Fusion as a large technical system

Macro Task Report (S 1)
EURATOM program Socio-economic research on fusion (SERF)

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1 Summary and introduction

1.1 Fusion as a large and complex system

”Large technical systems” has, perhaps not surprisingly, become a widely used concept, not only among engineers, but increasingly also among historians of technology and social scientists taking an interest in technology and science. The key point that should concern us here is that a whole body of research shows that the ”technical” and the ”social” can not be strictly separated. It is meaningful, in most cases, to speak about *socio-technical systems*: in fields such as energy, transportation, communication – in fact including a whole range of modern, systemic technologies.

We have found this approach appropriate for the study of fusion: both as an elaborate and large-scale research effort (a ”large technical network”) and eventually as part of large technical systems of energy supply in the next century. This research will profit from theoretical insights from a growing literature: from comparisons with other systemic technologies and from the use of generic concepts, such as ”momentum”, ”reverse salients” (a term borrowed from military terminology), ”complexity” and ”trust”. In addition, social and technical complexity puts demands on the institutional and regulatory framework surrounding fusion, relating to issues such as proliferation, safety, energy supply, environment, industrial policy etc. In these fields, there is strong dependence on specialised knowledge, raising issues of understanding and transparency in governance. In particular, the potentially favourable characteristics of fusion need to be appreciated by decision makers, often in quantitative terms, raising issues of reliance upon technical experts.

Closely related to large and complex technical networks in research is the modern concept of ”megascience”. The OECD Megascience Forum has defined a megascience project 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 needed to carry it out.*”[1]. 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. As will be argued later, there are good reasons to regard fusion research, in Europe and world-wide, as a megascience effort.

[1] OECD (1993) Megascience and its Background, THE MEGASCIENCE FORUM, p 52.

Three aspects have been stressed in the present Macro Task: the international and long-term character of the research and development, the interplay between international and national research priorities and the governance issues encountered in the national context.

1.2 The research system

With a remarkable consistency, the fusion research effort is discussed, financed and implemented on a European level – and to an increasing extent on a multicontinental basis (ITER and beyond). Research policies in participating countries have to work in harmony with priorities set on an international level. How the interplay between the national and the international has worked out in practice is a major research aspect in this task. Through a broadly distributed questionnaire, attitudes and positions in the ”fusion community” open up to analysis. One can find important differences in outlook from different Associations, which can partly be explained by size, research orientation and financing structure. To some extent also, the international character of the effort has protected some research groups from national competition: at times a source of jealousy. Study and comparisons then zoom in on Sweden, a long-standing but rather small participant in the effort. Certain comparisons have been made with Germany, a large player with three Associations.

1.3 Politics – and the question of governance

Two, relatively limited, studies in this task take on the issues of political acceptance and policy vis-à-vis fusion. Evidently, the role of fusion in a public discourse (e g in the press) has a bearing on policy making and political decisions: in short what is often called ”governance”.

With Germany as an example, key actors in this process are identified, together with their strategies and their potential for consensus or disagreement. Political actors such as the major parties, commercial actors (with the nuclear industry in the lead), and trade unions are seen as actors. An attempt to achieve ”energy consensus” 1991-1993 failed mainly because of controversy around fission nuclear power. By studying the press and other public sources, it appears that fusion could not be disengaged as an issue from this background. However, the distinct differences between fission and fusion tend to be more clearly recognised. Also, the increasingly international collaboration of fusion research seems to be recognised as a decisive factor in terms of governance of this large technical system.

A related study (in fact a discussion paper) from the UK focuses on the safety and environmental potential of fusion and how this can translate into decision making of regulatory agencies and policy makers. Using a framework developed for other purposes (related to fission) one can arrive at a systematic array of issues. Regulatory concerns are primarily related to economic and technical issues and they should, according the authors, be strongly favourable to the case of commercial fusion power stations. However, intermediate fusion devices are likely to be expected to meet high demands, being new and experimental. Policy making has to take into account a wider range of issues, such as perceptions of unfamiliarity, accidents, hazards and the technology being ”imposed” from above. The paper stresses that risk communication directly to the public or layman is complicated and can even be counter-productive.

1.4 Micro Task Reports

The following three studies are part of the Task (S1), and will be published separately as Micro Task Reports.

(GSF)

Sandström, Ulf, Benner, Mats and Sandén, Henrik (with a contribution from Persson, Olle): *The Global Scale of Fusion – European Labs and Opinions in Comparative Perspective.* Department of Technology and Social Change, Linköping University, Linköping, Sweden. (150 pp) January 1998

(DEG)

Bechmann, G, Lessmann, E, Rader, E: *Fusion in the ”Energiekonsens” debate in Germany*. Interner Bericht, Forschungszentrum Karlsruhe, Karlsruhe, Germany (10 pp). November 1998

(GBG)

Cook, Ian: *Final report on safety and environmental considerations relating to fusion governance issues*. EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxfordshire, UK (12 pp). December 1998

Obviously, (GSF) is the larger of the three reports both in terms of volume of reporting, and the amount of manpower behind it. Hence it dominates the present Macro Task Report. Chapters 4 and 5 take almost all their content from that study. Chapters 2 (on methodology) and 3 (dealing with Governance) cover results and observations from all three studies.

As the reader will notice, I have included a theoretical discussion on key concepts such as large technical systems, complexity and megascience. This is done in order to put the, admittedly limited, results from the first short round of empirical research into a wider frame: as ”research on research”.

References given in the reference list and in footnotes are only those needed to support this summary report. For full documentation and references the reader is referred to the above-mentioned Micro Task Reports.

2 Theory and methodology

2.1 Large technical systems

”Large technical systems” has become a household concept, not only among engineers, but increasingly also among historians of technology and social scientists taking an interest in technology and science. Much of the credit for the latter fact should go to professor Thomas B Hughes, whose book *Networks of Power* (1983) has inspired a still growing body of innovative research. The key point that should concern us here is that this whole research shows that the ”technical” and the ”social” can not be strictly separated. It is meaningful, in most cases, to speak about *socio-technical systems*: in energy, transportation, communication – in fact including a whole range of modern, systemic technologies.

One distinctive feature of LTS thinking is that rather than the tell-tale inventor, the *system-builder* becomes the hero of history. The need to *enrol* other actors and interests to the system expansion, and the ability to control social as well as technical links throughout the system are distinctive in this respect. Also, one can often see that a system works up its own *momentum*, in the sense that direction as well as expansive power are rather well defined from the system’s past history. It is often observed, however, that in the process of expansion *reverse salients*, weakened sections of progress, develop. They have to be handled by way of technical, legal, organisational etc. change in order for the system to thrive and expand. Finally there are remarkable differences in *technological style*, sometimes between countries, sometimes between related technologies. These signify preconditions for technical change that can not be ascribed to technological properties alone.

In the field of history of technology, Hughes’ work marks a definitive break away from the (sometimes, but not always, amateurish) tradition of writing such history in terms of particular technical artefacts: ”nuts and bolts”. In a volume that marks the start of a wider application of LTS thinking, the editors make the following declaration (Mayntz, Hughes 1988):

> Social science research on technology has long focused on the development, diffusion and especially the consequences of specific, isolated technologies or technical artefacts: the steam engine, the automobile, the telephone, the computer, etc. More recently, it has been recognised that an important characteristic of modern technology is the existence of complex and large technical systems – spatially extended and functionally integrated socio-technical networks such as electrical power, railroad, and telephone systems. These systems have played a focal role in the process of industrialization and economic development, and contributed to significant changes in life style. Aside from undoubtedly beneficial effects such systems are also creating

> problems – negative externalities, the risks of failure and disaster, management, control and coordination problems. Thus a new field of research is emerging where historians and social scientists have started to cooperate in the analysis of the development and functioning of large technical systems.

At first look, the use of the key terms ”large”, ”technical”, ”complex” and ”system” seem to create little difficulty. As long as they are used in a broad, non-technical way this is no doubt true. However, in order to create reliable ground for generalisations beyond semi-trivial analogies, stricter definitions are needed.

For the specialised discussion of these conceptual and epistemological issues I have to refer the reader to a well-informed and temperamental article by Bernward Joerges (Joerges 1996, with an extensive bibliography) and to three books on Large Technical Systems rich in theoretical as well as empirical content: Mayntz and Hughes eds. (1988), LaPorte ed. (1991), Summerton ed. (1994).

A problem that presents itself when ”system” is used more analytically, is whether one can specify the relationship of the systems under discussion to their environments. Are LTS’ *responding* to forces ”outside” themselves? Such forces can be science push, market forces (”pull”), international competition, political and regulatory exigencies, even profound cultural factors. Or do LTS’ rather *shape* their environments: define scientific problems, create their markets, destroy their competitors, enlist state agencies, shape cultural meanings?

A useful distinction, first made by Joerges (Mayntz and Hughes eds., 1988), comes from the need to keep clear lines between LTS and various forms of subsystems. Two variants can be seen, posing rather different problems, namely large technical networks (LTN) and large technical projects (LTP). Typical LTP:s are the space shuttle program, the Cabora Bassa dam; the classical example is the Manhattan project. Typical LTN:s, on the other hand, are large infrastructural systems (canals, railroads, electricity grids, telephone etc.) They blend sometimes in research projects such as SDI, Eureca, Esprit etc. (Joerges puts ”the fusion reactor” in the LTP category.)

