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# EUROPEAN FUSION RESEARCH

Report of the CERN Study Group on

FUSION PROBLEMS

by

J.B. Adams

GENEVE

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## PART I. General.

### 1. Reasons for setting up the CERN Study Group on Fusion Problems.

In March 1958 a number of scientists met at CERN for a few days to talk about the results of plasma physics experiments aimed at controlled thermonuclear reactions being undertaken in various laboratories. At that time the most notable results were from the Zeta machine at AERE, Harwell and consequently most of the discussion was centred about these results. It became clear during the discussions that there were many European laboratories engaged in this type of work and many others seriously thinking of entering the field. Due to security classification, very little of the work done on fusion had been published at this time and many laboratories found themselves in the awkward situation of planning research which they feared might have been already completed elsewhere. The partial lifting of the security restrictions at the beginning of 1958 was the main reason for these first discussions at CERN. It was hoped that very much more information would be released at the 1958 Atoms for Peace Conference in Geneva and that it would then be possible to form a comprehensive picture of the real state of fusion research in the world.

As a result of these first talks at CERN in March 1958 and the steady release of information on fusion work in the following months, CERN was asked by many laboratories to extend the original discussion group into a more formal study group and to arrange a series of meetings during the remainder of 1958.

At the June 1958 meeting of the CERN Council approval was given to form a CERN Study Group on Fusion Problems and to hold the meetings at CERN in Geneva.

### 2. Objectives of the Study Group.

The CERN Council, in giving its approval to the formation of

the Study Group, agreed that the main objectives would be to exchange information on fusion research, to discuss the programmes being undertaken in the various laboratories and to consider ways of facilitating fusion research work in Europe.

The final report of the Study Group to the CERN Council would be issued as a CERN report with the normal circulation and be freely available.

3. Participants of the Study Group.

Each European laboratory working in the field of fusion research was asked to send along a few representatives to the Study Group meetings. In addition to CERN, Euratom and OEEC were asked to participate as international organizations. Also the AEC was invited to send its European representative, Dr. Amasa S. Bishop, to the meetings.

The list of participants was as follows:

BELGIUM

Prof. P. Baudoux
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Dr. Ch. Lafleur
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DENMARK (cont'd)

Dr. T. Hesselberg Jensen
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Risö
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Dr. Carl F. Wandel
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Prof. W. Fucks
Director Phys. Institut
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Prof. A. Schlüter
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Mr. J.B. Adams (Chairman)
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Dr. G.L. Munday
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(attended 2nd, 3rd meetings)

Dr. E. Regenstreif
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Dr. A. Schoch
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Genève 23
(attended 1st, 2nd, 3rd meetings)

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4. Brief review of the activities of the Study Group.

The first meeting of the Study Group took place on 25th and 26th September 1958, shortly after the 1958 Atoms for Peace Conference in Geneva.

In the months previous to this meeting a great number of reports had become available to the members of the Study Group from the laboratories participating in the Atoms for Peace Conference. Also nearly all the members of the Study Group had taken part themselves in the Conference and had many discussions with colleagues abroad already working in this field of research for many years.

The first meeting of the Study Group was therefore devoted to trying to assimilate the information released at the Atoms for Peace Conference. Four half-day sessions were arranged as follows:

1. Stellarator Devices.
   (session led by Dr. A. Schlüter - Göttingen and Munich).

2. Toroidal Pinch Devices.
   (session led by Dr. R.J. Bickerton - AERE, Harwell).

3. Linear Devices.
   (session led by Prof. K. Siegbahn - Uppsala).

4. Mirror Devices and Centrifugal Devices.
   (session led by Dr. J.G. Linhart - CERN).

Each of these discussion sessions opened with a review of the device, its state of development, results of experiments and the difficulties encountered, both theoretical and experimental. During the discussions members of the Study Group outlined their own programmes of research work.

It became clear during the meeting that too little time had elapsed since the general release of information on fusion research for any serious evaluation of the state of the work to be made at the first meeting. It was therefore agreed that members of the Study Group would undertake to write critical surveys of the various devices and lines of approach to the fusion problem and circulate these reports in time for a second meeting.

The minutes of the first meeting were circulated to all the members together with a technical summary of the discussions that took place.

