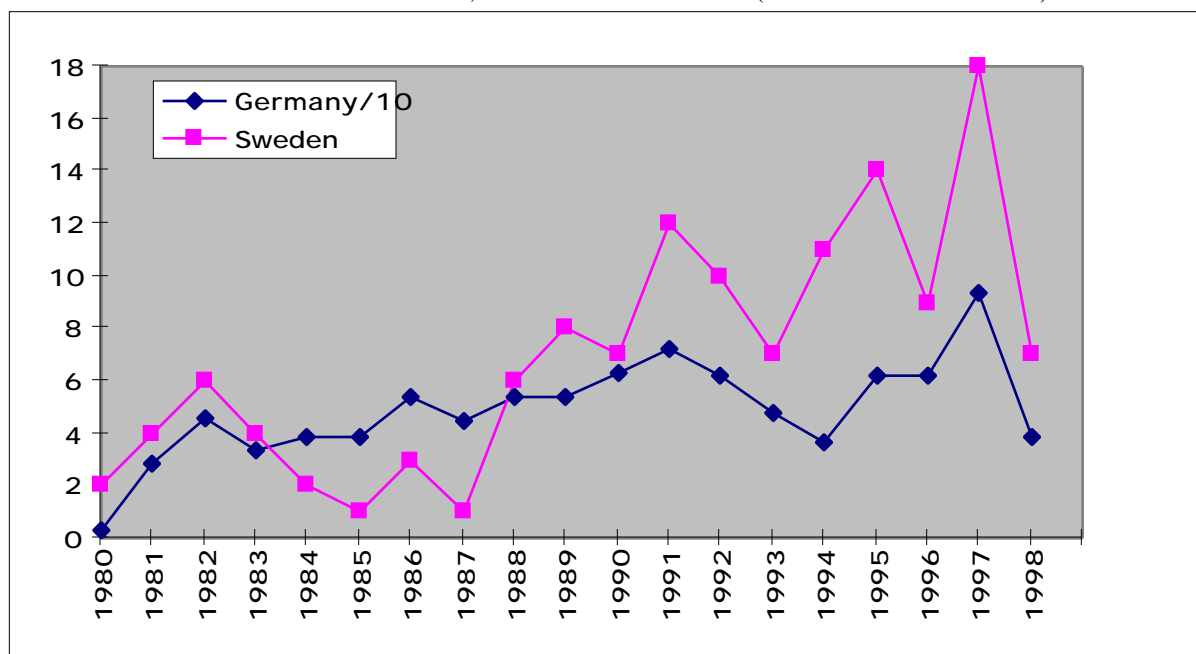
If papers are excluded from the analysis it becomes clear that the Swedish activities in fusion research are a bit higher than in physics in general (Physics Abstract database). The relation is 1/7 in fusion and 1/8 in physics. The relation expressed in monetary terms (budgets for fusion research) is 1/15. Germany had 108 MECU and Sweden 7 MECU year 1992.

Production of articles in fusion research has increased in both countries since 1980. In the beginning of the 1980s the average number of papers and articles were approximately 10 in Sweden and 100 in Germany. During the 1990s has risen to 16 per year in Sweden and close to 200 per year in Germany. Consequently, productivity in fusion activities seem to develop a bit faster in Germany. But, if we exclude papers and keep our interest on articles in scientific journals instead we achieve quite another pattern. Activities in Germany are rising slowly, from five to eight articles per year, while activities in Sweden raises faster, from four per year during the 1980s to ten per year in the 1990s. In terms of qualified publications Sweden seem to have a slightly better performance, which might be explained from two instances: 1) that Sweden has more of activities in theoretical research, and 2) that the Swedish association NFR has put pressure on the researchers to perform better in articles production. An explanation to the latter

point is given below in section 5.1. Empirical evidence is given in figure 5.1. which clearly shows that the performance got better some years after that NFR became the Swedish association.

General patterns of collaboration seem to be very stable and alike in the two countries. The average number of authors per article was around three during the 1980s and is nowadays (1990s) four authors per article in both countries. The Swedish collaboration with the JET team sometimes gives very high figures and seems to be of significant importance for some of the Swedish researchers. This will be investigated more closely in section 5.3.1.

FIGURE 5.1 NUMBER OF ARTICLES 1980-98, SWEDEN AND GERMANY (GERMANY DIVIDED BY 10)



5.2 Sweden – Organisational Structure

5.2.1 Background³²

Sweden's national research on fusion was established two decades before Sweden signed the EURATOM-agreement 1976. One of the most important persons in the history of Swedish fusion research was the Nobel Prize winner Hannes Alfvén (1908-1995). He received the prize 1970 for discoveries in magnetohydrodynamics (MHD) with applications in different parts of

³² The presentation of the Swedish RU:s activities is mainly based on *Swedish Fusion Research Strategy*, September 1996.

plasma physics. Although MHD is one of the simplest description of a plasma, it illustrates the plasma as a very complex dynamic system. When entering the collaboration, the national research on fusion was concentrated at the Royal Institute of Technology (KTH), Chalmers University of Technology (CTH), and AB Atomenergi (later Studsvik). Soon the discipline attracted more researchers, and the number of groups increased. It also spread to other universities, and today groups at Uppsala and Lund University (UU and LU) have joined the Swedish fusion programme.

The Swedish fusion research is mainly conducted at universities, which denotes a divergence from the institutionalised research in most of Europe. This university based research model has certain qualities that will be more closely investigated in section 5.1.4 and 5.4. The research at Studsvik AB is an exception to this rule.

When the Swedish Fusion Programme became associated to the European Fusion Programme the national activities also became organised in a Research Unit. The contract of association was initially with the National Board for Energy Source Development (1), NE, but the task has been transferred via the Energy Research Council (2), Efn, to the Swedish Natural Science Research Commission, NFR. The Swedish interaction with EURATOM is since mid 1987 handled by the NFR. The NFR also takes care of all the funding and accounting procedures, that is, all the money received from EURATOM for fusion research passes through the NFR. Within the NFR there is a Fusion Research Committee, FFK, whose purpose is to advise NFR on matters concerning Swedish participation in the European Fusion Programme. The committee involves the leading fusion researchers in Sweden, from all universities and from Studsvik.

The projects are proposed by the Swedish side and executed by the Research Unit, RU. The structure and the distribution of tasks are approved by the bilateral Steering Committee (EURATOM/NFR). Head of RU, (HRU), is Prof. James Drake, positioned at the Alfvén laboratory, KTH. His task is to direct the personnel and projects in conformity with the instructions of the Steering Committee. The Committee approves the RU programme and budget and is thereby co-ordinating the RU activity with the EURATOM programme. The Committee consists of three members from EURATOM and three members from Sweden. The problem of co-ordination will be further discussed in 4.4.

5.2.2 National Labs and Research Groups

There are five centres in Sweden where fusion research is conducted: KTH, CTH, UU, LU and Studsvik. The research has experimental, theoretical and technological approaches, and is divided over 9 groups. The experimental fusion plasma physics device is located at the Alfvén Laboratory (KTH), the theory work at the universities/institutes of technology in Stockholm, Gothenburg, Uppsala and Lund, and the fusion technology activity is based at Studsvik, Nyköping.

Experimental activities: The Research Unit includes an experimental device, EXTRAP T2, which is a reversed field pinch (RFP). It has a priority status in the EU programme and has received

preferential support for the investment (45%). The RFP studies involve fundamental areas of magnetic confinement,

- *Plasma Surface Interaction.* The Surface Physics group is located at KTH and specialises in measuring parameters relevant for the plasma wall interaction.
- *Atomic Spectroscopy.* A group at the physics department at KTH is developing methods and analysis techniques to derive plasma parameters and impurity parameters. At LU a group is developing atomic and molecular physics databases used for modelling impurity concentrations etceteras. The spectroscopy programme is carried out at EXTRAP and JET.
- *Neutron Diagnostics.* There are two projects are involved in this field, based at KTH and UU. Both do work on JET.

Theory: The Swedish research effort in this field is mainly concerned with Tokamak physics and is oriented toward JET and ITER. This research work is located at KTH and CTH, and at KTH there is also RFP theory work. The JET/ITER work at KTH is in Radio Frequency (RF) heating and current drive and Plasma Edge Physics. At CTH, work is done on MHD Stability, Transport Modelling and Analysis, and Fast Particle Effects. A considerably amount of the research effort is made in collaboration with foreign institutes.

Technology: The Fusion Technology programme includes activities on design, research and development in the EURATOM fusion programmes for Next Step Technology, Long Term Technology and Underlying Technology. It is mainly carried out at Studsvik, which also collaborates with industry. The activities include Materials Development, Safety Analysis and Environment, Waste Management, and Plasma Facing Components.

5.2.3 The Association

The Natural Science Research Council (NFR) is the Swedish Association. As a research council it is having some difficulties in handling fusion research, since it differs a lot from how other science areas are handled in the Council. Normally all proposals are sent to a committee of peers. They evaluate each proposal and give them a grade from 1 to 4. After that a process of negotiations takes place and the line is drawn somewhere among the 40 percent most highly appreciated project proposals. In theory it is of no importance from what science area a proposal emanates. Fusion projects should have to compete with other proposals on the same conditions. The European partnership brings in a bit of disturbance to this process.

The success rate for fusion research applications to the NFR – during the period 1989–1996 – was slightly above 80% compared to a less than 50% for applications to other areas within the NFR (Physics had 55%). Also, fusion projects have been much larger than other NFR-projects: Almost half of the projects has received 0,1 MECU per year, which is very unusual in other areas; only 12% of the projects normally receive such a large amount of funding per year. Almost half of the 20 largest projects NFR funded during that period were fusion related research. In summary, this indicates not only that fusion is a highly prioritised area of research, but also that

fusion researchers have had a low level of competition over resources for their activities.³³ As an university based system Sweden in many respects have the same profile as an institute based system. The reason for this is obvious: The EURATOM Fusion Programme.

The Swedish effort has a total financial volume of 67 MSEK (9 MECU). Half of the funding comes from the EURATOM and the NFR, while the other half are financed from faculty (core funding) money and support from industry.

5.3 The Internationalisation Process

The concept of internationalisation is undoubtedly central in political and scientific communities of today. The society is nowadays more internationalised than ever and collaboration is often thought of as having a value of its own. The formal internationalisation of the Swedish fusion research was established by 1976 when Sweden became an associate member of the European Fusion Programme. It is motivated to ask why this happened: What were initially the motives for the internationalisation of the fusion research and who benefited from it? It is also motivated to examine the current internationalisation process, i.e. the ITER collaboration: What are the motives for international collaboration today? There are three relevant actors on this field; political actors, fusion researchers and the Swedish Natural Science Research Council (NFR).

5.3.1 Motives

The categorisation of the different actors' motives is more complicated than it first may seem. The complexity lies in making a clear differentiation between actors, which sometimes experience adjacent considerations in their policy performance.