A part of LTS research has been strongly influenced by ”social construction”. Since a rather long time social scientists recognise that there is always an element of social agreement in the understanding of social phenomena. When the same kind of thinking is applied to technology, by many considered the most ”objective” reality of all, even modest attempts to point out ”interpretative flexibility” tend to be controversial. Some researchers go very far in this direction. For instance ascribing to technical artefacts some degree of ”acting” on their own is one such direction (Latour 1987). Another is the assertion that technologies do never really ”exist” outside of our interpretations of them, and these interpretations can be made very freely. It has been pointed out that the constructionist position may be more provocative in science studies than in technology studies. Everybody can, to some extent, agree that technology, as a man-made artefact, is a construction. The affront increases if this is applied to nature: when it is claimed that there is no distinct form of reality ”out there” to be found out by the scientist.

A key work in technology studies is the book *The Social Construction of Technological Systems* (Bijker, Hughes and Pinch 1987). This book and the accompanying ideas are often referred to as SCOT. In spite of some exaggerations, a lasting insight is that technological systems have to be understood as socially constructed – to some extent.

2.2 Complexity

Part of the research under the LTS heading, though not all, puts the issue of *complexity* at the centre. Clearly some large systems are not complex at all, while some small or modest-sized systems can be very complex.

Characterising a system as ”complex” can be done in many ways. It seems to be somewhat easier to describe ”increasing complexity” than complexity itself: a growing number of components, increasing variations in interrelations, overlapping subsystems, causation becoming less and less clear.

It is almost trivial that complexity raises new challenges to *technological* understanding. Many research projects pride themselves with this term in the title. But challenges are combined: interwoven with political, social and psychological aspects.

Let us listen to two sharp observers from outside technology. The first is the Finnish philosopher Georg Henrik von Wright (von Wright 1989). He stresses the fact that modern socio-technical systems are difficult to comprehend: obviously for the general public, but for specialists as well.

The keyword for the ideational tradition to which von Wright belongs, is *reason*. The original, still valid base for reason is a usually tacit assumption that it is possible, without assistance of supernatural authorities, to comprehend the meaning of our world and its intrinsic order. This is the belief in an inherent *intelligibility*, a comprehensibility of the general scheme of things. On this foundation rests everything that justifiably can be given the name of science.

Further, there is an indisputable link between comprehensibility and democracy. The democratic form of government rests on two assumptions: that the average citizen can make up his own mind on questions that concern him and his future, and that he can foresee the consequences of his actions sufficiently well to take responsibility for them. An analysis of our highly technological, specialist-dependent and mass-media-influenced society leads to deep-lying doubt, summarised thus by von Wright himself:

> ”It is possible that the complications of the industrialized and technified society are so great, that democratic participation in the public decision processes in the long run *must* degenerate to an empty formality of either assent to, or protest against, incomprehensible alternatives.”

The entire reasoning orbits the question of comprehension, and von Wright is fairly pessimistic on that point. That the situation cannot be remedied by abandoning reason in its classic sense, is the most profound ingredient of the writer’s message. Comprehensibility remains a basic value.

The second voice belongs to Torsten Hägerstrand, world famous Swedish geographer, now retired.

> ”Complexity has perhaps a negative ring for most people these days. It suggests something complicated and hard to handle. In fact, though, I think one should have the right to distinguish between that which is *complex* and that which is *complicated*. It is not the first time such a distinction has been made. There are complex realities which there is every reason to concern oneself with and which one can very well learn to understand and live with. Cultures are complex realities like this, as are the societies formed by plants and animals together. And the human individual, taken as a whole, is another complex system. But the complicated is something else – difficult to grasp, involved, unpredictable. What is inherently complex, it would seem wisest to let remain complex. The complicated, however, is another matter.
>
> My thesis here is that modern technology taken as a whole does not understand the complex, especially when the complex has living components. I believe that one can sum up the problem concerning present-day technology by saying that it is a narrowly conceived and insensitive technology with an accompanying organisation permeated by the same spirit, threatening to cut the grass from under the feet of important things which are genuinely complex and which must remain so in order for human life to be preserved. When it comes to this type of limitation of understanding, technology goes hand in hand with the major part of the exact sciences. Usually there is no thought of this, because of the enormous achievements of research. There is no harm in emphasising, however, that the exact sciences have hitherto concentrated on simple systems or on such systems as can easily be analysed in simple components. Important comprehensive systems are not reducible in this fashion.”

Bernward Joerges (1996) has investigated the treatment of the complex – ”the discourse of complexity” – in a large body of literature. He finds, not surprisingly, a lot of ”empty talk” and inflationary use of the term. One should thus beware of ”complex-speak”!

On the other hand, systemic complexity seems, in spite of a certain vagueness, to hold a promise that similar questions can be asked across very different intellectual fields and address very different subjects. A main distinction may be between two kinds of systemic complexities: one that are close to technical, meaning that systems may be approximated through modelling and simulation, the other non-systemic complexities where difficulties lie more in conceptualising the whole and ”variables” of ”co-ordinates” are not easily found.

2.3 Megascience

Since the beginning of this century the development of scientific research has changed dramatically. The scientific research of today often implies more of political and economic aspects than earlier, which as a result has transformed the role of the researcher. The necessary scientific instruments are becoming increasingly complex, long termed and expensive, and the financing must nowadays be legitimised by different actors. In order to create a better understanding of these kind of large scale projects, we use the concept of *megascience*. In very short words, 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 a megascience project 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 needed to carry it out.”*[2]. 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 sited or distributed. 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. These kind of projects are represented by, for example, climate or ocean observation programmes (World Climate Research Programme, WCRP, International Geosphere Biosphere Programme, IGBP, etc.)[3] Fusion represents, in this respect, a mixed case: to some extent fixed sited, in other respects distributed (e g in Europe, to many Associations). Although one has not arrived at a universal definition of megascience, it does provide a basis for examination.

Big science was a fairly unknown phenomenon until after the second world war, although the phrase was not coined until the 1960s. According to E.K. Hicks and W. van Rossum (1991), this kind of 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*, which was the name for the US effort to produce an atomic bomb during World War II. These kinds of projects involved large interdisciplinary teams of engineers and scientists, and the industry, which had a central role. The governmental direction and funding were however essential to the subsistence of the actual project, and the government became structurally involved as the main financier. When the government entered the field of big science and became an

[2] OECD (1993) Megascience and its Background, THE MEGASCIENCE FORUM, p 52.
[3] The OECD Megascience Forum, (1995), p 66f.

important actor in the development of large scale projects, the former laissez-faire policy approach was dropped. Consequently, scientific efforts on large scale project became dependent on governmental support, thereby loosing some of its former autonomy.[4]

W.D. Kay discusses the problem of political legitimacy in his article *Democracy and Super Technologies*.[5] According to his observations, these kinds of new 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.[6] For example, the Apollo moon landing was described as ”the most important event since the creation.” Similarly, proponents of fusion have described the development of fusion power as equivalent to the discovery of fire. These sort of statements or descriptions are intended to achieve public acceptance and thereby legitimating large, long term costs. However, the enterprise of gaining public support can be hazardous in case of setbacks (delay, breakdowns, etc.): the public are prone to see these problems as total failures. This comes as a result of their enormously high expectations, and they often do not have patience nor the reliance to overlook the more or less natural setbacks of a scientific project. For the proponents, e.g. the scientists, the situation is difficult to handle; it is necessary to gain public and political acceptance, yet creating 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.[7]

In the early years of fusion science, the fusion researchers laid it down that a viable fusion reactor would be constructed within the near future (20-50 years). Slowly, it became apparent that this promise would not be fulfilled; the researchers had run into serious difficulties on several fields, and the fusion power problem appeared to be more complicated than first assumed. The consequence was a delay which most likely 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.”*[8] 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 for their field.

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[4] E.K. Hicks, W. van Rossum. Policy Development and Big Science, p. 1ff.
[5] W.D. Kay. (1994) ”Democracy and Super Technologies” in SCIENCE, TECHNOLOGIES & HUMAN VALUES, Vol. 19 No 2.
[6] See The OECD Megascience Forum, (1995), p 66 ff.
[7] W.D. Kay. (1994), pp 135-140.
[8] 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, must have a legal framework for defining the conditions for the collaboration. This is necessary in order to guarantee sufficient long term commitments from the national actors. 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 presence 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 presumed gain will not be observed until many years from now. In other words, the political actors have little incentive to allocate large resources to long term projects when the observable profit lies 50 years in the future. As a result of the political system, they find it more attracting to invest money and political prestige in short or medium term projects. This is of course most apparent when the proposed long term project holds a certain amount of risk of failure.

In the publication by *The Megascience Forum* (1995), important aspects of megascience and national decision making processes are extensively discussed. Projects of magnitude, based on international co-operation, implies a complex decision making. The decision making do not follow a linear sequence, rather, it is interactive and must respond to changes in the scientific, technical and financial situation. Since such a project holds many different actors (political actors, scientific actors, national actors, funding agencies, etceteras), it is hard to reach to a rapid consensus in the operation.[9] The decision making process for megascience is thereby somewhat irregularly structured and difficult to comprehend.