The second meeting of the Study Group took place on 11th and 12th December 1958. Nearly all the reports promised by the members of the Study Group were available at the second meeting. The full list of these reports is as follows:

1. Remarks on the Stellarator Scheme, by members of the M.P.I., Munich.
2. Brief Review of the Toroidal Stabilised Pinch, by R.J. Bickerton, Harwell.
3. Report on Linear Pinch Devices, by R. Latham and J.A. Nation, Imperial College.

4. Les machines à miroirs magnétiques, par M. Bineau, T. Consoli, F. Prévôt, P. Ricateau, C.E.A.
5. Les machines à miroirs magnétiques, Résumé et esquisse d'un programme de recherches, par M. Bineau, T. Consoli, P. Hubert, F. Prévôt, P. Ricateau, A. Samain, C.E.A.
6. La machine d'Osovetz, par Ch. Maisonnier, C.E.A.
7. Notes on fast Magnetic Compression of Plasmas, by H.L. Jordan, H. Kever and K. Schindler, Technical University, Aachen.
8. Confinement and Heating of Plasma by R.F. Electromagnetic Fields, by C.M. Braams and J.C. Terlouw, F.O.M. Instituut voor Plasma-Fysica, Rijnhuizen-Jutphaas.
9. Relativistic Electron Beam Devices for Fusion, by J.G. Linhart and A. Schoch, CERN.
10. Notes on some Theoretical Investigations of the Physics of High Temperature Plasmas, by Dr. Lüst, Munich.
11. A Compilation of Cross Sections and Rates of Interest in Controlled Thermonuclear Research, by the Risö Study Group.
12. The Betatron Method of Heating a Plasma to High Temperatures, by G.I. Budker, translated from Russian.
13. The Instability of a Plasma in a Magnetic Field in the Presence of Ionic Beams, by Kadomtsev, translated from Russian.
14. The Physics of Plasmas, U.S.S.R. Academy of Sciences. Abstracts of 4 volumes, translated from Russian.
15. Plasma Diagnostics by Spectroscopical Means, by H. Wulff, M.P.I.
16. Detection of Heavy Particles in Thermo-Nuclear Reaction Experiments, by L.H.Th. Rietjens and C.M. Braams, F.O.M. Instituut voor Plasma-Fysica.
17. High Speed Photography, by A. Folkierski, Imperial College.
18. Les sources d'ions et de plasma, par T. Consoli, P. Hubert, R. Le Quinio, D. Véron, C.E.A.
19. Short Note on Energy Storage, by D.Th.J. ter Horst, KEMA.
20. Ultra High Vacuum Technology, by G.L. Munday, CERN.
21. High Magnetic Fields, by S. Berglund, Uppsala Institute of Physics.
22. Investigation in Magneto-Hydrodynamics and Plasma Physics of Interest to the Thermo-Nuclear Problems, by H. Alfvén, Technical University, Stockholm.

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On the first day of the second meeting a discussion took place on the above reports when the authors had the opportunity to give a brief review.

The Study Group, having by this time more or less assimilated the vast amount of published literature in the field of fusion research and having reviewed, in the light of this knowledge, their own fusion programmes, were able on the second day of this meeting to begin to discuss the general problem of fusion work in Europe.

A record was made on the plans and programmes of the European laboratories working on fusion problems and allied fields of research together with the effort in terms of staff and money that each laboratory intended to put into the work. A comparison was then made with the work being undertaken in the USA and the USSR. The question of an international European laboratory for fusion problems was discussed. Education, staff training and exchange of information in various forms was also considered.

At the end of the second meeting it was agreed that the Chairman should prepare a report summarizing the views expressed by the members of the Study Group and that this report, which would be considered as the first draft of the final Study Group report, should be circulated before the third meeting and form the basis of the discussions at the third and final meeting of the Study Group.

The third meeting of the Study Group took place in Geneva on 5th and 6th March 1959. Most of the first day was spent in a detailed discussion of the Draft Report of the Study Group to which many corrections, additions and changes of emphasis were suggested. The later part of the first day and the whole of the second day were devoted to status reports from the members of the group. Dr. Colgate from the Livermore Laboratories of the University of California, Berkeley who attended the second day sessions gave a review of the work of his group, which includes sodium model experiments to investigate the hydromagnetic instabilities in pinch geometries, an electron beam experiment for analyzing the cooperative phenomena associated with runaway electrons and a Hard Core (or unpinch) experiment. The contributions of the members of the Study Group are reported at length in the Minutes of the third meeting.