5.3.1.1 The Political Actors

Before discussing the explicit political motives for the formal internationalisation of Swedish fusion research, it might be important to scrutinise the situation in which the political understanding was formed. In the early seventies the world suffered from the oil crisis, initiated by the OPEC-countries. The crisis revealed how vulnerable it could be to depend on an energy source controlled by a few actors. It became apparent that the oil supply could not always be guaranteed, thus a broad spectrum of other sources of energy received attention. Furthermore, a few years before the agreement, the world acknowledged a long-term energy crisis caused by a global decreasing oil supply and a continuously increasing demand for energy. These aspects of energy policy was debated in the Swedish parliament and the debaters often stressed the

³³ The investigation is based on the project data base of NFR. The principles for using the database are explained in Sandström (1997, 1999).

importance of an international approach to the problem.³⁴ Although fusion reactors would not produce power in many years, the concept promised a long-term solution to the energy problem.

According to the public documents from 1976, the political arguments for the internationalisation of the Swedish fusion research were mainly based on three reasons. First, it was assumed that collaboration constitutes a way to reach a rapid progress on this field. The sharing of knowledge between the collaborators would make the research more efficient since extra work is then being avoided. Second, as one of the leading nations in R&D, Sweden had a responsibility towards other countries. It was argued that Sweden, out of solidarity, should participate in solving the energy problem in the world. Also, Sweden possessed considerable knowledge on the field of fusion, why collaboration would be of mutual interest. Third, the Swedish participation in the European Fusion Programme was thought to be beneficial for the national technological and industrial qualification and development.³⁵ The broad argument for the this kind of internationalisation of the national fusion research was that Sweden had a rather large fusion research activity and it would therefore be efficient to integrate it more in the European programme.

However, when scientists in the Swedish fusion community are asked to comment the reasons for this first step of formal internationalisation, it becomes clear that they have a slightly different version on how the process started. According to them, the agreement was primarily based on a political interest of linking Sweden closer to the former EEC. The agreement did not initiate Sweden's participation in international collaboration on fusion research; Swedish researchers had well-established collaboration patterns with foreign colleagues long before the agreement. This suggests that the specified official motives insufficiently explains the grounds for the agreement. It is likely that the agreement on fusion research collaboration was considered to be an acceptable mode for Sweden, as a neutral country, to get a non-provocative connection to the Western European countries. The politicians were very eager to establish contact with EURATOM, and the fusion researchers felt they were almost forced to obey this process (although they did not mind being incorporated). They supported the resolution, which, in a way, became a formalisation of the already existent international contacts.³⁶ However, the agreement implied more to the researchers than just a judicial arrangement; it improved their financial situation and co-ordinated the national research activity with the European fusion programme.

5.3.1.2 The Fusion Researchers

It is likely that the EURATOM-agreement initially was based more on political than scientific reasons. But the Swedish researchers also had a few important incitements for bear up this co-ordinated form of scientific progress, and later on they grew in number. At first, they saw the agreement as a way to obtain more resources to fusion research. This was a proclaimed necessity since they felt that the national research on fusion had grown rapidly and needed more

³⁴ See debate § 11 Resurs- och energipolitiken m.m., 30 Nov. 1972.

³⁵ Regeringens proposition 1975/76: 86.

³⁶ Interview with former HRU Bo Lehnert.

fundamental support to reach an efficient level. Moreover, the idea of building a common experimental reactor, more advanced than any other in the world, made the researchers support the participation. The plan to build the Joint European Torus (JET) held opportunities greater than any potential national experiment, and promised to produce a tremendous amount of information. There are hardly any reasons why the Swedish researchers would object the integration of the national fusion research into the European programme. However, it is possible to detect some discontentment from the researchers at the CTH group. In the early seventies this group was focused on inertial confinement fusion (ICF), which is an alternative to the magnetic confinement fusion (e.g. Tokamak). With the new agreement, the CTH group was more or less forced to abandon the ICF principle in favour of the Tokamak. Since the Tokamak was given the priority by the European Fusion Programme, it became difficult to receive funding for alternative concepts, and the ICF concept was merely banned.³⁷ Everyone at the CTH group did not welcome this shift of focus, at least initially, but soon there was a great deal of acceptance on this matter. The results from the questionnaire shows that Swedish researchers are rather positive to the idea of executing further research on the ICF concept. Although few in number, 75 percent of the respondents at CTH express a desire to explore this field further. It should be noted that, at time for the agreement, the somewhat discontented actors hardly opposed the agreement as such, rather, they disapproved on having to give up a field in which they believed.

With this exception, it is obvious that the fusion scientists were gaining on the agreement. To begin with, it gave attention to the field of fusion, which was stipulated by the outspoken ambition to build a commercially viable reactor. This ambition included the construction of three experimental reactors (JET, NET, and DEMO), that would have a vital influence on the evolution of fusion power. Also, the formalisation of the fusion research collaboration not only meant a consolidation of the funding, but an increase of the total research budget. For the budget year 1974/75, the government estimated the cost for the national fusion research to 3 million crowns.³⁸ Three years later, the Swedish fusion research held 20 million crowns a year.³⁹ Finally, the agreement included a political obligation towards the other members of the EURATOM. As a participant in the common programme it became very difficult to withdraw its position on fusion research, since it would be a somewhat deceptive behaviour.

To sum up, the national fusion research became more secure than earlier in terms of funding and political commitment. As in the German case, the internationalisation of the fusion research yielded a certain scientific independence towards the State. This process might to a certain extent undermine the freedom of action of the national political actors. The fusion researchers are therefore not as vulnerable of shifts in national political commitment as they were before. Also,

³⁷ According to the findings from the questionnaire, many European fusion researchers see an improper connection between research on the ICF concept and military research. This understanding explains some of the disaffection towards ICF. However, the main reason for favouring the Tokamak concept is undoubtedly that this is considered to be the most promising concept of confinement in the European programme.

³⁸ Regeringens proposition 1975/76: 86, p 6.

³⁹ See Proposition 1977/78: 110, p 160.

the common research challenge of the field of fusion undoubtedly attracted the Swedish researchers.

5.3.1.3 The Swedish Natural Science Research Council

Later, the motives for internationalisation of the national scientific efforts evolved, or, one might say, they were specified more clearly than before. In the public material, such as the Swedish Natural Science Research Council's Anslagsframställning (budget proposal), the connection between internationalisation and science is being emphasised more and more over the years. This holds for fusion research as well as for other sciences, and the process of internationalisation is constantly being encouraged by the public institutions. The NFR presents four reasons explaining the magnitude of supporting the general process of internationalisation:

1. Science is to its content international, i.e. it is not constrained to a national territory.
2. Collaboration between nations is necessary when equipment and establishments becomes larger.
3. The scientific citation system is of international character.
4. Interdisciplinary research programmes based on regional or global data accumulation demand international collaboration.⁴⁰

These reasons illustrate the policy followed by the funding organisation. Although internationalisation is supported in a general sense, special attention is given to the collaborative opportunities within the EU R&D programmes. From this rationale we can understand the internationalisation process that is going on. However, there are additional explanations to this phenomenon that will be discussed in section 5.3.2 and 5.3.3. In these sections, we discuss how the collaboration pattern is affected by the funding system and by the structure of the national fusion research.

5.3.1.4 A Concluding Discussion

The scientists might be right in their conviction that the political actors initially used fusion research as means to get a moderate connection to the former EEC. According to this interpretation of the situation, the point was not primarily to support international collaboration, but to support *formal* international collaboration. It is therefore necessary to make a distinction between formal and informal internationalisation. While the political actors at this time had

⁴⁰ NFRs Anslagsframställning 1993/94, p 61.

interests in a formal internationalisation, the NFR more or less supports the whole idea of internationalisation, formal as well as informal. As presented above, the NFR.

Even if it is true that the politicians saw fusion research as an excuse to approach the EEC, the three reasons that were presented in the public material can be seen as plausible. The actual step from informal international collaboration to a formal agreement involves not only a decision on foreign policy, but also a commitment to the idea of eventually building a fusion reactor. The previous achievements on fusion research in Sweden called for partaking in the common research effort. However, in our investigation we have come across conflicting opinions on the quality of Swedish fusion research at the time for the agreement. One of the interviewed researchers claimed that the national research quality on fusion was rather poor in Sweden at that time.⁴¹ If this is true, the Swedish political actors clearly overestimated Sweden's position on fusion research. This might imply that the argument of Swedish excellence in the field of fusion, presented by the political actors, seem invalid. Still, the political argument was not primarily based on Swedish fusion research per se, but on the general belief that Sweden was a leading country in R&D. It is not motivated to take this discussion any further; the researchers opinion is merely an indication of a political misinterpretation which might be interesting to explore further, but is infeasible at this stage.

If the political actors were eager to extend the international collaboration on fusion research with Europe in the mid-seventies, the situation is rather different today. The Swedish government cannot use the common fusion programme as a vehicle for international politics any more. A plausible explanation for this is that the cold war is over and that Sweden is now a member of the EU. From a political point of view the current fusion issue is over costs and national research policy. This situation will be further discussed in section 4.5.2.

The reasons for the present international collaboration on fusion are partly the same as before, that is, it is more economic and efficient to collaborate on fusion research than to conduct the research on a national base. When it comes to ITER, it would be infeasible for a country like Sweden to accomplish a large project by its own. This is also likely to be true in the case of the EURATOM members. If ITER is not realised, it will hardly be replaced by the analogue NET-project, at least not in NET:s present form. If NET is to be built, it would consume all the fusion research funding in Europe, claimed one researcher. This argument implies a fear for an unbalanced approach towards the Demonstration Reactor, DEMO. As an example, research on alternative confinement concepts would hardly receive the current level of funding. Altogether, this leads to the conclusion that it is rational to share the costs with as many partners as possible. This also explains the current reasons why the ITER project is a further step towards a global collaboration. This internationalisation process is by many seen as a natural step in the challenge of constructing a commercially viable fusion reactor. It will be cheaper and more efficient to focus on a common approach. These arguments are similar to the justification of the EURATOM-collaboration. Therefore, the extension of the European collaboration is seen as a "natural step" on the research on fusion. However, the ITER project is also likely to have the same problems as the

⁴¹ Interview with Swedish fusion research leader.

EURATOM-collaboration; difficulties in co-ordination, discussion of the site of the experimental device, cultural and traditional differences, and so on.

5.4 Collaboration

As discussed in section 2.4, it is a complicated task to quantify level of collaboration in an accurate way. There are many pitfalls to avoid, and even so, the result can be questioned from a number of perspectives. In the Swedish case we have tried to identify patterns of collaboration by employing several methodological instruments. The aim is that they jointly will expose valid level of collaborative activity. The estimation is based on information from the questionnaire, interviews with fusion research leaders, and a bibliometric analysis of published articles.