2.4 Surveying the Associations

A system-wide study should in principle cover all 18 Associations of the EURATOM. In spite of their equal footing in a formal sense, it is clear that an analysis of attitudes and other judgmental issues in the Associations is very much helped by a certain categorisation.

The research has led to the idea that four categories can be used to describe and understand the behaviour row pattern of research units and labs. These categories are *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; then institutional setting split in two: university department or institute department. For instance NFR (the Swedish Association) can be categorised as medium aged, small and covering all different lines of orientation. The actual research work is mainly university based. IPP (Garching, Germany) is considered as old, large and mainly experimental and theoretically oriented. The research performance is institute based.

[9] The OECD Megascience Forum, (1995), p 85.

The main research tool was a questionnaire on fusion research and ITER. It was intended to investigate the current situation in the European Fusion Programme, as described by the fusion research leaders.

The questionnaire focuses primarily on the variances in attitudes. It includes different groups of questions, that is, identification, trajectory of the lab, resources, activities and attitudes. The main focus is on the researchers' attitudes on questions related to ITER, EURATOM, future research challenges, etc.

In order to locate *fusion research leaders*, a request was send to Heads of Research Units within European Fusion Programme, asking for names and working addresses of relevant persons (not including JET nor other joint labs). 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, and the response rate was 97 (i.e., 52.5 %). The answers were not evenly balanced in terms of national belonging, and in some cases countries are not represented at all (France and Greece). Nor were memberships of the associations evenly represented; for example, only 15 percent of the KFA-Jülich (Germany) researchers responded.

2.5 Case study: materials and methods

Case studies were conducted in two countries with the aim of collecting information focused on three main research questions: 1) Attitudes (national motives for international research collaboration); 2) Co-ordination (differences in institutional set-up and conditions for research groups); 3) Collaboration (national patterns of collaborations between researchers).

In (GSF) it was decided to conduct case studies in two countries that ex ante seem to be radically different on several dimensions – Germany and Sweden. 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 data bases 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 research”.

For the Swedish case study there was the opportunity to use the following types of material:

(*i*) Bibliometrics (INSPEC database);

(*ii*) Research Council project data base (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 going on on the national and international arenas. The first use mentioned are of fundamental importance for the case studies. Bibliometric data have given a hint about were to start, which people to contact and were 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 (GSF) 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 draw-back is that INSPEC only gives information on first author addresses, but using the on-line service it has been possible to pick out information form 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 data base (NFR);

The Swedish Association NFR has a project data base 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 economic and administrative. No scientific information is collected, except research field and project title. But data from other fields of research were also available to the researchers. Hence it was 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.

(*iii*) Material from the Questionnaire;

The questionnaire has already been described and discussed above (2.4). 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. Its main focus is on the researchers attitudes on questions related to ITER, EURATOM, future research challenges, relations to politicians and to other physicists (the inward, outward and international dimensions).

(*iv*) Documents from the Swedish Association (NFR);

The material includes minutes from meetings in the fusion committee of the Swedish Natural Science Research Commission (NFR), the Consultative Committee for the Fusion Programme (CCFP) and the JET Committee.

(*v*) Interviews with research group leaders;

When investigating the Swedish case, interviews were conducted with the following types of informants: research leaders or principal investigators at NFR; research administrators at NFR; and other physicists in the NFR committee for physics. In total, 11 interviews were made.

2.6 Mapping the debate (Germany)

The investigation (DEG) was to a large extent based on document study and selected interviews. The study of ”energy consensus” with involved actors, representing the major positions in the discussions:

Nuclear Industry

Political Parties: CDU/CSU, Green Party and SPD

The Trade Unions

An important part of the study was based on a *media analysis*, which provides a momentary picture of the current public discussion of the issues revolving around nuclear fusion. For the purposes of the media analysis it was decided to research the keywords ”Energy consensus” and ”nuclear fusion”. Searches were restricted to the period 1993-1998. The study could use full-text press data bases (DBI) for most national newspapers, weekly periodicals (e.g. Focus) and specialist periodicals. During the course of this, we were provided with roughly 900 articles. The press archive of the IPP was also at the researchers’ disposal.

2.7 The fusion/governance interface (GB)

The key issue in this discussion paper (GBG) is whether, in the deliberations of lay decision-makers, the safety and environmental advantages of fusion can compensate for the governance problems which may arise from fusion’s novelty, technical complexity and dependency on specialised knowledge.

In order to avoid unconscious bias in favour of fusion, a framework of reference available in the literature (Högberg & al, 1996) is strictly adhered to. Hence the issues are considered in two distinct ways:

(1) Evaluating fusion against the main concerns which have appeared in public debate in European countries over the past decades, and which can be most readily stated and discussed in quantifiable form

(2) Evaluating fusion against the much-less-analytical and intuitive factors which experts in risk perception and communication have concluded determine the attitudes of the public to the risks of new technology.

Issues of fusion governance can conveniently be divided into two categories:

- Decision-making by regulatory bodies, public administrators and utilities.

Such decision-making relies primarily on the quantifiable(technical and economic) factors described under heading (1) above.

- Decision-making by policy makers.

Such decision-making takes into account also the much broader issues considered under heading (2) above.

3 Governance

3.1 Energy Consensus in Germany

Fusion research has the aim of providing fusion power plants as a source of energy supply to supplement fission reactors in the future. The acceptance or lack of acceptance, of a technology is determined largely in a societal process of communication, its actual shape, and the groups of societal actors who influence it.

In Germany, the discussion in energy policy has in recent years been centred around the debate on the *energy consensus*. This is where the strategies and conditions of a societally acceptable energy policy are formulated. Fusion is also part of this comprehensive debate. Its acceptance depends to a great deal on progress in the debate on energy consensus. For this reason, we start by analysing this process.

Under the sign of the impending global climate catastrophe and the claimed advantages of nuclear power plants with respect to the greenhouse gas CO_2, the nuclear industry launched a new offensive in 1991. The call for a basic consensus on energy policy was its own idea. The Federal economics minister at that time, Möllemann, gratefully adopted the idea. While the motivation of the power utilities was to avoid further losses for nuclear investments, the Economics Ministry, in harmony with the nuclear lobby, emphasised how essential nuclear power supply was. In the ”Energy Programme for a United Germany”, the only social innovation was the call for a ”non-partisan consensus” and it also contained the announcement of the ”setting up of a commission consisting of independent personalities”. This was intended to contribute to the co-operative clarification of consensus opportunities and produce options for long-term strategies in energy policy. The commission was unable to commence its work at the beginning of 1992, since neither the Bundestag nor the Federal Government had approved financing for its work.

There were widely differing positions in the electricity industry. The use of nuclear power is regarded as essential by the Bayernwerk, Preussen-Elektra and south-German members of the VDEW. They were opposed to both the abandonment and a time restriction. In contrast, the boards of the RWE and VEBA adopted a more strategic approach. For them the decisive question was: how can the SPD revise its Nuremberg decision on the abandonment of nuclear power without losing face? How could the social democrats gain distance from their anti-nuclear programme without losing credibility among voters for all time? (Support for phrasing this emerged from the top floors of the IG Chemie and the IG Bergbau (the chemical and mining trade unions). In their common guidelines for energy policy, these trade unions called for a change to ”safe” nuclear power plants, and for a final decision on the issue of final storage of nuclear waste.) The letter from the managers in the electricity industry to Chancellor Kohl, written on 23 November 1992 and published in the press in December 1992, contains not only the demand for a

”non-partisan consensus on nuclear energy”, but also a list of topics which had been negotiated with the SPD-strategist Schroeder.

During the Summer break, Minister president Schroeder probed whether any approximation of points of view was possible. On 25 October 1993, after 5 rounds of very complicated discussions, the consensus discussion finally broke down. The SPD refused to discuss the future use of nuclear power with the government coalition. In November 1993 the societal groups were informed of the breakdown of the talks. The discussions on the energy consensus were the last outstanding event trying to achieve a common energy policy in the Federal republic of Germany. A second attempt to develop some kind of guiding vision for long-term energy policy also failed.

The debate on fusion must be viewed against this background. It does not represent separate political matter, depending rather on energy policy in general. For the most important actors in energy policy too, fusion merely plays a minor role within the overall framework of the general option pro or contra nuclear energy. To this extent, one should view the results of the media analysis and expert interviews in the context of energy policy in general.

The *media analysis* provides a momentary picture of the current public discussion of the issues revolving around nuclear fusion. Greifswald provides the focal point for this, since there is currently a controversy on the actual project here. The analysis revealed that there were four main causes for reporting on nuclear fusion during recent years:

Discussion on the immanent decision on (1) further procedure on the construction of Iter, (2) the success of JET by producing a record value of fusion power in 1997 (3) in Greifswald, the laying of the foundation stone for the construction of the fusion research facility Wendelstein 7-X on 19 June 1997 (4) the Energy Research Conference of the Minister for the Economy of the Land Mecklenburg-Vorpommern of 25 and 26 August 1997.

The laying of the foundation stone led to a renewal of the debate on whether fusion research is sensible and thus worthy of support. The controversy took place mainly during the conference on energy research. Particularly remarkable is the fact that the State of Mecklenburg-Vorpommern, including the local SPD, wishes to offer Greifswald as the site for ITER, while the Federal SPD has a sceptical or negative attitude towards the option of nuclear fusion.