## Part II. Review of the activities of European laboratories working on fusion problems.

A record was made by the Study Group of the plans and programmes of European laboratories working on fusion problems. It must be made quite clear that this record does not bind the laboratories to the plans announced below in any way. The object in making the record was simply to see how the various programmes interlocked together as far as they could be determined at the present time.

### a) BRITAIN

The largest laboratory working on fusion problems in Britain is at AERE, Harwell (CTR Division). In addition to this major effort there are smaller groups at AWRE, Aldermaston, an industrial group at AEI, Aldermaston and several university laboratories.

#### i) AERE, Harwell (Dr. P.C. Thonemann, Dr. R.S. Pease, Dr. R.J. Bickerton)

Their programme is centred around the toroidal pinch system and the largest device is the machine called Zeta. Many modifications have been made to the original Zeta and will be made in the future, but for some time to come this machine will be the largest single device in the programme. Many smaller toroidal devices have been made and many more are in course of construction, all of them designed to answer specific problems concerned with the toroidal pinch geometry. In this general programme linear pinch systems are also being investigated in so far as they lead to an understanding of the pinch phenomena. A full range of diagnostic devices have been built and are constantly being added to as the need arises and development is possible. There are plans to increase the energy storage facilities of the laboratory, firstly in order to extend the use of Zeta as an experimental tool and secondly to have available in four or five years' time a large energy storage facility for general use with magnetically

confined plasma. This new power facility will be in three sections, namely a condenser bank store of about 25 M joules for "fast" experiments, an inductive energy store of about 200 M joules and a store using batteries or rotating machinery of about 1000 M joules. Such a power facility, which is about the same size as that planned for the Stellarator C device at Princeton, will take a great deal of development effort and time and will cost about 20 M $. It is the largest power facility planned as yet in Europe.

ii) AWRE, Aldermaston (Dr. S.C. Curran)

This group has contributed to the linear pinch devices and particularly to the technology of fast switching of condenser banks. This work continues, but in parallel work on a device labelled Thetatron is being prosecuted. Relatively small systems, straight and toroidal, are employed. Heating and stability are both studied and crowbar techniques are involved. X-rays and neutrons are examined. Work has begun on Hitex, which is similar in principle to the DCX machine at Oak Ridge. It is not intended that this device should represent a large investment - it is an effort to examine the principles as economically as possible in terms of equipment and it may be tackled at say about 50 kV rather than at say 500-800 kV. Most of the work would be on hydrogen rather than deuterium.

iii) AEI, Aldermaston

This is an industrial group working on the toroidal pinch device called Sceptre, in collaboration with AERE, Harwell. In a sense their work is complementary to that at Harwell and might be considered as part of the Harwell pinch programme. A new device, called Sceptre IV, using a 1 M joule condenser bank and a torus 30 cm bore, 1 m diameter is being built to study slow discharges up to 300 K amperes.

iv) University Laboratories (Dr. R. Latham - UCL)

Several university laboratories are engaged in work on specific aspects of fusion problems, notably Imperial College, London, which is concerned with linear pinch systems using fast photography and also shock wave systems, Sheffield University which is undertaking development of microwave diagnostic techniques, and Liverpool University where some work is in progress on condenser bank switching.

It is hoped to get more universities in Britain interested in plasma physics work, both theoretically and experimentally.

b) GERMANY

The Max-Planck-Institute for Physics and Astrophysics in Munich, formerly in Göttingen, has added to the original theoretical group an expanding experimental group. Also in Munich there is a group at the Technical University engaged in fusion problems, which cooperates closely with the Max-Planck-Institute. At Aachen a group at the University is already working on fusion problems, and several other universities are also interested in specific aspects.

i) Max-Planck-Institute for Physics and Astrophysics, Munich (Prof. W. Heisenberg, Dr. G. v. Gierke, Prof. L. Biermann, Prof. A. Schlüter)

The theoretical work, started in 1956 and based on the earlier studies of astrophysical applications of plasma physics and magnetohydrodynamics, is concerned with the general problems of confinement, stability and heating of plasma and with a number of special problems arising from experimental work.

The experimental work is mainly with devices using toroidal field geometries, particularly those using external magnetic fields, such as Stellarators with helical windings.