5.4.1 Collaboration on the National Level

When it comes to the internal collaboration within the national fusion research community, it seems clear that the collaborative frequency is rather low. This is a striking fact, seen by almost every researcher in the field, and a majority also seem to regret this situation. According to our investigation the national collaborative activities have increased over the last ten years, but still collaboration with outside groups is quite an exception. The problem is discussed in a report ordered by the NFR; International Evaluation of Fusion Research (June 1997). The report expresses concern over the competitive funding system, which is believed to have a prejudicial effect on national collaboration⁴². The researchers see the funding system as one of the main reasons for lacking collaboration.

The low level of collaboration on the national level is illustrated by a net work analysis done from INSPEC-material over the period from 1990–1998. Through bibliometric investigations and interviews with the actors themselves, we have tried to identify different collaboration networks and thereby exposing the nature of fusion research collaboration pattern in Sweden. The findings from this study indicate a rather separate and parallel mode of establishing collaborative contacts and execute collaborative activities. By clustering the bibliometric data into different networks it is revealed that national collaboration is often very much dependent on geographical factors and that international collaboration is the predominant mode of collaboration.

Discussing national collaboration, it is apparent that collaborative contacts are almost exclusively to be found between groups connected to an individual university. There are a few exceptions; for example, the groups at CTH have a certain amount of collaborative contacts with counterparts at UU. It is, of course, common with regular "inter-university" contacts; fusion researchers of different fields and universities meet and exchange ideas at, for example, the sessions on fusion research committee. Other kinds of contacts are also frequent, but seemingly they seldom result in joint publications. Therefore these activities are considered as low level collaboration, i.e. they do not qualify as 'collaboration' in terms of our definition. When discussing the example of

⁴² International Evaluation of Fusion Research, June 1997, NFR.

collaboration within an individual university it is apparent that especially the groups at KTH have rather successive collaborative contacts.

As mentioned above, each group routinely collaborate with international counterparts. This is motivated by the special fields of interest of the different groups; it is often the most rational to look for collaboration partners outside Sweden, since relevant knowledge is to be found in Italy, USA, Russia, at JET etc. It seems as if the technological research groups at Studsvik has little or no contact with research groups at the national universities. Instead, the actors at Studsvik look for collaborative partners abroad. Their partners can be found at NET, ITER JCT, UKAEA, and ENEA.

The national collaboration often consists of input and discussions between the different research groups, i.e. they meet to exchange ideas and to make comments on each other's projects. The question is: should these meetings and discussions be considered as a collaborative activity? The situation could be interpreted as a loose form of collaboration, but still, by the presented definition in section 2.4, the conclusion must be that it does not fulfil our criteria for collaboration. When meeting, they can hardly be considered to work together on a common project, or to share responsibility of each other's project. The meetings in the FFK are mostly based on communication between representatives from the separate national research groups. It is safe to say that this input situation is not considered as true collaboration by most of the involved researchers.

The group at Uppsala University, dealing with neutron spectroscopy, closely collaborated with the Swedish industry on the development of a magnetic proton recoil spectrometer (MPR). The neutron spectrometer was installed as a diagnostic on JET in 1996 and is a prototype for an ITER diagnostic. This demonstrates an example of a successful collaboration, although there are no external research groups involved.

Our conclusion is that JET has had a strong influence on the collaboration patterns of Swedish researchers. Otherwise this field of research does not seem to have any potential for national collaboration. More intensive forms of scientific collaboration are executed between specialised researchers in one country together with expert in other countries. In summary: Most of the collaborations in Sweden have a internal university character and does not exceed the organisational limits of the home university. The analysis also illustrates the big influence from JET and other international efforts (see Appendix II and III⁴³).

5.4.2 Collaboration on the International Level

When asked whom they collaborate with and why, the researchers give the same answers: They collaborate with the leading groups or persons who are available at the moment. Mostly, these

⁴³ Appendix II and III visualise the national collaboration patterns, including the international dimension of collaboration on fusion research in Sweden. Please note that the scheme might include collaborators that are not related to fusion research. The information is based on list of publications from 1991 to 1997.

partners are not to be found within Sweden, which means that international collaboration is quite predominant. However, the collaboration pattern does not always seem to be as focused on instrumental collaboration as implied above. Undoubtedly much of the existent collaboration is based upon personal network. The collaboration pattern seems to be rather fixed, because the researchers often choose to collaborate with people they know personally and with whom they have collaborated with earlier. It is also common to collaborate with their own Ph.D.-students that are placed at international centres, e.g. JET. This constitutes an international collaboration between fellow-countrymen. Further, the Swedish research leaders use their Ph.D.-students in order to establish connections abroad. The students are helping the researchers to create networks and they seem to be very important for the group's international collaboration.

The JET establishment works very much as a meeting place for researchers in the EURATOM programme. All groups have more or less frequent contacts with the activities at JET, and JET is often considered as the most important collaboration partner. One research leader, concentrating on theoretical aspects of fusion research, expressed a willingness to work at JET although his work could easily be done from the domestic base. According to him, the reason for working at JET is solely for the purpose of meeting the right people, establish contacts and so on. There might of course be financial reasons for working at JET, but nevertheless, it all together shows how experimental facilities constitute important places for networking. This also partly explain why researchers feel it is important to realise the ITER-project, since it will become a leading site for international interchange on fusion research. When JET is dismantled, ITER will succeed the role as centre of collaboration and networking. In case the idea of building ITER is rejected, JET will probably be extended, i.e. the European fusion community will not lack a place for networking, although it will not be based on global international collaboration.

Besides JET, the Swedish groups frequently collaborate with institutes or universities in USA, Russia and Italy. The experimental group at KTH works on the EXTRAP-T2 Reversed Field Pinch (RFP). This give rise to collaboration with the RFP-group in Padova, Italy. Since the groups are dealing with the same experimental concept, they face the same problems, and are therefore mutually interested in exchanging information and experiences. The collaboration has evolved within the frame of the EURATOM agreement.

5.4.3 Collaboration and Internationalisation

According to a leading fusion researcher the formal connection to EURATOM had no effect on his groups collaboration with the actors outside Europe. From his point of view, the agreement did not lead to a collaborative concentration to other members of EURATOM. On the contrary, the contacts with outside European actors were evolving. This leads to the conclusion that the agreement did not hamper the informal internationalisation, but might even have invigorated the general collaborative process.

As presented above, it is rather rare with collaboration between the research groups in Sweden. The international evaluation, made 1997, strongly recommends strengthening of several parts of the national collaboration. Inevitable, this rises the question why the national collaboration cannot

evolve in as expected by the international reviewers. Our investigation gives two primary explanations to the observed pattern:

1) The Swedish funding system is very competitive, thus collaboration is not rewarded. According to our interviews, this explanation has a wide support in the national fusion research community. In the evaluation mentioned above, the committee even identifies the funding procedure as "[...] potentially harmful to Swedish fusion research"⁴⁴.

2) Swedish fusion research is rather heterogeneous. The different groups are dealing with different aspects of fusion research, that is, theory, experiments and technological activities. Therefore, they have different interests in their collaboration.

One of the scientists also explained the lack of national collaboration from a historical perspective. According to him, the current situation has occurred because of the design of the hierarchic former system, when the research was controlled by a few research leaders who met only to distribute the available funds. This was carried out without a preceding scientific discussion, which thereby led to an unhealthy manipulation of the structure of Swedish fusion research. The scientists of today are raised in this tradition, he argues.⁴⁵

It should be noted that the recommendations from the international evaluation have had a certain effect on the mode of collaboration. The theory groups at CTH and Uppsala University have responded to the request on improved collaboration and are now seeking to come together on various activities.

5.5 Co-ordination of the Swedish Fusion Programme

The Swedish RU has a rather long tradition of fusion research and was an associate member of the EURATOM programme for almost twenty years. Since 1995 Sweden is a full member and must therefore be described as a rather old member of the global fusion research community. As discussed in the introduction of the Swedish case study, national groups dealing with this discipline have increased over the years, and the current RU includes theory work, experimental activities and technology. Even though there has been an expansion in both size and orientation, the RU is to be considered as small in comparison to other RU:s in, for example, Germany.

⁴⁴ International Evaluation of Fusion Research, June 1997, NFR, p. 10.

⁴⁵ Interview with Swedish fusion research leader.

As presented above, the Swedish Fusion Programme is organised quite differently from the mode in other Associations. University based research is commonly thought of as guided by a concept of independence, that is, it is not (explicitly) regulated by external actors. Ideally, this autonomy implies that the researcher in question can produce and present any research without the influence of an external actor, e.g. the Government. This scenario does not give a valid description of the actual situation, but it describes the university based research activities in general. In practice, university based research often depends on external funding and is also engaged in commissioned research (or contract research). Although this type of funding directs the research to certain fields, it does not immediately steer the researchers in their work. In the case of fusion research, participation in the European research programme suggests steering and co-ordination by a central committee. The organisation of the Swedish fusion research as a Research Unit, associated with the European Fusion Programme and thereby also participating in JET and the ITER collaboration, creates a complicated situation in which the researchers undergo regulative mechanisms.

The common fusion programme has a clear objective; to develop a commercially viable way to yield fusion power. This goal-orientation demands shared strategic efforts by a number of actors, and it may therefore be necessary to suppress some non-consistent directions of research. This is an indirect process; the non-approved projects do not receive funding from the EURATOM. In doing this, the researchers are forced, or promoted, to present projects matching the stipulated strategy. This situation can be illustrated by an example from the experimental research at the KTH. During the late 1980s the KTH held an experimental device called EXTRAP T1. The EXTRAP concept is an alternative to the Tokamak configuration and has the potential of producing fusion plasmas with lower magnetic field requirements. When seeking to upgrade this experiment with a more advanced model (EXTRAP T2), the Commission denied any preferential support unless the project became more integrated in the European fusion programme. The EXTRAP concept did not sufficiently correspond with the stipulated European strategy, hence, the EXTRAP T2 experiment at the KTH was thought to be too isolated from the general path of the European programme. From the KTH point of view, this problem was solved when it was decided that the new experimental device also should act as a support project for other fusion experiments within EURATOM. In correspondence with the commission's request, the new device was constructed to support the analogue RFP experiment at Padova (RFX). This modification was a necessary move for the experimental group at KTH in order to receive the required funding, and today the EXTRAP T2 has a preferential support of 45 percent in the European programme. The presented example also illustrates how the Commission is executing co-ordination and steering.

Although fusion research labs in Europe must face the same situation when applying for financial support by the EURATOM, it constitutes a certain problem for the university-based researchers in Sweden. The Swedish researchers must to some part neglect their own perception of independence in order to secure a continuous activity on a high level. It should be noted that the development path towards ITER and DEMO includes other research activities than the Tokamak principle, i.e., alternative concepts holds attention within the programme.

5.6 National Fusion Research and External Relations

This section deals with the question how fusion research has been discussed within different forums in Sweden. It might not always be accurate to categorise the discussion in the below manner, since it often affects more than one category at the time. External actors involved in the debate on fusion research often belong to more than one category, which suggests a mindful perusal.