”There is need to probe further whether nuclear fusion is an alternative” demanded the Hamburg Senator for the Environment, Fritz Vahrenholt (SPD) at the energy research conference in Greifswald. Vahrenholt also remarked that he considered Greifswald as a suitable location for the international research reactor, ITER. With this clear statement in favour of nuclear fusion research and of ITER, Vahrenholt departed from the previous course of the SPD. If Europe desires ITER and Germany wishes nuclear fusion and ITER with the rest of Europe, then one should stand by this viewpoint.

Further developments were hampered mainly by the high costs. There has not yet been any decision on the distribution of costs between guest and partner countries. Scientists insist on the construction of Iter, if at all possible on the Greifswald site.

3.2 Safety and environment in fusion governance (GB)

Issues of fusion governance have for purposes of the discussion been divided into two categories:

- Decision-making by regulatory bodies, public administrators and utilities.
- Decision-making by policy makers.

Decision-making by regulatory bodies, public administrators and utilities is related primarily to technical and economic issues. It is clear that the purely technical safety and environmental factors are strongly favourable to the case for commercial fusion power stations. These factors should turn into the tangible advantages of it being easier to obtain legal consents for the construction, operation, decommissioning and disposal of commercial fusion power stations. Financial considerations are another vital consideration for utilities: here the balance will depend upon whether limits have been placed, by the policy-making authorities, upon carbon dioxide emissions and/or fission power.

For intermediate fusion devices (e.g. ITER), there are additional factors. If developed in the near term, such devices cannot gain the safety and environmental advantages of using low-activation materials. Moreover, being new and experimental, they are likely to be expected by regulatory authorities to satisfy a particularly high burden of proof in supporting their claims.

Decision-making by policy-makers has to take into account a wider range of considerations, especially the major non-technical issues of public risk communication and risk perception. In this area, the main points appear to be as follows.

- Fusion technology labours under the difficulties of being unfamiliar and, like fission, being imposed, not under the individual’s control, and man-made.
- However, the following points are very positive, provided they can be communicated effectively:
    - major dreaded accidents are impossible;
    - unfair burdens (waste management problems, global climate changes) are not immorally placed upon future generations.
- Fusion benefits from the fact that there has been no experience of even the most minor hazards from fusion devices. It is important to keep things that way.
- It is difficult to influence public perceptions of fusion by a risk communications approach stressing the much lower risks of fusion, without generating public fears at the same time. This problem arises because giving a lot of explanation of a complex technology usually increases

the fear of it in the public's mind, even if the point of the explanation is to show that the risks are very low.

- It is of the utmost importance that the public's first experience of a real fusion power device (e.g. ITER) should be strongly positive, from the safety and environmental viewpoint, and the design must secure this.
- Various factors suggest that fusion should seek to explain itself primarily to prominent persons widely regarded as trustworthy, rather than directly to the public or media.

3.3 Government and scientists taking several stands (S)

This section deals with the question how fusion research has been discussed within different fora in Sweden.

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 of the arrangement. From a political perspective, it was no longer easy to legitimise increased costs on fusion research. When Sweden became a member of the European Union in 1995, the internationalisation process formally began. 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 whether other sources of energy should be supported at 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.[10]

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.[11] The initiative was supported by Vattenfall, which is Sweden's most important utility company and besides the owner of Studsvik. Up to 1992 Vattenfall was a State-owned company, and its supportive position on the hosting the ITER reactor had a substantial influence on the governmental attitude[12]. The Department of Education and Science also assigned the Assistant Under Secretary Anders Karlqvist to investigate the conditions for hosting ITER[13]. 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 involve favourable spin-offs on

[10] Department of Education and Science, 1995-10-30.
[11] See Studsvik Report/NS-91/84, and Studsvik Report/NS-93/4.
[12] Interview with Swedish fusion research leader.
[13] Anders Karlqvist (1994), Förläggning i Sverige av den internationella fusionsforskningsanläggningen ITER.

other technological disciplines.[14] 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 the election of 1994 resulted in a change of governing parties, all this came to an end. 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.

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 argued that the research on fusion must be restrained. According to their perception, the international collaboration 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.[15] 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, argued that production of destructive weapons does not lie in the nature of fusion. Instead, he emphasised the great potential of fusion power, which in time will be able to succeed nuclear power.[16]

During the last phase of the Cold War the arguments based on fear of the destructive potential of fusion were more or less deserted in the public debate. In 1987, the arguments against fusion research were only 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 have been one of the most important initiators of this debate. In his article, Professor Lidsky (Massachusetts Institute of Technology, MIT) criticised the continued research on magnetic confinement fusion. According to him, this approach was not only extremely expensive but also technologically inadequate. Lidsky also mentioned the possible use of fusion for military purposes, but as the debate in Sweden evolved, this matter was left aside.[17] A Swedish physicist at the National Defence Research Establishment (FOA), Erik Witalis, supported these arguments, stressing the importance of finding new methods of confinement. The ensuing debate focused little attention on the political aspects of fusion research; instead, it concentrated on how the research was performed. Later, this topic was further debated when the question of building the ITER reactor became more urgent.

In the present debate, ”ethical” arguments against fusion are rare. As the memories of the cold war fade away in the mind of the public, the connection between fusion and

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[14] Interview with Swedish fusion research leader.

[15] A referendum in 1980 decided on a gradual phasing out of all nuclear power plants. See e.g. Ivar Franzén, ”Fusionskraft lika illa som kärnkraft”, Dagens Nyheter Debatt 1986-07-16.

[16] See Bo Lehnert, ”Fusionskraften är ett miljövänligt alternativ”, Dagens Nyheter Debatt 1986-08-12.

[17] See Lawrence E.Lidsky, ”The Trouble With Fusion”, TECHNOLOGY REVIEW Vol 86 (Oct. 1983), pp 32-44.

military research is progressively weakened. The opponents of fusion focus rather on the time aspect, claiming that fusion energy is too much of a long term project to solve the environmental problems we have today. Moreover, they feel that fusion research continues to receive 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.[18] 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. [19]

[18] See, e.g., Fredrik Lundberg. ”Stoppa forskningen om fusionsforskningen”, in DAGENS INDUSTRI 1997-08-04.
[19] See, e.g., Mikael Fridenfalk and Jan Stenis. ”Fusionsforskningen är nödvändig”, in DAGENS INDUSTRI 1997-08-11.

4 The fusion research system: an analysis of attitudes

4.1 Background of the study

The reason for composing a questionnaire on fusion research and ITER is to investigate the current situation in the European Fusion Programme, as described by the European fusion research leaders. Its purpose is to give information about attitudes and collaboration patterns, focusing on the ITER collaboration. The study intends to expose the fusion research system on a higher, international level. Thus, it expands and balances the forthcoming case study investigations.

The questionnaire includes different groups of questions, that is, identification, trajectory of the lab, resources, activities, and attitudes. Our preliminary focus is on the researcher's attitudes towards certain statements. In order to perform a systematic analysis of the attitudes, the statements have been divided into five different groups of significance. In this categorisation the groups are also discussed in terms of inward, outward and international dimension. First, the perceived obstacles and hazards for fusion research are discussed and analysed. This includes questions on political and scientific perspectives on fusion research, as well as aspects of future problems. Second, a few attitudes on collaboration are scrutinised. In this context, the attention is on EURATOM and the international dimension of collaborative research efforts. Third, the analysis concentrates on issues regarding power and influences on the field, stressing the role and position of the political actors. Fourth, the attitudes towards the general research directions are analysed. This section discusses how the programmes' priorities and stipulated research efforts are accepted by the fusion researchers. Finally, the analysis includes a section on the fusion researchers perception of relations between fusion and other branches of physics.

The first, third and fifth group of questions corresponds to an *outward* dimension of the global system of fusion research, the fourth to an *inward* and the second to an *international* dimension of fusion research.

4.2 Background variables

As mentioned above, the questionnaire used several background variables. A major ambition has been to arrive at a valid classification of research units according to their orientation in three classes: theoretical, experimental and technological. In our material technological orientation is the largest (40%). We identified 22 as theoretical and 34 as experimental.

Most of the fusion research units have been in the field for a long time. It was found that almost half of the respondents were active in labs that started before 1970. Medium-aged (1970–1987) were almost 30% and young labs 20%.

Size of the lab was found to be a interesting variable in our analysis. Units were classified according to their associations' annual budgets (small, medium and large). We also asked for lab budget and from this we constructed three groups called ”Economy class”. Class A had less than 1MECU, class B had 1-10MECU and class C at least 10MECU in their respective budgets. The first two groups represent about 37% each among our respondents and the last groups are 25 %. A cross-tabulation with the category ”orientation” shows that most theoretical labs are economy class A.

Another interesting category is called ”trajectory”, which is divided in three groups: growth, no growth and decline. Respondents were asked to answer this question by drawing a figure on the growth (in terms of research staff) over the last ten years. From this we have analysed the answers and categorised them in respective groups. One third belongs to the growth group and one fifth to the decline group. Cross-tabulations with economy class shows that the largest labs are declining and that the smallest are growing. Trajectory were also correlated to institutional setting (institute or university) and significant differences were found: institutes are declining while university based labs are in the growth category.