The necessary diagnostic techniques, such as spectroscopy, microwave measurements and probes, are being developed with special emphasis on

the basic physics aspects. At the present time only experiments on the scale of Stellarator B and Sceptre are being prepared.

A group under Dr. E. Fünfer at the Technical Physics laboratory (Director Prof. Maier-Leibnitz) is working in close collaboration with the Max-Planck-Institute on linear discharges and other fast systems.

Prof. A. Schlüter holds a chair of Theoretical Physics at the Munich University and devotes part of his teaching to plasma physics.

A site has been reserved and plans are being contemplated for a larger laboratory than the present Max-Planck-Institute which will ensure that future developments including larger power facilities will be available in due course.

ii) Physical Institute, Technical University, Aachen (Prof. W. Fucks, Dr. H.L. Jordan)

The programme is mainly concerned with "fast" devices, including shock tubes and involving fast condenser banks with the appropriate diagnostic techniques. Some work on relativistic electrons in plasma is contemplated.

iii) Other University Laboratories

Apart from the two main groups mentioned above, several university laboratories are engaged in fusion work, notably Kiel University where particular attention is given to the spectroscopic aspects.

c) FRANCE

Two groups, both of the CEA, are engaged in fusion work in France. Apart from these groups, small university laboratories and industrial groups are contracted by CEA for specific problems.

i) CENFAR, Fontenay-aux-Roses, Paris (Dr. G. Vendryes, Dr. P. Hubert, Dr. F.Prévôt)

This group has been engaged in fusion work for some time, mainly on a pinch programme. No very large projects in the toroidal pinch

programme are planned, but rather a series of devices of about 1-2 m diameter aimed at obtaining basic physical understanding. In addition to this work a new programme on mirror devices is planned using various injection systems. The group has developed a range of diagnostic techniques in the course of its work, including microwave measurements in the 8 mm band. New laboratories for this group will be ready in about one year's time. No decision has yet been taken on the power facility for this new laboratory, but a 1 M joule bank of condensers and possibly a 1 MW D.C. generator will be installed.

ii) Accelerator Division, CEA, Saclay, Paris (Dr. S.D. Winter, Dr. J. Taillet)

This group, which has recently built the Saclay 3 GeV synchrotron, is now turning to fusion work. Their plans are centred around mirror machines of the injection type similar to the DCX. They are in course of building up the necessary diagnostic techniques, including microwave measurement apparatus in the 4 mm band, and the appropriate technology. They also contemplate setting up an R.F. confinement system in order to have a quiescent plasma for study purposes.

d) HOLLAND, FOM (Prof. H. Brinkman, Dr. C.M. Braams)

The Dutch work on fusion is carried out in five groups covering the following topics: theory (Prof. H.C. Brinkman, TNO, Delft), diagnostic techniques and ion cyclotron resonance heating (Prof. J.A. Smit, University, Utrecht), ion magnetron (Prof. J. Kistemaker, FOM, Amsterdam), power facilities and linear pinch (Dr. D.Th.J. ter Horst, KEMA, Arnhem), and a central institute with a programme including general plasma physics, toroidal pinches and R.F. confinement (Dr. C.M. Braams, FOM, Jutphaas). The fusion work is in the general programme of scientific research of the foundation FOM and includes the assistance of KEMA, TNO, Philips, and University laboratories.

e) SWEDEN

i) Stockholm, Technical University (Prof. H. Alfvén, Dr. A. Dattner)

The group of Prof. Alfvén, which has studied problems in plasma physics for many years, is continuing its researches along some lines that may be of interest to fusion. The programme includes studies of magnetized rapidly moving plasma rings, instabilities in linear gas discharges and electron beams in longitudinal magnetic fields. Theoretical and experimental studies of the propagation of electromagnetic waves in plasma are being carried out together with investigations of the interactions between waves and fast electrons in plasma. Dr. Lehnert has started the construction of a machine for confining plasma at 30 million degrees using the magnetic field from a circular loop. Development and studies of diagnostic techniques are carried on along with the different experiments. A condenser bank of 50 kW is under construction.

ii) Uppsala, Physics Institute (Prof. K. Siegbahn, Mr. L. Högberg, Dr. N.R. Nilsson)

The programme includes work on toroidal discharges and linear pinches.