5.6.1 The Political Debate on ITER

As discussed earlier, the political actors were initially eager to reach an agreement on fusion research. This formal internationalisation was, among other things, a way to improve the foreign policy situation. But as the international security situation changed, it altered the political perception on the arrangement. The improved foreign policy situation, which was an important spin-off of the agreement, was no longer a rare and precious product which made it easy to legitimise increased costs. When Sweden became a member of the European Union, 1995, the political internationalisation process formally begun. The governmental scepticism towards large-scale research on fusion became a fact in 1995, when the Social democratic Minister of Education and Science, Carl Tham, asked for an evaluation of the ITER-project. The evaluation was to review how the project proceeded and if other sources of energy should be supported on the expense of fusion. Even though Sweden is positive to fusion research, the ITER project is very costly and the outcome is uncertain, Mr. Tham claimed in a speech to the European Commission.⁴⁶

This attitude formed a sharp contrast in comparison with the former non-Socialistic government, which clearly was more favourably disposed to the ITER project. In 1991 and 1993 Studsvik presented thorough reports on how much it would cost to host the project in Sweden, how this could be arranged, and what effects it would have on e.g. environment and unemployment.⁴⁷ The initiative was supported by Vattenfall, which is Sweden's most important producer of energy and besides the owner of Studsvik. Up till 1992 Vattenfall was a State-owned company, and its supportive position on the hosting the ITER reactor had a substantial influence on the governmental attitude⁴⁸. The Department of Education and Science also assigned the Assistant Under Secretary Anders Karlqvist to investigate the conditions for hosting ITER⁴⁹. The idea was discussed enthusiastically, and the involved political actors spoke of two main arguments for supporting the initiative. First, hosting the ITER project would strengthen the national reputation in a field where Sweden already had a strong tradition. Second, the project was considered to

⁴⁶ Department of Education and Science, 1995-10-30.

⁴⁷ See Studsvik Report/NS-91/84, and Studsvik Report/NS-93/4.

⁴⁸ Interview with Swedish fusion research leader.

⁴⁹ Anders Karlqvist, Förläggning i Sverige av den internationella fusionsforskningsanläggningen ITER, 1994

involve favourable spin-offs on other technological disciplines.⁵⁰ In November 1994 there was in CCFP a presentation of preliminary sites in Europe by the German, French and Swedish representatives. Thus, the non-Socialists had extensive plans on applying for hosting the ITER reactor.

When losing the election 1994, all this came to an end. As discussed above, the new Social Democratic government (or at least the Minister of Education and Science) questioned the costs and the future of fusion power. This also meant that the proposed plan of hosting ITER was dropped. Later, the government ordered a new investigation, examining the Swedish participation in large-scale European research projects. The intention was to investigate how to cut the spending on large-scale research projects by 150 million SEK. In the report the investigator proposed a 11 million SEK reduction on Swedish participation in fusion research projects.⁵¹ However, the report's proposition did not receive support.

5.6.2 The Public Debate

During the eighties, the public discussion in the leading Swedish newspapers was to some part focused on the military aspects of fusion. The debaters opposing fusion power saw fusion as the knowledge that gave the world the H-bomb, and therefore the research on fusion must be restrained. According to their perception, the international collaboration (on INTOR) was supporting the nuclear arms race. Also, they saw no real difference between fission and fusion, which led to an automatic disqualification of fusion power.⁵² At this time the debating opposition consisted primarily of members of the Centre Party, the Left Party and the anti-nuclear power movement.

The fusion researchers denied having any substantial relation to the military dimension of fusion research. The former HRU, Bo Lehnert, described the situation as analogous to the relation between the everyday use of oil and the production of napalm for military purposes, meaning that the decision on producing H-bombs lies in the hands of the political actors. According to his argumentation, production of destructive weapons does not lie in the nature of fusion. Instead, he emphasises the great potential of fusion power, which in time will be able to succeed nuclear power as an energy source. He also defends his research field with environmental arguments: *"Fusion power is an environmental alternative"*.⁵³

During the last phase of the cold war the arguments based on fear of the destructive elements of fusion, were more or less deserted in the public debate. In 1987, the arguments against fusion

⁵⁰ Interview with Swedish fusion research leader.

⁵¹ See Storforskningsutredningen. The proposition was disapproved by the largest oppositional party, the Moderates, who thought the proposed reduction gave an example of short-sighted research policy.

⁵² A referendum in 1980 established a gradual settlement of all nuclear power plants. See e.g. Ivar Franzén, "Fusionskraft lika illa som kärnkraft", Dagens Nyheter Debatt 1986-07-16

⁵³ See Bo Lehnert, "Fusionskraften är ett miljövänligt alternativ", Dagens Nyheter Debatt 1986-08-12.

research were merely focused on the physical and technological aspects. Although published in *Technology Review* a few years earlier, Lawrence Lidsky's article *The trouble with fusion* (1983) can be considered to be one of the most important initiators of this debate. In his article, professor Lidsky (Massachusetts Institute of Technology, MIT) criticizes the continued research on magnetic confinement fusion. According to him, this approach is not only extremely expensive but also technologically insufficient. Lidsky too mentions the usability of fusion for military purposes, but as the debate in Sweden evolved, this matter was left aside.⁵⁴ A Swedish physicist at the National Defense Research Establishment (FOA), Erik Witalis, supported these arguments, stressing the importance of finding new methods of confinement. The following debate focused not as much on the political aspects of fusion research, but on how it is performed. Later, this topic was further debated when the question of building the ITER reactor became more apparent.

In the present debate it is rare with "ethical" arguments against fusion. As the memories of the cold war fade away in the mind of the public, the connection between fusion and military research becomes weakened. The opponents of fusion rather focus on the time aspect, claiming that fusion energy is too much of a long-term project to solve the environmental problems we see today. Moreover, they feel that fusion research receives a considerable amount of funding without being able to present any substantial results. According to the opponents, this should be compared with other alternative sources of energy, e.g., solar and wind energy, which already yield a certain amount of electricity.⁵⁵ Representatives of the fusion community and other supporters of fusion research dispute these arguments, claiming the potential profit of fusion power outweighs the costs of present research. They feel the research efforts and the public expenses should be seen as an investment for the future.⁵⁶

5.7 Germany – Organisational Structure⁵⁷

5.7.1 Background

After the Second World War, allied law prohibited German defence research. When the German R&D system was re-established in the 1950s, this regulation led to a concentration of public R&D to civilian purposes, including the peaceful use of atomic energy. A Ministry for Atomic Questions was established in 1955, which created, together with the federal authorities, a number of research institutes. This field of fusion research was therefore institutionalised in the period, marked by the creation of IPP and FZK. Organisationally, the German public R&D system is built around both universities and research institutes, with roughly the share of public R&D

⁵⁴ See Lawrence E.Lidsky, "The Trouble With Fusion", *TECHNOLOGY REVIEW* Vol 86 (Oct. 1983), pp 32-44.

⁵⁵ See e.g., Fredrik Lundberg. "Stoppa forskningen om fusionsforskningen", in *DAGENS INDUSTRI* 1997-08-04.

⁵⁶ See e.g., Mikael Fridenfalk and Jan Stenis. "Fusionsforskningen är nödvändig", in *DAGENS INDUSTRI* 1997-08-11.

⁵⁷ This part is written by Martin Meyer.

spending (Keck 1993). The importance of the academic system as a site of research has, however, diminished since the 1970s, since the universities have been overburdened by a massive inflow of students without financial compensation. As an effect, there has been a considerable concentration of the public R&D effort to the institute sector, although there is a great deal of interaction between the two spheres (i.e. exchange of staff, postgraduate students etc.). The institute sector is increasingly becoming the centre for public research, and in particular for natural science and technical research where, for instance, over 80% of the research within the Max-Planck institutes is in the natural sciences. Thus, the costly, big-science programs have been concentrated to the institute sector. This balance between academic and institute research is of course reflected in the organisation of fusion research in Germany, where the institute sector dominates, although it maintains contacts with the academic system. Funding of research in Germany reflects the dual (central-regional) structure of the German political system, with the Federal government and the regional Länder governments sharing the responsibility for research funding (and the Länder having the main responsibility). This also applies to the institutes in the fusion area.

Fusion research in Germany is concentrated to three research centres. The major facility is the IPP – the Max Planck Institute of Plasmaphysics with around 800 staff based in Garching/Munich⁵⁸. Then there are the former nuclear research centres Jülich and Karlsruhe with 200 and 150 staff respectively. They have formed associations with EURATOM.

Researchers within the IPP wanted to have several associations involved to share tasks and costs of fusion research. Thus materials research and supraconductors as well as activities related to normal reactor research, such as natrium activities, were established as an association of its own in Karlsruhe.

Another reason might be seen in German political Federalism as opposed to, for instance, French centralism. Apart from this, the German associations are *with CEA and ENEA among* the biggest ones. This IPP is one of the biggest fusion research facility in the world.

The research centres do not really share a common history. Though at least Karlsruhe and IPP originated from the same group of researchers and then went different ways, Jülich was set up by the Land North Rhine-Westphalia as a Land-own nuclear research centre. For financial reasons, the Bund took over. IPP and Jülich were the great competitors for funding in fusion over the decades. Karlsruhe focused on different research areas. The FZK was sub-contractor to IPP until its own association was established.

An estimate of around 300 m DM is spent on fusion in Germany. The following calculation shows who has to pay:

DM 300 m = 100%

25% EURATOM (running costs, ...)

⁵⁸ Information on IPP has to a large extent been accumulated from IPP's web site: <http://www.ipp.mpg.de/ipp/>.

- 75% national funding of which:
 - 90% Federal funding (maximum 200 m)
 - 10% funding coming from the host state ("Sitzland")

This calculation does not include the so-called preferential support given by EURATOM. Preferential support covers 45% of the costs for the new Greifswald Branch Institute of the IPP, which will be the site of the WENDELSTEIN 7-X experiment. The aim of WENDELSTEIN 7-X is to demonstrate whether the stellarator concept is suitable for a power plant. The project is funded by the European Union in conjunction with the Federal Ministry of Education, Science, Research and Technology and the state of Mecklenburg-West Pommerania.

Reliable data for national funding is available since 1974 only. According to the Parliamentary secretary of state with the BMBF data before this date had only been gathered in a systematic way. Thus, they are difficult to evaluate and contain great uncertainties. For periods following 1974, he gives this information:

TABLE 5. BMBF EXPENDITURES ON FUSION

1974-1981	c. 700 m DM
1982-1989	c. 1,380 m DM
1990-1996	c. 1,438 m DM
Total 1974-1996	c. 3,518 m DM

In 1997, around 226 m DM were available. Only 212 m DM of which were used. The increase to the year before (1996: 193 m DM) is due to the start of construction in Greifswald.