The collected background gives an opportunity to distinguish between different types of dynamics in labs, e.g. number of doctoral recruitments per MECU in lab budget could be used as a dummy for dynamics. Such analysis ends up with the following conclusion: The probability of finding labs with a high level of dynamics is higher in small, newly established and university-based units than in others. However, the chosen variable for dynamics might be questioned in a research system as the one under study. We will come back to these questions below.

Finally, a category called "productivity" has been formed out of data on publishing activities. This has been put in relation to budget and staff and we found staff-related productivity to be most convenient measure of productivity due to quality of data. Small units are more productive than others. Time period when the lab was established makes no difference. Not even "trajectory" give a distinct pattern even if declining labs tends to have a very low productivity. Theoretical labs are more productive, while experimental labs have lower figures. Technological labs are evenly distributed along this dimension. University-based labs have distinct high values while institute production of papers lies on a slightly lower level. So, the pattern is the same as the one found regarding dynamics of labs.

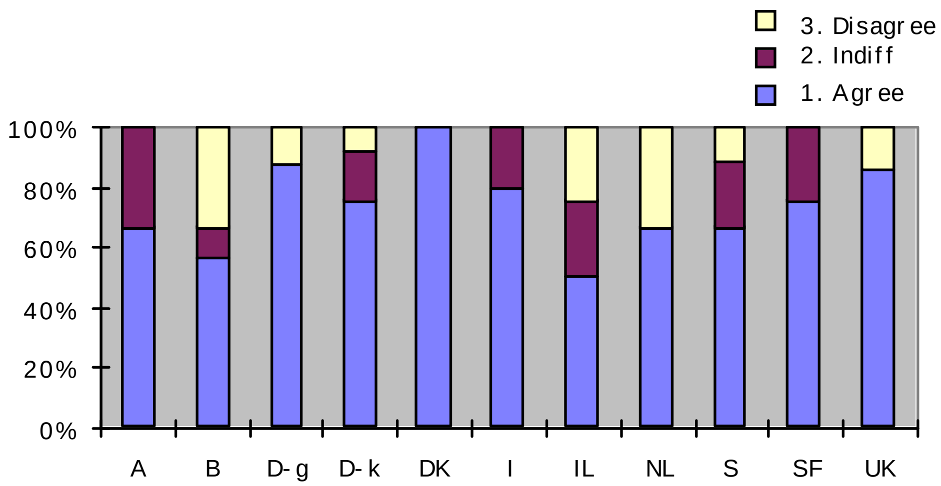
There is, of course a number of problems involved in this analysis. One obvious problem is that we have no data on cost for facilities. Such information will probably explain much of the received results. Another very important problem is that this analysis is unable to detect the systemic aspects of fusion research. The interdependencies and interrelations between different institutional actors (and units) is hard to grasp with methods and data not suited for dynamic analysis. We can easily understand this if we think of the fusion system as a specific division of labour, e.g. between theoretical and experimental labs. The latter might convey numerous efficient experiments which give theoretical labs lots of material for calculations. A comprehensive analysis has to take these systemic relations into consideration, but this is not easily done. It certainly would be a worthwhile effort for a continued SERF-project.

4.3 Perceived Obstacles and Hazards for Fusion Research

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 fusion researchers were asked if they 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%). 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 in declining research labs agree more strongly with this statement than other groups.

Many mention the indecisive behaviour displayed by the American partner, and some suggest 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.

Figure 4.1: Attitude question: ***The management of ITER will be problematic in the future due to complex interantional relations.***



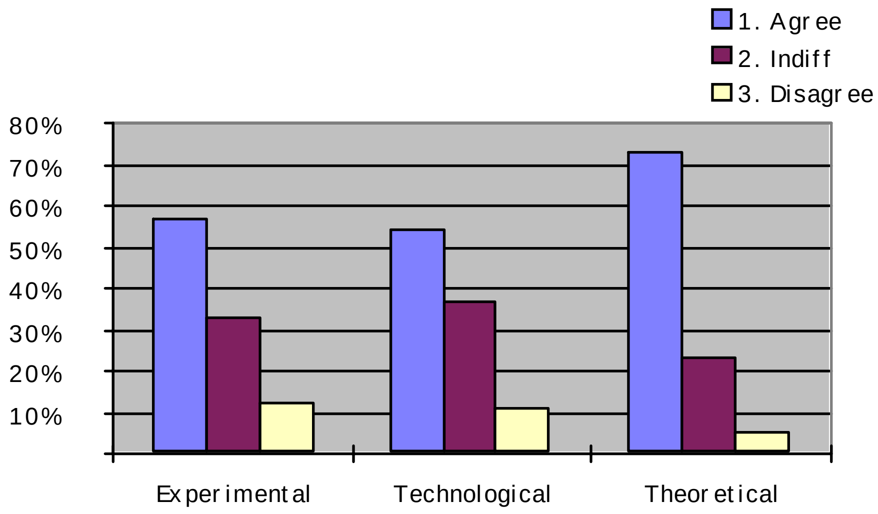
The outcome of the decision on ITER is obviously by many perceived as fundamental to the development of their field. According to the overwhelming majority of the respondents, a serious threat to the construction of the ITER reactor can be found on political and economic grounds. No less than 90 percent 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. According to some research leaders, the uncertainty of political commitment also leads to problems in the recruitment of the next generation of researchers.

4.4 Collaboration and co-ordination

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 on the following statement: EURATOM should support more collaboration with countries within Europe. The reason for including this statement in the questionnaire was to determine the researchers’ opinion of the current level of international collaborative activity. The outcome presents a clear statistical support for the statement (60% agree, 32% are indifferent, and 8% disagree). It thereby indicates a demand for increased efforts in European collaboration. There are no notable 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 proportion of indifferent respondents is a rather large percentage. From a perspective of orientation, a minor variance can be observed: The technology oriented group tends to be very positive to enlarging the internal European collaboration (69% agree, 20.5% are indifferent and 10.5% disagree), while the group of theoretical researchers are mainly indifferent to the statement (45.5% agree, 50% are indifferent and 4.5% disagree). Still, 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 as in the example above, and a majority (59%) feels that the mentioned collaboration should be increased. Again, quite a large group (31.5%) 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 to 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 4.2).

Figure 4.2: Attitude question: ***EURATOM should support more collaboration with countries outside of Europe (i.e. Japan, USA, Russia).***



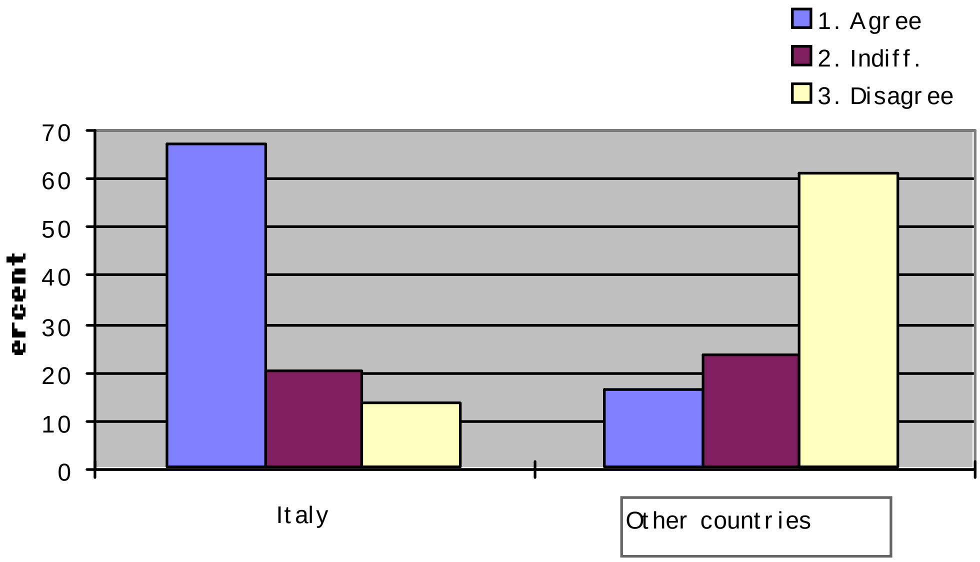
Obviously, researchers of theoretical orientation are rather satisfied with EURATOM's support of collaboration within Europe, but feel that it should be strengthened on the international level. Researchers of technological orientation present a slightly different position: it is more urgent to improve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

To conclude, most fusion researchers of any orientation 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.

4.5 Evaluations

In general, fusion researchers are not in favour of more frequent evaluations and a few of the respondents also question the competence of the evaluators. They imply that more evaluations are acceptable on conditions that they are performed by qualified people. There is little or no 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. As illustrated in figure 4.3, the Italian researchers welcome more evaluations, quite the opposite from other countries.

Figure 4.3: Attitude question***: EURATOM should more frequently execute evaluations of fusions research.***



Although the Italian respondents are in favour of more frequent evaluations they also have the opinion that most evaluations, hitherto, have been more focused on legitimising the whole research effort as such, rather than on its actual performance. People from old units and newly established labs are more willing to accept this opinion. 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.

In this context it is also revealed that most researchers (86.5%) feel that the political actors have difficulties appreciating benefits of large scale, long term research on fusion. In the eyes of the researchers, politicians are primarily interested in short term solutions. 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. These findings seem perfectly logical as these units have come into the EURATOM lately and appreciate the funds that have become available.