Both these Swedish groups are helped by the Swedish State Power Board and the industrial firm of ASEA.

f) ITALY, Laboratorio Gas Ionizzati, C.N.R.N., Institute of Physics, Rome University (Prof. E. Persico, Dr. B. Brunelli)

This group has only recently been formed and will shortly move to the Italian reactor site of Bracciano, north of Rome. The programme is based on the mirror geometry. A machine of a modified Scylla type will be built for experimental work on fast compression heating.

g) SWITZERLAND, ETH, Zürich (Dr. H.E. Knoepfel)

No group yet exists, but there are plans to form a plasma study group as part of the ETH at the Swiss reactor site near Zürich.

h) NORWAY, Technical University, Trondheim (Prof. K. Johnsen)

A small group is being formed to study some plasma physics problems.

i) BELGIUM, Physics Institute, Free University, Brussels (Prof. P. Baudoux
Dr. Ch. Lafleur)

A small group is building a linear pinch system for studies of diagnostic techniques and is interested in related theoretical problems. This work is now a part of the general programme of researches of the I.I.Sc.N. (Institut Interuniversitaire des Sciences Nucléaires).

j) DENMARK, Risö Research Center, Physics Department (Dr. O. Kofoed-Hansen,
Dr. C. Wandel)

A small group has been formed for fusion studies.

k) CERN, Geneva (Dr. A. Schoch, Dr. J.G. Linhart, Dr. G.L. Munday)

CERN is not engaged in fusion studies. A small group in the PS Division of CERN is however studying the problem of relativistic electrons moving in plasma, both experimentally and theoretically. This work is part of the accelerator research of CERN and is incidentally relevant to problems of the fusion device known as Astron. Studies in ultra high vacuum technology in relation to systems of a volume of several cubic metres are now being undertaken.

## Part III. Discussions.

### 1. On the nature of the fusion problems in the next few years.

In the months following the Atoms for Peace Conference and the release of information on fusion work it has been the task of physicists everywhere to reflect on the conclusions to be drawn from the impressive display of apparatus and ideas that was so suddenly revealed to them. Before any programme of fusion research can be seriously discussed, it is very important to define the nature of the work that has to be done in the near future. The

Study Group discussed this problem in the second meeting and the following is a résumé of the points brought out in these discussions.

One cannot escape the conclusion that much of the work done previous to the 1958 Atoms for Peace Conference was inspired by the hope of achieving a quick break-through in the problem of producing a fusion reactor and that the devices conceived and built were chosen because they might lead to a possible reactor. This technique of tackling a scientific problem, which has often succeeded in the past, assumes that concurrently with building large scale projects, solutions will be found to the more fundamental problems and that the two activities will progress together at roughly the same speed.

It seems to be a general conclusion that this state of affairs has not come about and that the fundamental physics, on which all devices and projects depend, has proved to be much more intractable than was originally estimated.

It is therefore clear that the major task before everyone engaged in fusion work in the near future is to accelerate the understanding of the physics of plasma.

However, such a conclusion does not imply that large scale experimental work should be abandoned, nor does it mean a slowing down of fusion activities. A properly balanced programme must allow for the study of fusion problems, theoretical, experimental and technological, on as broad a front as is economically possible. Small university research teams, large national groups and industrial development groups all have an essential part to play in the fusion programme. It is inevitable that the large scale experiments will be carried out in those laboratories where adequate facilities, particularly energy storage systems, can be built up on an appropriate scale, and it is worth bearing in mind that these experiments may well be as large as any of the devices described at the Geneva Conference.

A European fusion programme should aim at encouraging this diverse activity at all levels and by whatever means that are appropriate.

Looking at the programmes of work of the European laboratories listed above, one is impressed by the fact that there is a general coverage of the

different aspects of the fusion problem with remarkably little concentration by several laboratories on one problem. This is a very healthy state of affairs and to some extent has emerged from the discussions in the Study Group meeting which have enabled laboratories to arrange their programmes in the light of the work of other laboratories. The major divisions of the problem, namely toroidal pinch, mirror confinement and Stellarator confinement, form the central programmes of the three largest national laboratory groups, respectively British, French and German. Other problems are being tackled either by the large laboratories or by smaller centres or by university laboratories.

2. On the magnitude of the effort on fusion problems in Europe.

There is no absolute scale by which to decide whether or not Europe is putting enough effort into the fusion problem. It was stated at the Atoms for Peace Conference that it may well take twenty or more years to make a fusion reactor. However, fusion reactors, if they are possible at all, do in principle offer advantages over other energy producing methods and these advantages have been thought sufficient by the USA and USSR to justify a considerable effort on fusion research. Also it should be borne in mind that other important applications of plasma physics may be discovered in the course of the fusion work.