5.7.2 The three Associations

5.7.2.1 IPP

The IPP was founded in 1960. It is an institute of the Max Planck Society and one of the 16 big-science establishments in the Federal Republic of Germany. It has some 1,000 members of staff, making it one of the largest fusion research centres in Europe. Since 1961 IPP has been an associate of the European Fusion Programme, co-ordinated by EURATOM, which comprises the fusion laboratories of the European Union and Switzerland. This involves IPP in the joint European experiment, JET (Joint European Torus), at Culham, UK. IPP also participates in international fusion research through numerous co-operation projects. IPP is funded by the Federal Government, EURATOM, and the State Governments of Bavaria, Berlin, and

Mecklenburg-West Pommern. In 1994, a new branch institute was set up by the Max-Planck society and the state of Mecklenburg-Vorpommern in Greifswald, in the former DDR. It will be the site of the WENDELSTEIN 7-X experiment to demonstrate the reactor relevance of the Advanced Stellarator principle. When fully established, it will have a staff of 300, partly from Garching, partly freshly recruited. Its work will be conducted in collaboration with the University of Greifswald.

The IPP is a research establishment of a special kind, since it has a double status. On the one hand, it is a Max Planck Institute (MPI): Institutes of the Max Planck Society enjoy more autonomy according to the constitutional principle of research and science being autonomous. On the other hand, it also enjoys the financial support as being one of the large research facilities ('Grossforschungseinrichtung'). Federal large research facilities are usually organised as limited companies, and are to 90% funded by the Federal level. Unlike the other two research establishments involved in fusion research, which are normal 'Grossforschungseinrichtung', the IPP is not a limited company (a 'Forschungs GMBH') with the Bund as major shareholder, but a Max Planck Institute. It has not always been this way. The IPP used to be a limited company as well, however, not with the Bund as major shareholder but the MPG. The Bund though always had the function of a major financier. This led to discussions and debates in the 1960s and 1970s, which resulted in a partly revised organisational set-up. Scientists in the field do not see a particular control-political conflict here, but point out that tensions in this area are more or less natural between financier and financed institution.

5.7.2.2 Forschungszentrum Jülich (FZJ)

A staff of 4300, including more than 1000 scientists, is devoted to studies in topical fields of research at one of the largest research institutions in Europe. The Jülich programme concentrates on the following five research priorities: structure of matter and materials research, information technology, life sciences, environmental precaution research and energy technology. Fusion is amongst these tasks. The Research Centre regards itself as an interdisciplinary institution. It is a member of the Hermann von Helmholtz Association of German Research Centres. Like the institute sector in general, it also maintains close contacts with universities, industry and other non-university research institutions.

The Research Centre's programme on Nuclear Fusion and Plasma Research concentrates on one of the key problems, i.e. the interaction of the hot plasma with the wall of the plasma chamber. This involves the need for heat transfer to the wall and removal of the so-called ash (the helium formed) from the hot fusion plasma. The central test facility in Jülich is the specifically developed TEXTOR Tokamak. A so-called pump limiter system was developed at TEXTOR for the removal of helium ash and other impurities. It was thus possible to demonstrate adequate helium removal for the first time worldwide. Since all wall components are subjected to high thermal loads on the threshold of permissible material stressing, it is of great significance to reduce the temperature near the wall and avoid local overheating of the walls. A promising concept has been tested for this purpose in TEXTOR.

Initially, the FZJ was an institution of the State North Rhine - Westphalia. It was federalised in two steps; first 50:50 funding and later 90:10 financing (in 1969/70). While IPP founded as fusion monoculture already, Jülich was from the beginning established with a much broader base in nuclear research. Best comparable institution is Karlsruhe.

When W7X will start its operation, TEXTOR is to be shut down. This will be the case approximately in 2006. The implications of this are not clear. From the centre's point of view, the worst case scenario is that all fusion activities will be shut down. The most optimistic scenario is that there will be a new machine installed.

5.7.2.3 Forschungszentrum Karlsruhe

The FZK employs about 4000 employees; of these, approx. 1200 scientists and engineers; 60 professors, more than 100 guest scientists and foreign scholarship holders, more than 200 predoctoral students, and approximately 380 trainees for various occupations and professions.

Fusion activities in the Association EURATOM-Forschungszentrum Karlsruhe, FZK, is solely dedicated to fusion technology. *According to Dr Vetter of FZK, "in the Nuclear Fusion Project, all efforts of FZK are joined to address the most urgent engineering issues of next step devices (ITER and stellarator) and of future fusion reactors."* Karlsruhe is one of the large-scale facilities broad research programme. The nuclear fusion work is one of four major projects. Its activities take place in 10 departments co-ordinated by a project management team.

In the 70's, Karlsruhe's contributions to the fusion programme were materials development (with the background of the fast breeder programme) and the Large Coil Task, the first large supraconducting coil for fusion application.

Up to the 1960's high energy physics and reactor technology coexisted. Later, nuclear power development was given increasing importance. In high energy physics key technologies such as supraconductivity and microwave power and generation were developed, which were the roots for today's important contributions to the fusion programme in fields of supraconducting magnet and gyrotron development.

The current fusion budget is about 30 MECU. 150 staff work for fusion with an additional 70 technical support personnel. The technology to be employed in the future fusion reactor is the area of activity pursued by the Center in fusion research. Materials and extremely stable components for fusion plants are studied in simulation experiments under ion bombardment in accelerators and in-pile irradiation.

Supraconducting model coil is another area of activity. Within the ITER international fusion experiment, supraconducting magnets are developed for the coil systems. For this purpose, the Karlsruhe TOSKA coil test facility is expanded as a test system for the ITER toroidal field model coil. Besides, experiments and tests are conducted to try out ways of handling practical amounts of tritium in the Karlsruhe central tritium laboratory. Remote handling techniques are demonstrated for inspection and repair in the ITER plasma chamber.

FZK also contributes to the establishment of the new W7X stellarator in Greifswald. Tests of superconductors and prototype coils for the stellarator in Greifswald are being carried out. A further field of activity are plasma heating techniques. FZK develops gyrotrons in the 140 GHz frequency range. Finally, two blanket concept variants of future fusion reactors are under development.

Why was a third German association established? The establishment of a research unit dedicated to fusion technology was seen as desirable because, the NET activity was initiated in 1982, which in its turn created a need for more and new technologies. The need for coordination of fusion contributions in Germany and the role of Karlsruhe specialised in fusion technology made a third association accepted.

A balance of work in the research centres of Jülich and Karlsruhe played an additional role to allow Karlsruhe to enter the fusion programme with a larger effort. Both places cooperated on a *large spallation* neutron source project. With the decision to concentrate this work at Jülich, efforts at Karlsruhe were freed for the new fusion project. Some activities that had started in Jülich, in particular the tritium technology, were taken over by Karlsruhe and represent today one of the most important work fields centered in the FZK tritium laboratory.

5.8 The Internationalization Process

There has been a shift in motives for international collaboration. At the beginning of fusion research, European integration and research collaboration was promoted by the political actors for general political reasons. Scientists did not know what to gain in the beginning. They were sufficiently equipped with funding on a national level. Thus at this point European activities were due to political reasons, as a symbol of European unity. This has changed in the course of the years when they realized that they could gain more independence from their own government. An upper limit to national fusion funding and thereby a great need for savings also play a prominent role. Thus, there were gains from a political perspective too, since the high costs of fusion research could not be covered on a national level alone.

There is a clear division of labor between IPP and FZK. IPP does fusion physics on a basic research while Karlsruhe takes care of the technological (applied) aspects. IPP and FZK together formed the Entwicklungsgemeinschaft Fusion in 1982. Jülich used to have the function of the second research center ensuring high quality of German research by offering an alternative to Garching.

The close collaboration between IPP and FZK with its clear division of labor, did not include Jülich. FZJ is active in both fields - fusion physics and technology. However, due to their cross-border contacts that Jülich established, an international, trilateral cooperation emerged where Jülich provides the machine for the researchers in Belgium and the Netherlands. Thus, the close ties between IPP and FZK enabled FZJ to become more international in its collaborative links. Jülich had had a long history of collaboration with the Association EURATOM-Belgian State since

Belgium had given up their machine in the early 1980s. The Netherlands are now in a comparable situation because their own little Tokamak is to shut down in this year (1998).

TEXTOR is now the common machine for three associations. According to Dr. Eidens of FZ Jülich, national circumstances do play a role, even in fusion: "Of course, who does like to invest abroad?" - The Belgian-Jülich collaboration has been very successful. "There have been 15 years of good marriage." This has made the trilateral agreement easier for the Netherlands.

5.9 Collaboration

5.9.1 Collaboration on the National Level

5.9.1.1 IPP and its collaboration with the other research centres

The increasingly tight finance situation of fusion research in Germany has led to a number of gains and losses among the three research facilities involved, which led to different forms of collaboration and competition, respectively. This is illustrated by the different character of relationships the IPP has with the other two major research establishments in the field. While the relationship with FZK is of a complementary character ('Entwicklungsgemeinschaft'), there seems to be a more competitive element in the relationship to Jülich.

5.9.1.2 Jülich and its collaboration with the other research centres

Evaluations for TEXTOR were done by IPP, and vice versa. Garching and Jülich have a history of competition. This is seen as healthy ("Konkurrenz belebt das Geschäft") and helps to have a number of options so that there is more than just the party line that prevails. According to the personal experience of researchers at FZJ, differences and changes in rivalry and competition for funding are related to machines. For instance, ASDEX had been established 6 months before TEXTOR was set up (both of them are TOKAMAKs; one has a divertor, the other one has a *limiter*).

TEXTOR will have to be taken out of use in 2006. By then the machine would have reached 24 years of operation and would be close to a technical end anyway. The problem is that all options (see scenarios above) are connected to this particular date. The fear is that all activities at FZJ will be shut down by 2006. Jülich wanted to be W7X site, which instead went to the Greifswald branch of IPP. FZJ researchers do not see many scientific reasons for site Greifswald, which they instead see as a decision related to the German reunification process. The university environment in fusion research and plasmaphysics in Greifswald is not comparable to North-Rhine – Westphalia, it is claimed.

5.9.1.3 Karlsruhe and its collaboration with the other research centres

With the new balance of work in the German fusion associations, FZK and IPP joined their forces as 'Entwicklungsgemeinschaft Kernfusion' to prepare for the constructions of future large devices

by sharing responsibilities (IPP responsible for plasma physics, FZK for fusion technology). This cooperation now materialises in the joint construction of Wendelstein 7X, where FZK contributes by delivery of the complete plasma heating system and by development and testing of prototype supraconducting coils. An increasingly strong collaboration has been formed in the area of blanket development. Several European laboratories, in particular CEA and ENEA, cooperate with FZK in the European Blanket Project. Only recently FZK joined JET as a full member, expecting that a stronger link shall be established in future through tritium operation of JET.