Also, the majority feels that experts ought to have a stronger voice in long term policy decision making. 70 percent of the respondents share this request for more power over their field, although some merely stress 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 attitude 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.

When asked whether they find it likely that large scale fusion research projects will be hampered due *to scientific and technological problems*, the answers 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 express the opposite opinion, saying that scientific and technological problems have a good chance of suppressing the progress. As illustrated in figure 4.4 (below), most researchers in Belgium and the Netherlands resist the statement, while the situation is the opposite in Austria, Italy and United Kingdom.

Figure 4.4: Attitude question***: !It is likely that large scale fusion research projects will be hampered due to scietific and technological problems***

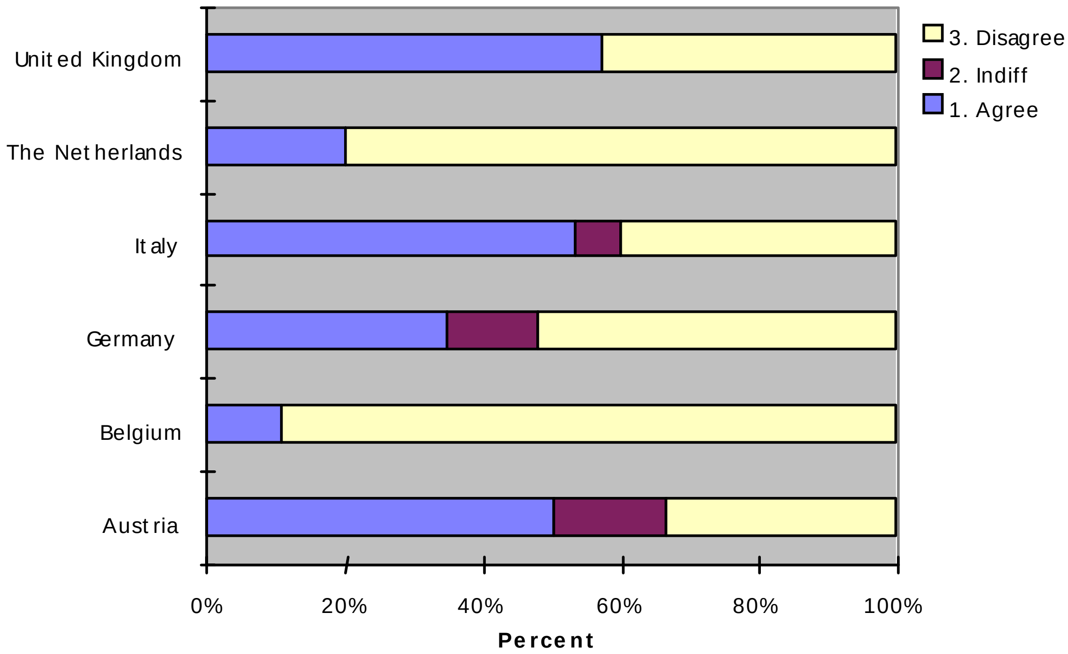
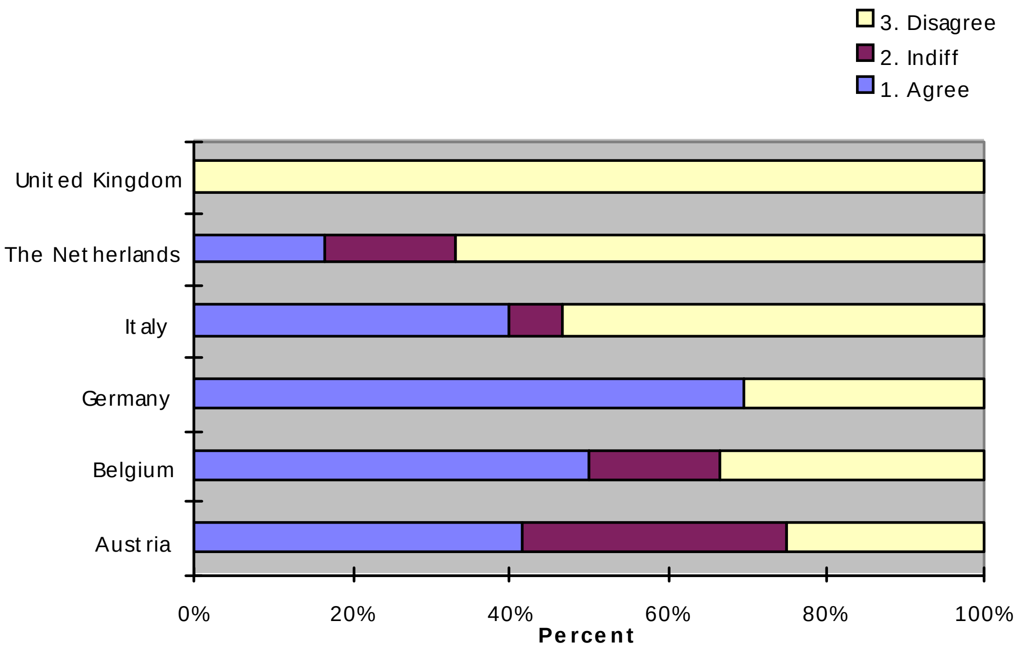


Figure 4.4 exposes a significant national variation regarding the perception of scientific and technological challenges within fusion research. The Belgian and the Dutch researchers seem to have a firm trust in the potential of current large scale fusion research projects, while, for example, the Italians and the British perceive critical difficulties within the field.

In this context, the questionnaire also investigates the question on possible 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 consist primarily of the uncertain evolution of the ITER-project. The attitudes vary among groups according to their orientation; while the absolute majority (52.5%) of the technologists agree to the statement, the absolute majority (54.5%) 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: Attitude question: ***The European fusion programme has been working without any nmajor external disturbances for the last five years.***



The diagram above illustrates 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 and 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 sensitive to such problems.

To sum up, the feeling of 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.

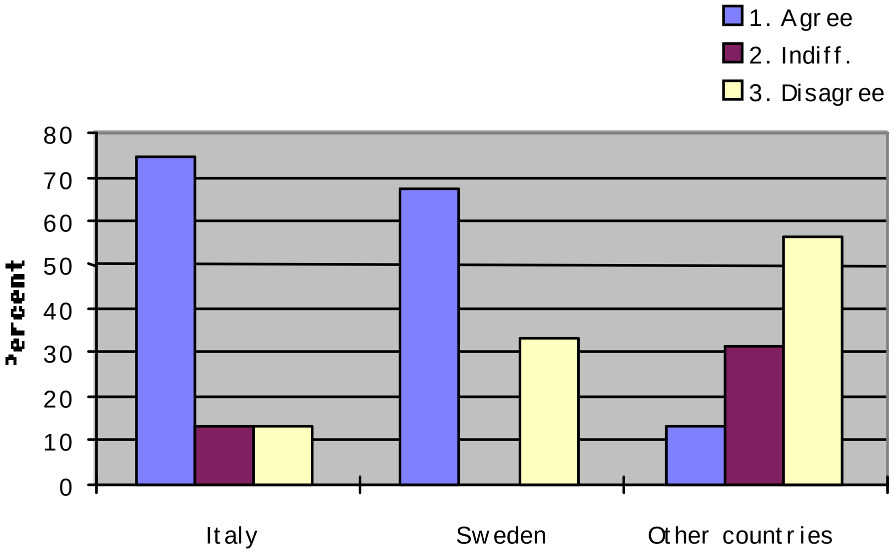
4.6 Research Directions

According to the investigation, the general belief among the fusion researchers is that the common programme has run rather smoothly from an internal perspective. Two out of three respondents held this belief, while only 19 percent took 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. We find that the UK research leaders are a bit more critical towards the internal management, probably due to these problems.

Although there is some deal of discord amongst the respondents, there is a clear tendency to welcome increased efforts on *concept improvements*. 57.5 % of the respondents strongly or mildly agree to the statement, while 22.5 % were of opposite opinion. The attitudes are, however, to some extent correlated to orientation. Technologists are more willing to support the idea of increased efforts on concept improvements. The medium sized RUs definitely approve such a direction of research in the future and the same pattern is found among newly established labs. The longer researchers have been in the area, the more eager they are to finish the whole effort.