The Study Group, in considering this problem, listed the planned effort on fusion research in the various European laboratories for 1958 and 1959 in order to compare this effort with that existing and planned in the USA. In making the comparison only the larger national groups have been recorded by name. The smaller laboratories are grouped together in order to make a comparison with the AEC effort. The record is made in terms of scientific staff and operating costs.

| Laboratories | Calendar Year 1958 Scientific Staff | Calendar Year 1958 Operating Costs M $ | Calendar Year 1959 Scientific Staff | Calendar Year 1959 Operating Costs M $ |
|---|---|---|---|---|
| Britain | | | | |
| AERE ) AWRE ) AEI ) | 120 | 3 | 150 | 6 |
| France | | | | |
| CEA | 31 | 0.8 | 60 | 2.5 |
| Germany | | | | |
| Munich) Aachen) | 65 | 1.2 | 110 | 2.0 |
| Other European Laboratories | -- | 1.7 | --- | 2.4 |
| Totals : | 216 | 6.7 | 320 | 12.9 |

The corresponding figures for the AEC fusion programme are:

| Laboratories | Calendar Year 1958 Scientific Staff | Calendar Year 1958 Operating Costs M $ | Calendar Year 1959 Scientific Staff | Calendar Year 1959 Operating Costs M $ |
|---|---|---|---|---|
| Los Alamos | 38 | 3.3 | 40 | 4.6 |
| Oak Ridge | 70 | 4.9 | 99 | 6.7 |
| Princeton | 97 | 12.0 * | 115 | 16.8 * |
| Livermore | 83 | 6.7 | 93 | 7.4 |
| Other laboratories | -- | 1.8 | --- | 2.5 |
| Totals : | 288 | 28.7 | 347 | 38.0 |

* Model C Stellarator fabrication costs: 7.2 M $ in 1958 and 10.6 M $ in 1959.

Although the figures for the European laboratories are approximate, it is nevertheless possible to see that the number of scientific staff working on fusion problems in 1959 in Europe is comparable with the corresponding staff numbers in the USA. On the other hand, the European operating costs for fusion research are but a small fraction of those of the USA.

In trying to understand these results many factors have to be taken into account. Whereas the American groups have been working on fusion problems for several years, most of the European groups are relatively new in the field. It is known that new groups need some time to establish themselves and their programmes before spending large sums of money. The tendency in the European centres is to concentrate their efforts on smaller experimental devices than the comparable American centres, and so spend less money on capital equipment. For example, the Stellarator C Project accounts for 17.8 M $ in the two years 1958, 1959, and there is nothing comparable with this planned so far in Europe. Another factor noticeable in Europe is the number of smaller laboratories engaged in fusion work. Although their operating costs are small, the numbers of scientific staff in these laboratories add up to nearly half the total staff in the larger centres (the exact figures are: Scientific Staff in other laboratories - 1958: 95, 1959: 154). It may be that in giving their operating costs the European groups have underestimated.

However, taking all these points into consideration, the Study Group were at a loss to explain the very large differences in the operating costs between American and European centres. It would be well worth while repeating this exercise in a year's time.

3. <u>On the problem of the education and training of staff and the exchange of staff between laboratories</u>.

The sudden preoccupation of European countries in fusion problems creates a serious problem of finding staff for the programmes, particularly scientific staff. Staff already familiar with plasma physics can only come from the astrophysics institutes or from those universities already occupied

with academic research in plasma physics. These institutes and laboratories, which are small in number, will obviously continue with their own problems and only a small fraction of their staff will be available for fusion work. Thus the supply of scientific staff already familiar with plasma physics is small. In addition to this staff there is also need of scientific staff familiar with many other branches of physics, such as spectroscopy, microwave techniques, nuclear physics, and all those techniques associated with particle accelerator machines. The growth of activity in high energy nuclear physics in Europe since 1950 has led to the formation of powerful groups of physicists and engineers well trained in accelerator physics and above all familiar with large scale project work. Such people, if and when they become available, will be invaluable to the European fusion programmes. With the other branches of physics involved there should be no real shortage of staff, provided that the interest of such people in fusion problems is aroused and maintained.