5.9.2 Collaboration on the International Level

The beginnings of fusion research can be traced back to the late 1940s and early 1950s. Then, a lot of the research was military and classified. National technological prestige and fluctuating belief in intergovernmentalism by European states restricted the level of European collaborative research in the 1960s. This was reflected by the fusion community as the 'years of wilderness' (Pownall - Wilson). With its emphasis on specialized scientific research, fusion policy did not suffer from the same competitive rivalry as experienced by nuclear fission in EURATOM. However, the development of a fusion reactor in a collaborative policy was excluded from explicit community initiatives prior to 1976. One reason is that fusion research in Europe did not command the same type of political and economic priority as the fission field. European-level collaboration in fusion research started in the mid-seventies. It is the only research program where all the participating member states are fully integrated.

Over the late 1960s the emphasis was on frequently undertaken researcher exchanges between the active fusion research labs. While a 5 year fusion research program was organized by EURATOM or the first time in 1958 already, it was the fourth program that suggested the creation of a large European project in 1973. In 1976, the decision to build a European reactor was made.

This includes France as well, reasons for European collaborations at this stage were not so much related to need for money but later hoped - for market-advantages and the interest in what others in the field were doing. Even if scientists had not agreed on and approved of European collaborations, they integrated themselves fast and without complaints. Nuclear technology got problematic in the mid-sixties in Germany. Through integrated, joint European research one wanted to achieve two aims: (1) to separate fusion from 'nuclear' (= fission) research, and later gaining more importance (2) the issue of saving money.

Around 15 years ago, it became clear that the efforts would become increasingly larger, much larger than in the beginning, and the money was getting scarce. Further integration seemed to be a way out. Thus fusion research was to be fully co-ordinated. It is said that fusion researchers were the first who really acted in a European manner. Thus JET attracted more and more responsibilities over the time. *NET - the 'Next European Torus' - was set up to bundle the*

European activities prepare for a European successor to JET. However, this project has been integrated in the ITER collaboration.

According to some observers of the fusion scene, this trend towards integration and concentration of finance support might lead to a restructuring of the German fusion research sites and a shift of activities from Jülich to Greifswald. In 1982, FZK formed together with IPP formed the Entwicklungsgemeinschaft Fusion. However, the integration and concentration trend can also open up doors for very close co-operation between institutions in different countries. In Jülich there is with TEXTOR a machine that is too small to be of much future use. The Association Jülich is dealing with remaining TEXTOR work. As Belgium and the Netherlands do not have the funding to do experimental fusion research on their own, their plasmaphysicists focus on the collaboration with Jülich.

5.10 Coordination in Germany

5.10.1 Steering committees

The 3 associations, i.e. IPP, FZJ and FZK, have their own separate steering committees. The only coordinating body of researchers is the Entwicklungsgemeinschaft Fusion between FZK and IPP.

Meetings of the directors of the research centers take place twice a year. Guests from the ministry are also included. In the 'Entwicklungsgemeinschaft' the discussions deal mostly with technical co-ordination issues. As the three associations are completely independent of each other in terms of their EURATOM status - the entire collaboration effort is voluntary. The committees, unlike its counterpart in Sweden does not have the task (or does not consider it has the task) of representing the public side of fusion.

The fusion research centers are members of HGF - the "Hermann von Helmholtz Association of National Research Centres". As a science organization, the HGF supports the exchange of experience and information among its members, ensures coordination of research and development work, performs tasks of common interest and represents the concerns of the Helmholtz Association to the public. The members of the Hermann von Helmholtz Association of National Research Centres pursue long-term governmental research goals on the basis of scientific autonomy. The concentration of considerable financial and staff resources, a sophisticated scientific and technical infrastructure, and efficient management enable the research centres to deal with complex scientific and technical issues and interdisciplinary tasks, to operate large-scale scientific and technical equipment and also to develop system solutions.⁵⁹

⁵⁹ The performance of such tasks requires a high degree of continuity and cooperation across subject area, institutional and national boundaries. The senate of the Hermann von Helmholtz Association promotes a consensus by science, industry and society.

In HGF, there are organs that take care of public relations matters. The usual way or representation is through the directors of the institute. The Entwicklungsgemeinschaft is a coordination platform within the HGF. For fusion the IPP is the decisive partner.

5.10.2 CCFP

The CCFP is the advisory committee to the European Commission. It is the de facto decisive body for policy formulation in European fusion. There is close interaction with the European Commission. The three German members are Professor Pinkau, IPP, Professor Hennies, Karlsruhe, and a representative of the Ministry. Professor Pinkau is chairman of the CCFP and also an expert member of the ITER Council.

5.10.3 IPP between MPG and HGF

The IPP has a special organizational affiliation, it is both an MPG institute and a Helmholtz Center. The MPG plays an important role in all staffing issues. For the IPP, all MPG rules apply. This is different for the other fusion research centers. They are not Max Planck institutes. The directors of the institute do not participate in all personnel decisions. This is considered a stricter selection process. However, also the selection and staffing regulations in the HGF centers are made stricter. As for funding, IPP is treated like a HGF institution. The annual Federal budget lists the budgets for individual HGF centers, whereas MPG institutes do not appear as single positions in it. The financial foundation of the Max Planck Society is a basic agreement between the Federal government and the individual German states.⁶⁰ The agreement provides for jointly supported research in accordance with Article 91b of the German Constitution. A supplemental agreement regulates financial support for the Max Planck Society: half of the subsidies contributing to the Society's budget are paid by the Federal Government and half by the states (Budget A). Moreover, financial assistance (special funds) exceeding the contributions allocated by one of the financial backers may be granted by the joint backers with the approval of all parties to the agreement.

On this basis, fundamental research, precaution research and technological development at the pre-industrial stage determine the projects and research programmes of the Helmholtz Centres. The centres perform their work within the framework of scientific self-determination and based on their own conceptual developments as part of the research programmes of the Federal Government and federal states. In this respect they are independent and neutral regarding competition so that they are destined to undertake tasks in the public interest.

The Helmholtz Centres perform scientific and technical as well as biological and medical research and development. They make a significant contribution to publicly funded programmes in the fields of energy research and energy technology, basic physical research, traffic and transportation systems, aerospace research, information technology, marine technology and geosciences, environmental protection and health, biology and medicine as well as polar research.

⁶⁰ Currently, some 95% of the financial support received by the Max Planck Institute comes from public funds provided by the Federal government and the states. The remaining 5% stems from donations from members, contributions, and from its own earnings.

The IPP, in contrast, is funded by the Federal Government and the states in which it has branch institutes - Bavaria and Mecklenburg-West Pomerania - in accordance with the regulations governing large-scale research institutions in a ratio of 90 : 10. Furthermore, the Institute receives a subsidy from EURATOM for a joint research programme within a framework of an association contract in the field of Fusion Research.

The IPP is financed out of a common pot of the MPG which is a single position in the federal budget that has to be decided over in Parliament. In this sense, HGF institutes including the IPP are under ‘tighter’ political, parliamentary control than other institutes of the MPG.

Max Planck Institutes usually carry out basic research in service to the general public in the areas of natural science, social science and the arts and humanities. In particular, the Max Planck Society takes up research that, because of the interdisciplinary character of such research, is hard to fit into the universities’ organisational framework or because the costs for personnel and facilities that it demands are beyond the universities’ means. Max Planck Institutes, therefore, complement the work of the universities in important fields of research. The situation of the IPP within the MPG, however, is special and unique in the sense that it is a research center that does applied research, which is different from the usual basic research focus of Max Planck institutes.

5.10.4 Steering committee IPP

This section will illustrate the functions and tasks of the steering committee in the largest German fusion association. Where appropriate, differences to the other German associations are pointed out. With regard to steering committees, originally there were different arrangements varying from association to association. In other associations than IPP, the influence of the steering committee is said to have been greater. As the IPP is a Max Planck institute enjoying special autonomy from government supervision, special arrangements were necessary in the past, as Professor Schlüter, the former head of the IPP, pointed out. In the meantime the arrangements between EURATOM and the associations have become more alike. One difference used to be the appointment of the scientific members.

The Steering Committee in Garching consists of

- the directors,
- the head of administration,
- the representative of the European Commission, as well as
- representatives of the Federal Ministry

At the IPP, the selection of leading scientists at the institute takes place locally through the institute board of directors.

Chapter 6:

Conclusions: Fusion in Context

6.1 Evaluation of Methods

This project has proposed, developed and tested a number of techniques and perspectives in socio-economic research on fusion. In this respect the report functions as an illustration to what can be done in this area. Nevertheless, the methodology involved (see section 1.3), including a questionnaire, bibliometric analysis and in-depth case studies all have limitations. The use of several research methods, therefore, is of vital interest when an area of research is developed.

The conclusions that we draw are the following:

- Local information for case studies are in many instances restricted in fusion research. If case studies are to be performed, very precise and clear cut questions should be in focus and pilot studies should be performed in a first step to test the feasibility of a proposed design. This is due to the dual nature of fusion research organization: it is hierarchical as well as sensitive to political and economic demands. The process of gaining access to fusion research laboratories is therefore more complicated than for “traditional” academic research laboratories (which explains why the Swedish case, with its more academic organizational structure, was easier to conduct than the German case).
- It has been shown that questionnaires, to some extent, can be used as a substitute when local information is restricted. We can learn a lot about the structure of a research laboratory from the individual researchers’ questionnaires. Furthermore, the pattern of reply from a laboratory, i.e. high or low rates of response, gives us some indications of the organizational culture of that laboratory.
- Bibliometric data is an important source of information concerning the organization of research, but mainly when precise and clear cut questions are focused and certain aspects of the research system are investigated. Bibliometrics should, furthermore, be complemented with other information since the interpretation of bibliometric data is not always unambiguous. Our work on collaboration is an illustration of this. We used accountability information sent to the Association from each principal investigator in Sweden as a correction to the bibliometrical information. From this we could establish reliable data on collaboration patterns (see Appendix II and III).
 - Socio-economic research has to be long-term research, i.e. several types of data bases has to be built up and developed. Since the development of fusion is a complex process where scientific, political, economic and organizational aspects are combined, the study fusion research demands a long-term perspective, where these different aspects are closely monitored and their mutual interdependence made clear. Fusion research must therefore be studied over a

long period of time if a fuller understanding of the area's dynamic is to be achieved. Due of its complexity the area is particularly ill-suited to traditional "snap-shot" evaluations.

6.2 The Fusion Community under Stress

The fusion community had to handle tough pressure during the period when we did our survey. This fact partly explains the results; As seen from the brief presentation below, most of our findings are not very controversial.

- many believe that the management of ITER will be difficult due to complex international relations
- scientific or technological problems do not, to most respondents, pose serious obstacles to large scale fusion research projects
- a solid majority supports the collaboration with countries outside Europe; theoretical researchers are the most convinced in this respect
- most researchers do not welcome more frequent evaluations
- support for more research on inertial confinement fusion is weak
- more research on alternative concepts within magnetic confinement has, however, a rather strong support
- fusion physicists claim to have a hard time justifying their own projects to non-fusion colleagues.