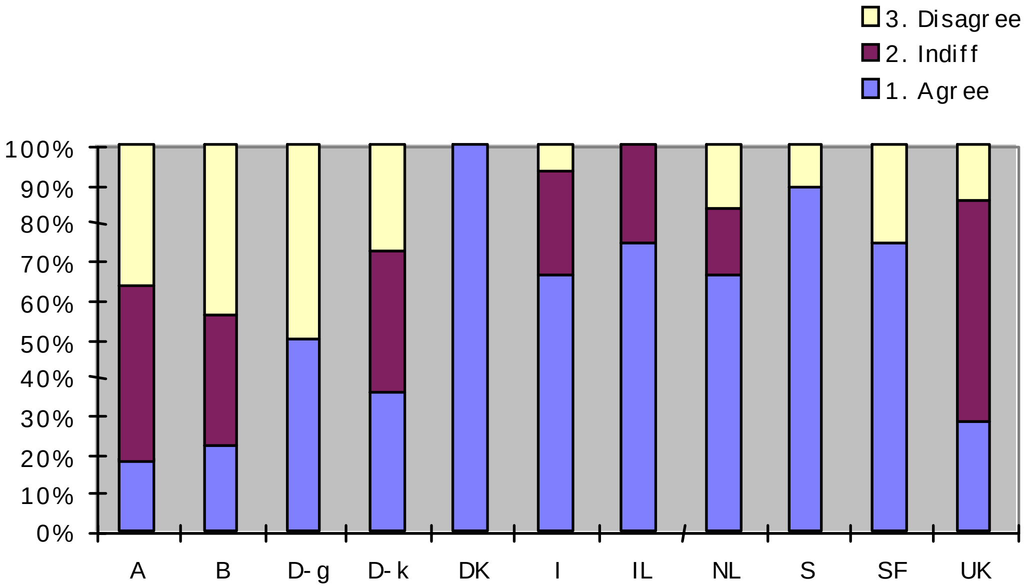
According to the responses, there is not a wide support for increasing supportive efforts on inertial confinement fusion, ICF; only 27 percent advocates increased efforts on this field of confinement. The written arguments against more support on ICF are very often based on an antipathy towards this type of confinement approach, as it is closely connected to military research. There is a positive national divergence to be found regarding the attitudes on this matter. Close to every associate member of EURATOM is statistically against more research effort on the ICF concept. The indisputable exceptions are Italy and Sweden, where 71 percent of the Italians and 67 percent of the Swedish respondents are positive to the idea. This position is in sharp contrast to the other nations (see figure 4.6).

Fig 4.6: Attitude question***: EURATOM should support more research on Inertial Confinement Fusion.***



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 rather than the current concentration on the Tokamak concept. As shown in the figure below (figure 4.7) the positions to some extent depend on national belonging. Still, present prioritisation of the Tokamak concept, and the general balance of the programme, seem to be supported by many researchers.

Figure 4.7: Attitude question***: EURATOM should support more research on alternative concepts within Magnetic Confinement Fusion.***



However, two out of three fusion researchers confess they have a hard time justifying their research projects to non-fusion researchers within physics. The perceived problem of legitimation of fusion research within the physics community is equally shared between 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).

Figure 4.8: Attitude question***: Fusion researchers have had a hard time justifying projects to non-fusion researchers within physics.***

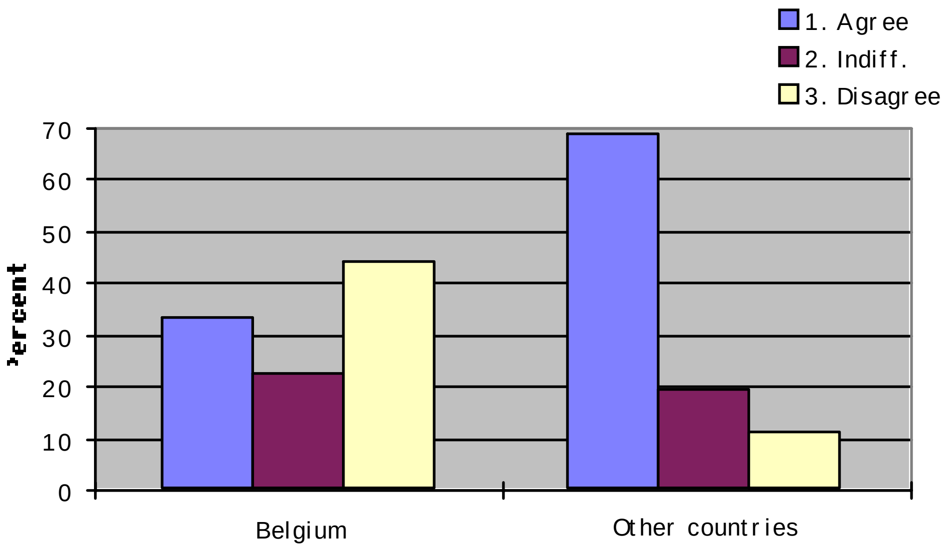
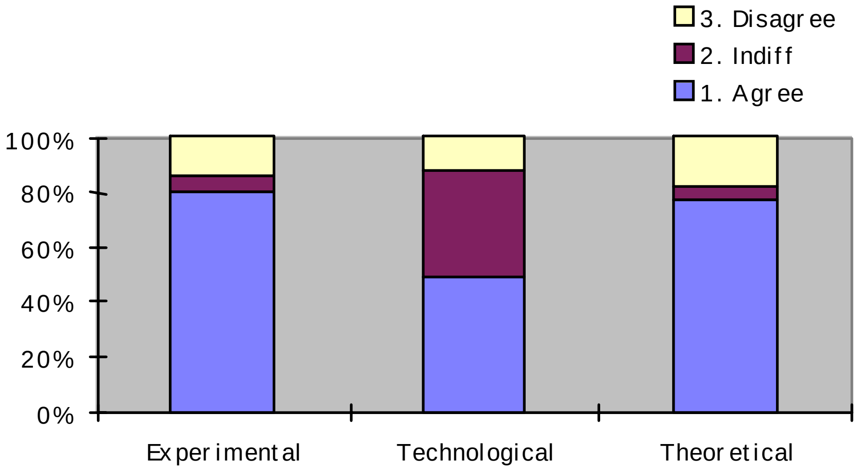


Figure 4.9: Attitude question***: Fusion researchers have had a hard time justifying projects to non-fusion researchers within physics.***



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 78.5 percent confirm the correctness of the statement, while only 6.5 percent dispute it. 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. Obviously this group feels beset, or at least misunderstood, by their colleagues within other fields of physics. Respondents of technological orientation are less worried over this issue, although the majority (63%) stress the importance of overcoming the perceived disbelief of other physicists. Almost one-fourth of this group indicate that they remain indifferent to the statement.

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.

4.7 Further Analysis and Conclusion

When executing a factor analysis on the collected questionnaire data, it is possible to detect certain patterns of attitudes. In order to describe the clusters we use concepts that to some extent are taken from political science and political debate. The concepts should not be understood too literally; their purpose is to indicate, rather than define, specific patterns of attitudes in the European fusion community.

”PC:s”

The largest group, Factor One, represents attitudes that signal an averseness to take position in any controversial issue. 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. All in all this leads to the conclusion that they are PC (politically correct): 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 who do 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. (Naming this group ‘Worried Democrats’ might sound provocative, as if it insinuates that members of other attitude groups are ‘non-Democrats’. However, in this context the labelling serves purely categorisational purposes and do not refer to political position of the individual researcher.)

Unconcerned Technicians

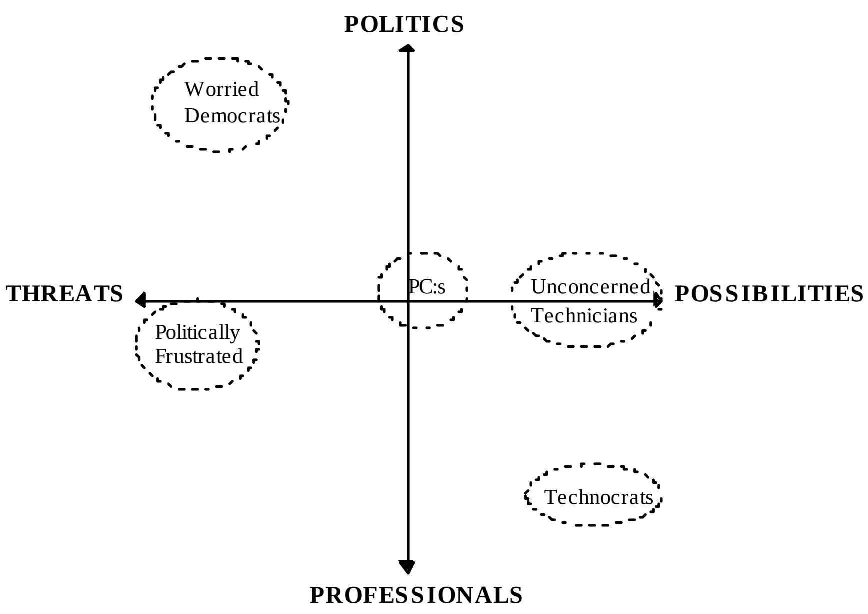
The forth group holds cool and calm persons which are often technicians. They are rather unconcerned over issues and problems related to recruitment of the next generation of researchers, relation to other non-fusion physicists, etc. They are content with what is and would hardly want any changes at 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.

The findings from the factor analysis is illustrated in the figure below:

Figure 4.10: ***Landscape of attitudes in fusion research.***



5 Fusion research: case studies

5.1 Introduction

In order to get a better understanding of some of the dimensions investigated in the survey (Ch 4) (co-ordination, collaboration and politics) of fusion the GSF group conducted case studies in two countries – Germany and Sweden. These countries 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.

The Swedish Association (NFR) was very helpful and made it easy to implement the study. In consequence, the results from the Swedish case are conclusive and more in-depth. In contrast the German case turned out to be a much more complex task. For various reasons the German study is fragmented and a full validation of certain observed patterns has been impossible to achieve.

5.2 Fusion research in Sweden and Germany: bibliometric analysis

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 reflect roughly the national budgets for fusion research. In table 5.1 we have made a distinction 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)

Country	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**
Spain	1	1	1
Holland	0,5	1	1,5
Belgium	0,5	-	1
Sum %	100	100	100

Source: Inspec-database Online.