The staffing problem in fusion research is not fundamentally different from the problem of finding staff for the other branches of physics. There is undoubtedly a serious shortage of physicists in Europe, and plasma physics and fusion research can only take a fraction of these people. The first need, therefore, is to train more physicists, and the special problem for the fusion groups is to interest a reasonable fraction of these people in plasma physics. Those universities where the professors and lecturers are themselves interested in the subject, and where lectures and research in plasma physics are actively undertaken, are clearly most likely to turn out the largest number of young physicists interested in fusion research. It seems from the discussions in the Study Group that there are now several universities already established in this field, for example Uppsala, Stockholm, Aachen, Munich, London etc.

Another way in which interest can be aroused is by special courses in plasma physics and fusion, such as are already run at Saclay and Munich. Saclay (CEA) has arranged courses extending over five months for graduates, and similar courses exist at Munich (Astrophysics Institute). In addition a summer school for fusion problems is being arranged in 1959 by the Italian Physics

Society at Varenna. All these courses are open to any European physicists who want to take part and who are accepted by the centres running the courses.

Clearly this type of training is of immense value in making physicists familiar with the problems of plasma physics and should be supported and encouraged to the full.

Another important question discussed by the Study Group concerns the exchange of staff working on fusion problems between the various laboratories. Now that there are no longer any questions of security or classification in fusion work, the problem is only one of arranging that European staff can move freely between the laboratories.

The reasons why such an exchange of staff is desirable need stating. In the first place there are many groups in Europe that will not have available large facilities with which their staff can pursue experiments started on a smaller scale. It is to their advantage to send their staff for a time to centres where these facilities exist. Secondly there is clearly a shortage of staff familiar with this branch of physics and it is in the interest of the larger centres to have as guests senior staff from other centres or from smaller laboratories. Lastly it is in the common interest of all the European laboratories to profit by the experience of other laboratories and this can very well be done by allowing scientific staff to work in other laboratories than their own.

Such exchange schemes are already an established tradition in the Max-Planck-Institutes of Germany, and it is an accepted way of life in high energy physics. At CERN, for example, where facilities for high energy physics exist, a system of CERN fellowships, research associateships and FORD fellowships enables physicists from all over the world to spend a year or more at CERN working on high energy physics problems. Also there are many guests not paid by CERN grants, but working at CERN with grants paid by their own institutes.

4. <u>On the subject of national and international laboratories for fusion problems.</u>

One of the ways in which fusion work in Europe might be facilitated is by setting up a European laboratory for fusion problems, and this idea was considered by the Study Group.

It should be made clear that the Study Group did not consider any idea of a European laboratory for fusion problems that would replace the national laboratories. The problem considered was only if there was a need for such a laboratory in addition to those already existing. Also the Study Group did not concern itself with the way in which such a laboratory could be set up.

The advantages of such a European laboratory can be stated as follows:

a) It could build up larger facilities than would be possible in a national laboratory.

b) It could act as a centre for fusion work in the sense that conferences, exchange of staff between laboratories, training of staff, exchange of reports etc. could be arranged by such a laboratory.

c) It could act as a centre for contacts with USA and USSR on fusion work.

d) It could help the smaller national centres and university laboratories in fusion problems.

Some disadvantages are the following:

a) It may take staff and money away from the national laboratories at a time when they were trying to expand their activities.

b) At the present time the national laboratories can manage the fusion programme themselves and build sufficiently large facilities for the immediate future.

It was felt by the Study Group that unless it can be demonstrated that a European laboratory is needed in order to build larger facilities than can be built by national groups, the many other advantages of such a centre may prove insufficient to overcome the difficulties in its creation and maintenance.

The facilities, often mentioned in this report, which can be compared with accelerating machine facilities for high energy physics, need to be specified. By far the largest expense in the work on fusion is in setting up the energy storage system, the diagnostic techniques and the general laboratory technology and services. It has been mentioned that Britain is planning to set up a fairly large energy storage system consisting of condenser banks, rotating machines, inductive storage and batteries with all the necessary switching plant. This system is comparable with the Princeton energy storage for Stellarator C now in course of construction and will cost about 20 M $\not\$$ over about four years. Such an energy store is useful for fusion devices using magnetic confinement and, if it is sufficiently flexible, does not commit the laboratory to one device or line of approach. No comparable plan for an energy store has been announced by any other European group. Also the energy store is by no means the only expensive part of the facilities used for fusion work.