The dominant mode of behaviour seems to be "Political Correctness": the replies reflect the fact that fusion researchers seem to be very well aware of the area's social and political implications as well as its deep integration in a "non-scientific" environment. Researchers in the area have, as a result, developed a sensitivity as to what is expected from them and there seems to be a general understanding of how fusion researchers should present themselves outside the "Community" (see discussion in section 4.9). From this, we draw the conclusion that the fusion community is well-integrated and has developed mechanisms to ensure a collective identity. Presumably, this reflects the level of co-ordination and co-operation is much higher than in other areas of research. Furthermore, the peculiarities of fusion research has led to a specific form of research organization, evident in, for example, the number of administrators and instances where research proposals are negotiated. The area is not only more hierarchical than most other scientific areas, but it is also much more "negotiated" in this sense. Thus, the fact that fusion research is highly visible and controversial has not paralysed the researchers: they have instead developed intra-organizational as well as external mechanisms to handle the disturbances caused by this.

6.3 Discussing Research Questions

In this section we will return to the research questions in section 1.2. These were divided in two groups: *Attitudes* and *Co-ordination and Collaboration*.

6.3.1 Attitudes

What are the particular national political motives for participating in the international research collaboration?

With regard to national political motives for participating in international research collaboration, there seems to have been a shift in motives. Initially, European integration was promoted by political actors for broad political reasons. International collaboration on the field of fusion was a step in the evolving process of European integration. Presumably, the oil crisis triggered the search for a more stable and long-lasting solution to the problem of energy supply. Furthermore, the 1970s and 1980s were marked by a squeeze of state expenditure when most European states were plagued by increasing budget deficits. At the same time, there was a shift in government industrial policy priorities, away from large-scale prestige programs (à la fusion research) to a more process-oriented support of "innovations". These changes forced through changes in science policy priorities. As an effect, fusion research was lifted from the national to the supranational level.

There were other more general political considerations operating. For instance in the Swedish case, the internationalisation of fusion research (through joining the EURATOM agreement) was considered a (more or less legitimate) way for the Swedish government to approach European integration without actually joining the EEC.

In the initial phase of fusion research internationalisation, fusion researchers in Sweden and Germany were not uncertain about the gains, although in the Swedish case the agreement resulted in an increase of resources for fusion research. The projects of developing a common experimental reactor (the Joint European Torus, JET) did of course also seem like an attractive outcome to many fusion physicists. The internationalization also increased the security of the fusion researchers in terms of funding and political commitment. The internationalisation of the fusion research yielded a certain amount of scientific independence from the nation-state. This is of course not a strong political motive, and might instead be seen as an unavoidable shortcoming from a national political perspective.

Initially, the internationalisation process was begun for political reasons, and the political actors were eager to reach an agreement on fusion research. But as the international security situation changed, it altered the political opinion of the arrangement. Like other research fields which thrived on the basis of the geopolitical instability of the "cold war"-era, fusion research is now confronting vociferous demands for cuts. This fact has occasionally lead to a political questioning of the whole European Fusion Programme and the ITER-project. Thus, fusion research exists in a

very complicated geo-political environment, which makes any predictions of its future very uncertain.

What are the attitudes among researchers and research directors towards the management of the fusion programme?

Fusion research leaders have only very little critique against the organisation of the programme. Instead, the European fusion community appear to be a rather homogeneous group which supports the stipulated path for progress within applied fusion research. There is a slight disapproval to be found regarding the issue of concept improvements: some researchers feel that promising lines of confinement are neglected in favour of the current Tokamak. Others are also troubled by controversy regarding the wage differences at JET, claiming that this situation is affecting the programme negatively. But on the whole, the organization of the fusion programme appears to be uncontested among the researchers.

What are the attitudes towards politicians among participants in the fusion programme?

In general, fusion research leaders are skeptical towards the actions and motives of politicians within the fusion research field. Only one fifth express a favourable attitude towards the level of understanding among politicians in the field of fusion. Medium sized labs and the labs with a long tradition have a particularly negative experiences of political actors. As a result, a vast majority feel it is necessary to explain the importance of fusion research to the political actors. According to them this matter must be improved.

In correspondence, they argue that the political actors have difficulties appreciating benefits of large scale, long term research on fusion. In the eyes of the researchers, the politicians are primarily interested in short term solutions. The indecisive signals from the political actors clearly generate an uneasy feeling among several of the members of the fusion research community. This situation convince many researchers that experts ought to have a stronger voice in long term policy decision making, while other merely stresses a desire to have more of the politicians attention.

These findings reflect the highly politicized nature of fusion research and the researchers' attempts to limit political pressure. Fusion researchers quite naturally wish that the area should be viewed from a scientific and technological perspective, since political swings and ideological shifts could disturb scientific and technological progress. Thus, there is a general orientation among fusion researchers in all countries involved to seek independence from what they see as shortsighted political interests.

What are the relations between fusion physicists and the physics community?

The relations between fusion physicists and the physics community are a bit complex. A majority of the fusion researchers confess they have difficulties justifying their research projects to non-fusion researchers within physics. This situation can be related to budget problems but also to the unclear and slow progress of fusion research. The fusion researchers are aware of fact

that the production of electricity lies in the future and that many in the physics community demands substantial results today. Therefore, many feel it is important to convince other physicists of the usefulness of the fusion research, especially researchers with a theoretical orientation. The fusion physicists sometimes feel beset by non-fusion researchers within physics and, thus, the investigation reveals a significant justification problem.

Fusion physicists operate within a tightly structured discipline, where specialties are ranked within a strict status hierarchy according to their theoretical stringency and depth. The application-orientation and the importance of non-scientific (i.e. political) actors in the decision-making process marginalise fusion researchers within the greater physics community. This fact is also related to the troubled relations between fusion researchers and politicians (see above). Fusion physicists thus operate in a most complex environment, where they have to defend their territory from political interests in order to increase their scientific standing. On the other hand, if the area loses its connection with the goals set up by the political system, fusion research loses its political legitimacy.

6.3.2 Co-ordination and Collaboration

What are the differences in organisational and institutional set-ups for the nationally organised research and how do they affect the conditions for co-ordinating different research groups on different levels?

National differences in European research and political systems do play a role for the conduct and organization of fusion research in different countries. For instance, France, being a highly centralized state, has just one association while Germany, with its federalized structure, has three. Since central government cannot exercise the same control as in other countries, German institutes also enjoy more freedom and independence than other European organizations in this field. This means that the institutes themselves become important actors in the implementation of the fusion programme in Germany, making collaboration somewhat more difficult to develop than in a centralized system. The Swedish system represents a third model for fusion research organization, with a national programme organized by a research council and implemented in the academic system. This means that coordination is even more difficult than in the German system, since fusion researchers can be found in many different organizational settings. On the other hand, this has also forced through a system of voluntary coordination and division of labour within the Swedish fusion community. Thus, a high degree of decentralization does not necessarily mean that coordination is made impossible.

How does the division of labour function between researchers/research groups on the international and/or national level?

and

What are the specific national patterns of collaborations between researchers and engineers and how do they affect the international framework of collaboration and co-operation?

From our investigation based on European fusion research leaders it seems as if the division of labour is rather distinct in several respects. In most cases coordination of fusion research is kept within the different lines of orientation. The division of labour is preferably of international character and JET is the main coordinating factor.

In the case studies, especially in the Swedish case, national collaboration is often dependent on geographical factors, and intra-university collaboration is much more frequent than inter-university collaboration. According to our findings, international collaboration appears to be the predominant mode of collaboration. In a way, it constitutes a framework for the collaborative activities performed nationally. The findings indicate a rather separate and parallel mode of establishing collaborative contacts and execute collaborative activities. It is often the most rational approach to look for collaboration partners outside Sweden because of the specialization of the different groups. Although national groups might be isolated, they converge at JET; JET has a strong influence on European collaboration patterns in general and Swedish collaboration patterns in particular. JET therefore functions as an important coordinating factor for national research efforts.

6.4 Cases in Context

This section is a short summary of the main findings of the empirical studies on supranational R&D programs and their implementation in a national organisational setting (see Chapter 5). The main argument and conclusion of the case studies is that the implementation process is affected by, but not predetermined by, the national trajectories in research policy and research organization. A supranational R&D program such as the one under study here is channeled through relatively stable national patterns of organizations, procedures and evaluation criteria. Thus, the organization of these programs will not be similar in the various participating countries, and this needs to be clear in the evaluation of such initiatives.

Nevertheless, the national institutional set-ups are not unaffected by supranational programs, although influences are channeled in different ways and transformations during the process might be more or less intensive. So, national patterns are not unchangeable, and international programs influence the national organization of R&D e.g. through some of its criteria for evaluation, organization etc. For instance, the research groups involved have become increasingly international in their work and co-operation patterns, and in this respect supranational co-operation and collaboration has been one incentive for this pattern. Furthermore, the programs – through their political visibility and the ensuing organizational structure – have affected national research systems more generally, especially those with the university at its centre (like Sweden). Here, the organization of the program has, to some extent, collided with traditional academic notions of flexibility and the "free" pursuit of research. On the other hand, the conduct of fusion research in forms (such as research institutes) that might be more congenial to the orientation of

fusion research in other countries (e.g. Germany) have also created a number of problems, such as inflexibility and organizational inertia.

Our argument is therefore that the end-result of the international programs for fusion research follows from a "negotiation" between the supranational programs and the national trajectories. Thus, there is a two-way process of influence in operation, between national and supranational factors. There are no definite conclusions that can be drawn regarding the most efficient model for organizing and implementing international programs in a national setting. Instead, two quite distinct models, one quasi-academic and another semi-bureaucratic are contrasted.

With regard to particular national political motives for participating in the international research collaboration, there has been a shift in motives in the German case. At the beginning of fusion research, the European integration was promoted by the political actors for general political reasons. Scientists were, however, sufficiently equipped with funding on a national level, mainly because of the role of fusion research as a national prestigious project. This was the case not least in Germany, which began its large-scale operations in this field when for instance US laboratories were looking for new tasks (Keck 1993). Thus, European activities were mainly due to political reasons (European integration) at this time. This has changed in the course of the years when researchers have used European funding as a vehicle to gain more independence from their own government's funding. For the political system, the enormous costs and complexity of fusion research has also contributed to making European collaboration more attractive.