If only articles are included in 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, as shown in the INSPEC database, has increased in both countries since 1980. One important explanation is that the database covers a wider range of journals, conferences and report-series. Another might be that fusion researchers have intensified there publications and that refereed journals are more important than before. Databases are often a good approximation of activities, but they seldom cover all relevant activities. When using this database for comparison between Germany and Sweden our point of departure is that there are no systematic distortions.

In the beginning of the 1980s the average numbers of papers and articles in the database were approximately 10 in Sweden and 100 in Germany. During the 1990s they have 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. If we exclude papers and keep our interest on articles in scientific journals instead we see a slightly different pattern. Activities in Sweden are rising a bit faster than in Germany. In terms of qualified publications Sweden seems to have a better performance, which is an expected result as the Swedish unit is heavily involved in theoretical work. (The actual number of journal publications per year from the Swedish unit is 30-40 during the second half of the 1990s).

In the Swedish case, the fusion researchers' collaboration pattern has been investigated more closely. Through bibliometric investigations and interviews with the actors themselves, different collaboration networks and clusters are found, nicely illustrating the nature of fusion research collaboration patterns in Sweden. By clustering the bibliometric data into different networks it is revealed that international collaboration is the predominant mode of collaboration.

As for national collaboration, it is apparent that collaborative contacts are almost exclusively to be found between groups connected to the same university. There are a few exceptions; for example, the groups at CTH (Gothenburg) have a certain amount of collaborative contacts with counterparts in Uppsala. It is, of course, common with regular ”inter-university” contacts. Fusion researchers from different fields and universities meet and exchange ideas at, for example, the sessions on the fusion research committee. Other kinds of contacts are also frequent, but 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 the definition chosen for the study. When discussing the example of collaboration within an individual university it is apparent that especially the groups at KTH have rather elaborate collaborative contacts.

As mentioned above, each group routinely collaborates with international counterparts. This is motivated by the special fields of interest of the different groups; it is often 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 group at Studsvik has little or no contact with research groups at Swedish universities. Instead, the actors at Studsvik look for collaborative partners abroad. Their partners can be found at NET, ITER JCT, UKAEA, ENEA et cetera.

A further conclusion is that JET has had a strong influence on the collaboration patterns of Swedish researchers.

5.3 International R&D programs in a national context

This section is a short summary of the main findings of the empirical studies in the (GSF) project on supranational R&D programs and their implementation in a national organisational setting. The main argument and conclusion of the case studies is that the implementation process is affected by, but not totally determined by, the national trajectories in research policy and research organisation. A supranational R&D program such fusion is channelled through relatively stable national patterns of organisations, procedures and evaluation criteria. The organisation of these programs will not be similar in the various participating countries. This needs to be clear in any evaluation of such initiatives.

Nevertheless, the national institutional set-ups are not unaffected by supranational programs, although influences are channelled 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 organisation of R&D, e.g., through some of the criteria for evaluation, organisation etc. Clearly, the research groups involved have become increasingly international in their work and co-operation patterns. Furthermore, the programs – through their political visibility and the resulting organisational structure – have affected national research systems more generally, especially those with the university at their centre (like Sweden). Here, the organisation 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 organisational inertia.

The 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 organising and implementing international programs in a national setting. Instead, two quite distinct models - one *quasi-academic*, and another *semi-bureaucratic* - are contrasted.

Sweden is somewhat exceptional in the sense that the EURATOM program has been integrated mostly into the university rather than into the institute sector. Nevertheless, the organisation 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 that 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 ”politicised” 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 also valid for Swedish fusion research.

Nevertheless, the organisation of Swedish fusion is a mixture of the two mentioned models, since there are many organisational 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 was, during the period 1989–1998 slightly above 75 percent.[20] Budget cutbacks during the late 1990s has changed the situation in this respect quite dramatically. After 1995 the fusion area has much lower success rate and is generally in line with the normal NFR rate around 50 percent. At the same time it should be noted that most projects meet reduced budgets due to the cutbacks. The proposed budgets are cut with more than 50 percent. A more detailed analysis regarding the distribution between the eight groups in Sweden shows a stabile allocation pattern, but the EXTRAP group at KTH nowadays receives a smaller share, while the neutron diagnostics groups is getting a larger share.

The main argument for characterising the Swedish unit as a mixture of models is the function of the fusion committee. This committee does not interfere in the scientific evaluation of proposals, but has a mandate to argue for the context of each project as it evaluate from relevance criteria developed from the EURATOM programme. Members from the committee are often appointed as reviewers of proposals by the physics committee. The mixture is a necessary by-product of this process.

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 case of the EXTRAP concept developed by the KTH group, where the research strategy had to be changed to facilitate integration with the European fusion program. Thus, researchers have to be more politically and organisationally sensitive in their planning. Moreover, the advisory board for fusion research (FFK), which consists of representatives of the leading fusion research labs in Sweden, has the privilege to

[20] All types of applications in the NFR database.

formulate and influence the agenda of fusion research within the research unit. As its task is, among other things, to discuss the relevance of different projects, the board can decide the future of each project. Indirectly, FFK has the possibility to control the allocation process, and the result is therefore board which is rather similar to a research institute.

The ”quasi-academisation” of Swedish fusion research creates some organisational anomalies, as pointed out by the international review conducted in 1997 (International Evaluation of Fusion Research, June 1997). For instance, the potential for conflict between scientific evaluation criteria inside the NFR and fusion relevance criteria is considerable, since the EURATOM fusion program to a large extent is a technological effort. The review committee found that this dilemma was handled by the researchers through a strategy that emphasised their respective individual profiles. This has lead to a centrifugal dynamic in the Swedish fusion community. Instead of collaboration and streamlining of resources, each principal investigator has his own very specific area of research. This situation seems to have made the combining of interests somewhat harder to achieve. The NFR fusion committee has had no alternative but 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 organised in a university-like model, but with clear political and organisational constraints, this confronts the area and the researchers with a mixture of roles and ideals. However, this problem might be alleviated by the rather long tradition of sectorial research in Sweden (*sektorsforskning*). There is already an awareness among Swedish researchers, in areas that are more or less politically visible, 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 is also well in line with the national trajectory. In Germany, the institute sector has become increasingly important as a site for research, especially for ”megascience”. The institutes have distinct organisational hierarchies, and decision-making tends to be highly centralised. The institute sector is in itself divided into different ”families” with different traditions in organisation and research orientation, such as the Max-Planck Society (basic research), the Fraunhofer institutes (applied research), etc.

Thus, 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, but also more stable and predictable in relation to the given tasks of EURATOM. Furthermore, the institute sector seems to have developed with different institute families operating in isolation, making collaboration among them less likely, or at least quite difficult in some cases. This feature is also reflected in the organisation of German fusion research. There is a competitive element operating in Germany too, but it seems to reflect organisational hierarchies and status differences more than scientific merit. Furthermore, the German case, and especially the process of unification, highlights the symbolic value of fusion research, where political reasons are given for the move of one fusion research facility to the former GDR. Thus, German fusion research also reflects national political and organisational peculiarities, albeit quite differently than in Sweden.

6 Summing up: results and additional research needs

The major part of the work reported here belongs to the field ”research on research”. As a research enterprise, fusion is extreme in many respects. Three of the characteristics that set fusion research somewhat apart are: the long time horizon, the broad international co-ordination and the dependence on large research facilities (such as JET and ITER). The findings on Sweden and Germany show important imprints of these characteristics, while at the same time scientific ”normalcy” (peer group review, refereed publishing, open international exchange etc.) is repeatedly stressed. National structures of research may vary considerably – as between a powerful institute sector or strongly university based systems – but seem to adapt quite well to the goals of the fusion program.

From empirical research we still do not know enough about the nature of international co-ordination, be it European or multi-continental. More attention to these aspects, perhaps in terms of fusion as ”megascience”, seems natural from the partial findings reported here. Also parallels and comparisons with other forms of supra-national, highly systemic research seems very much called for: do for instance high-energy particle physics or space research show important similarities or differences in terms of the possible tension between national and international setting of priorities and mechanisms of funding?

The issues brought to the surface by fusion – long term, large scale, complexity, international networking, risk etc. – demonstrate important dilemmas in policy-making in a ”systemic” society. They are seen here in relation to regulation and licensing issues as well as to the broader questions such as energy policy, research funding and industrial policy. However, such policy discussions seem to come and go. Political attention to fusion occurs by chance rather than through consistent probing. Fusion is not regularly on the public agenda and public attention is on the average fairly low (cf also results on public attitudes, reported in Macro Task S2). Nevertheless, the key points discussed here (including differences and similarities between fusion and fission) will remain on the public agenda for a long time, and need more systematic attention from research as well as from policy-making bodies.

I end these concluding words with a reflection slightly outside the research as such. When this line of investigation started (in 1997) the ”fusion community” was not at all mentally prepared to being ”researched” by social scientists. A non-trivial amount of suspicion was voiced, as if this research was part of an evaluation or perhaps even an operation launched by enemies to fusion. To an encouraging degree, such fears have been dissipated. Many of the informants in these studies now seem to accept the value, not least to themselves, of a deeper knowledge and more transparency of the ”system” in which they are working.

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