- Differences in organizational and institutional set-ups influence national research and the conditions for coordinating different research groups on different levels. For instance, France has just one association while Germany has three. This is due to the different cultures and institutional structures of centralism and federalism. German institutes also enjoy more freedom and independence than other European organizations in this field because of the liberal regulation of higher education and research in the German constitution. As an effect of these special conditions in Germany, the national government cannot exercise the amount of control as it is the case in other countries.
- Specific national patterns of collaboration between researchers – scientific and technological styles seem to exist. With the large and complex system fusion, big investments into machinery go along. Research institutes can be wiped out if they cannot update or renew their instrumentation to do fusion physics. Rivalry thus focuses on the machines. This might happen to one of the research centers in Germany, FZJ, which feels the threat from the new Greifswald plant. Thus, there is a direct relationship between the start of operations in one site and the end of another. At least in fusion physics, gadgetry seems to play a role. There are clear opinions about what is legitimate research and what is not in this field. This is related to the fact that decisions on research organization have widespread consequences. This leads to a sense of uncertainty and a search for „non-scientific“ elements in the decision process.
- On another, more aggregated level, the subject-matter of fusion as such seems to be important. Fusion as such is questioned in its legitimation. Sometimes, as the narrative has shown, fusion seems to survive 'accidentally'. Politicians are getting impatient and want to see results. The international community of fusion researchers is thus interested in gaining more independence

through international collaboration, by getting a more mixed source of revenue and by decreasing their dependence on one political patron.

Sweden, on the other hand, is somewhat exceptional in the sense that the EURATOM program has been integrated mostly into the university rather than in the institute sector. Nevertheless, the organization of Swedish fusion research shares some of the characteristics of institute research in other countries. The program is implemented in an academic form, with research groups within academic departments (with traditional academic appointment structures, positions etc.) at the centre. Funding is distributed in a traditional academic manner, namely through peer review and a research council (the Council for natural science research, NFR). Funding of fusion research is also, as in traditional academic fields, used as a vehicle for international collaboration rather than, as might be expected, national science/technology collaboration (even to the extent where national collaboration might be seen as underdeveloped). The academic orientation is also stressed by the interviewed researchers, who view the traditional academic routines (publication, international orientation, collegial recognition) as being as important for fusion research as for any other scientific field. They thus refuted any claims that this field of investigation was more "politicized" or bureaucratically structured than other fields. The hierarchies of academic research are also less important than in for instance institute research, and this characteristic is valid for Swedish fusion research too.

Nevertheless, the organization of Swedish fusion is only quasi-academic, since there are many organizational characteristics resembling those of a research institute. Funding is, for instance, guaranteed to a much higher extent than for a "traditional" academic department. The success rate for fusion research applications to the NFR, as shown above, was slightly above 80 percent. Furthermore, political considerations play a much greater role in fusion research than in other fields in the natural science and technology faculties. This can be exemplified with the destiny of the EXTRAP concept developed by the KTH group, where the research strategy had to be changed to make it integrated with the European fusion program. Thus, researchers have to be more politically and organizationally sensitive in their planning.

The "quasi-academization" of Swedish fusion research creates some organizational anomalies, as pointed out by the international review conducted in 1997 (International Evaluation of Fusion Research, June 1997). For instance, the potential conflict between scientific evaluation criteria inside the NFR and fusion relevance criteria are considerable as the EURATOM fusion program to a large extent is a technological effort. The mentioned review committee found that this dilemma was handled by the researchers by a strategy that emphasised their respective individual profiles. This has led to a centrifugality in the Swedish fusion community. Instead of collaboration and streamlining of resources each principal investigator has his own very specific area of research which seems to have made combining of interest a bit harder to achieve. In the NFR fusion committee has been hard to come any other result than to give each member and each group funding for their projects. Then again, centripetal competition and collaboration are not functions central to the present system of fusion research in Sweden.

Along with this it should be underlined that the political elements of fusion research make it more difficult to develop a classical academic approach to the formulation of research issues in Sweden. When funding and research is organized in a university-like model, but with clear political and organizational constraints, this confronts the area and the researchers with a mixture of roles and ideals. On the other hand, this problem might be alleviated by the rather long tradition of commissioned research in Sweden (*sektorsforskning*). There is already an awareness among Swedish researchers that areas are more or less politically visible, and that academic and political or industrial interests are not mutually exclusive.

The German system represents a rather different approach to the implementation of supranational R&D programs, although this model too is well in the line with the national trajectory. In Germany, the institute sector has become increasingly important as a site for research, especially for "big science". The institutes have distinct organizational hierarchies, and decision-making tends to be highly centralized. The institute sector is in itself divided into different "families" with different traditions in organization and research orientation, such as the Max-Planck Society (basic research), the Fraunhofer institutes (applied research), etc.

As a reflection, fusion research has been integrated into the German institute system (although the institutes themselves maintain some contact with the academic system). The German institute system is highly structured with clear and important hierarchies operating. This makes the organisation of German fusion research much less flexible than the Swedish system, if however also more stable and predictable in relation to the given tasks of the EURATOM. Furthermore, the institute sector seem to have developed with different institute families operating in separation, making collaboration between them less likely or at least quite difficult in some cases. This feature is also reflected in the organization of German fusion research. There is a competitive element operating in Germany too, but it seems to reflect organizational hierarchies and status differences more than scientific merit. Furthermore, the German case and the process of unification reflects the symbolic value of fusion research, where political reasons are given for the move of one fusion research facility to the former GDR. Thus, also German fusion research reflects the national political and organizational peculiarities, if however quite differently than in Sweden.

6.5 Concluding Discussion

The European Atomic Energy Community, EURATOM, was created by the Treaty of Rome in 1957, in a time when most of the European states recently had recovered from the Second world war. The former open war had been replaced by the Cold War which divided Europe into East and West. In the latter region a strategy for peaceful cooperation was set up, and the creation of EURATOM represented an important step in the prevailing economic and political integration of Europe. The institution focused, among other things, on nuclear research and the development of nuclear safety standards. In the early seventies the discussion on a joint fusion research device coincided with the global oil crisis, and fusion power was by many seen as a long term solution to a serious energy problem. As a result the Joint European Torus, JET, was built in England which

became a materialisation of the European research effort on fusion. In our report we have concentrated on different perspectives related to the succeeding project, i.e. ITER. The execution of this project truly indicates an internationalisation of fusion research and leads to a discussion on megascience and problems of international research collaboration. As the collaboration on fusion research intensifies it is no longer possible to talk about this scientific effort as a separate phenomenon in society. ITER as a megascience project involves a wide set of countries, cultures and traditions, and concerns plenty of different actors. It has economic and political aspects, as well as scientific, hence investigating this field implies a multi-level perspective.

The European fusion programme must deal with a few questions that might block or delay the development path towards a viable fusion reactor. First, the political actors within the European states have from time to time questioned the scientific and economic favouring of fusion research. Fusion researchers cannot promise a substantive break-through in producing fusion power within decades from now; in fact it cannot be absolutely assured that fusion power can be produced and tamed satisfactorily. The political support for fusion research has therefore varied, leaving researchers in distress. Second, fusion researchers are obviously having a justification problem towards non-fusion physicists, at least if we are to believe fusion researchers themselves. This problem is primarily based on the special treatment of fusion research, e.g. research council's tendency to consider it as applied research. Third, fusion research has occasionally been attacked by public groups, which have criticised and questioned both costs and essence of fusion research effort. During the Cold War, the Swedish public debate on fusion research occasionally circulated around the question whether fusion should be considered as a "peaceful" energy source or not. This discussion is however not as significant today as it used to be. Fourth, a megascience project like ITER demands substantial long term economic and political support from the involved countries. It is necessary to deal with the problem of different cultures, traditions and geopolitical factors in the management of a megascience project. Thus the project must by necessity deal with questions related to international relations and must gain the support of the national governments involved. When this support wither, the project is in great danger of dying in early age.

Several of these aspects play significant roles for whether the ITER-project will be successful or not. The megascience project is exposed to a number of threats, and as a consequence a large part of the fusion research community is quite defensive in the discussion on the fusion programme and political and scientific problems related to their work. The strategy is to declare a consensus on the matter in order to strengthen the project as such; rectified forces and opinions indicate a successfully coordinated project.

As seen from the discussion a megascience project is a complex and delicate affair which needs a well defined structure and coordination. In general, the coordination of the different Research Units of the European fusion programme seems to be rather sufficient. The trick is, among others, to combine different institutional set-ups into a well functioning entity which must aim to fulfil a common goal: the building of ITER. The quasi-academic set-up (i.e. university based research on fusion) in Sweden constitutes an example of coordination necessary to undertake joint research efforts. Academic freedom must partly be restrained in order to secure and synchronise a desired research progress.

6.5.1 The transition from "Big Science" to "Megascience": fusion research as an illustration

The evolution of fusion research neatly illustrates the general trend of the changing organization of large-scale research. It has, arguably, moved from a state often referred to as "big science" to "megascience".

The concept of "big science" usually refers to national, single-unit, state-controlled and prestigious research programmes. They tend to be national programmes based on one or a few research facilities with a relatively simple organizational matrix. This means that the programmes are processed only through one political system. "Government" – in the sense of state budgets, Ministries of Science as the responsible agent, and with the facilities controlled by state regulation – is the dominant steering mechanism in the coordination and implementation processes of such programmes. Big science facilities are often tied to the search for national prestige and/or to the enhancement of "national champions" in various sectors of industry. This has been reflected in their notoriously overdrawn budgets. Big science facilities have tended to have more or less unrestricted budgets.

Megascience refers to internationalized, network-based, governed, and pragmatic research programmes. Megascience programmes have grown out of the negative effects of big science programmes, in particular their uncontrollable budgets, but also the redefinition of "national interest" in the post-cold war period and with the rise of global competition. In these programmes, national government pool their resources to control costs (and to free resources for other R&D programmes with a more clear impact on national competitiveness and wealth creation) and increase efficiency. This means that megascience programmes normally have none or only a few central facilities and instead a network of facilities joined together in the programmes. This leads to a complicated, organizationally heterogeneous and internationalized process of coordinating large-scale research programs. In this sense, one could describe megascience programmes as organized through governance, that is, non-centralized processes involving many actors and interests. Megascience programmes are pragmatic in the sense that they operate with clear budget limits and with an established system of cost and efficiency evaluations, as well as a continuing political assessment of the programmes' impact on society.

All of these factors mean that "megascientists" – such as fusion researchers – have to increase their awareness of their political environment as well as the consequences of organisational complexity of research. In the Big Science era, "Big scientists" were given a *carte blanche* to develop prestigious technologies without considerations of costs and time limits. Our attitude survey indicates that fusion researchers still try to recreate the era of scientific optimism and unrestrained budgets of the big science era. Such a change seems highly unlikely. The fusion community thus confronts uncertain times. Also, despite international coordinating efforts, the ITER-project suffered a severe blow as the United States depart from the common project. What we see is lack of consensus among some of the involved actors, and at present the original operation is clearly endangered. Formal international collaboration on fusion research might even

be dissolved in favour of regional solutions. Fusion research is very much based on international collaboration (exchange of information, scientists, etceteras) and will doubtless continue to be so. Still, it is possible that the current formal international collaboration on the ITER-project converts into smaller, regional collaboration units. Presumably, this circumstances will imply reduced ambitions in matter of scale and time.

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