The Study Group therefore considered whether another similar or larger facility of this kind could be justified in Europe, which might then be considered as the raison d'être of a European laboratory. There was no clear unanimity in the views expressed by the different members of the Study Group. The British group considered that their facility could be justified, but this did not enable them to justify another similar or larger one in a central laboratory. The German groups in general did not see the need for the Stellarator C installation at the moment and preferred to work on a smaller scale, although they are making plans to expand the present energy storage system if the need arises. The French groups expressed a similar opinion; they felt that although the immediate building of a large scale store is perhaps premature, it is advisable to make studies right away, especially considering the long time needed for the study and for completion of the installation. The matter was therefore left for a later review of the whole problem.

The part being played by EURATOM in the fusion work was discussed by the Study Group. EURATOM represents five of the twelve member states of

CERN and does not contain the most currently active member state in the work on fusion, namely Britain. The policy of EURATOM on fusion is to encourage the growth of large centres in its member states by placing contracts for fusion work. They plan to place a contract with Saclay (CEA) and possibly Munich with this aim in mind. Their policy does not exclude other countries than the six EURATOM countries from joining in this work. They have at their disposal about 10 M $ in the next four years, and this sum of money can be increased if the need arises. They also plan to set up a central laboratory for fusion work if this is shown to be necessary. Their general policy is to concentrate the fusion work in order to counteract the dispersion tendency. They are offering 5 or 6 scholarships to the Saclay fusion courses this year and 8 scholarships at Munich in order to help with the training of staff.

Some of the members of the Study Group expressed concern that no central organization available to them existed for fusion research.

In America the policy with regard to fusion work seems to have been to let the laboratories financed by the AEC choose their own programmes within wide limits. However, behind all these laboratories there has been the general organization of the AEC forming a backbone to the whole venture. In Europe on the other hand there is no such common organization although the large national centres can be compared with the AEC laboratories in the States.

With the work of the Study Group coming to an end, there does seem to be a need for some centre to continue the initiative shown by CERN in setting up the Study Group.

5. <u>On the exchange of information between European laboratories and with those of the USA and USSR</u>.

To take again the example of high energy physics, it has been the practice for several years now for each laboratory to issue its own series of reports and to distribute them to all other laboratories working in the field. These reports are in a sense interim and do not have the same status

as publications in scientific journals. Nevertheless their circulation has been, as it were, the life blood of the high energy physics organism. It has been the function of the libraries in the various laboratories to arrange exchange schemes for these reports and nowadays the whole system is highly efficient and extremely valuable.

No such system exists generally as yet for fusion research although there is now no reason why it could not be set up. Nearly all the laboratories are equipped with reproduction facilities and are used to issuing these reports in other fields. For a healthy situation to exist it is very important to establish this exchange of information as soon as possible.

CERN has already set up an exchange scheme with the AEC for fusion reports as an extension of its normal exchange scheme for other reports, and these are now becoming available in the CERN library as they are declassified in the States. If the laboratories cannot arrange their own exchange scheme with the AEC, they could obtain the reports from CERN. It has been made clear by the AEC that it is very convenient for them to have as small a number of exchange libraries as possible in Europe. CERN also has an exchange scheme working for nuclear physics publications with the Russian laboratory at Dubna. So far this scheme has not been extended to fusion reports although this could perhaps be arranged. There exists a real need for a translation service for Russian reports. This does not necessarily mean setting up a new service since one already exists in the USA. It would suffice that European laboratories could have copies from such a service.

## PART IV. Recommendations of the Study Group.

It seems fitting that the Study Group should end its report with specific recommendations covering the objectives that it was asked to consider. These recommendations, which, the Study Group hopes, will be seriously considered by those national and international organizations that are interested in the

problem of fusion research and development in Europe, are listed below with brief commentaries on each.

1. There should be set up a regular review of the European programmes for fusion research.

It has been mentioned many times in this report that the plans of the European laboratories are very tentative and many groups are only just being formed. Also it has been pointed out that the investment programme in Europe seems to fall short of the American programme by a large factor, and the staff plans may be difficult to realize in practice. For all these reasons a regular review of the situation would be of general interest.

In particular the question of the creation of a European laboratory should be reviewed in a year's time, to see whether such a centre is then needed. There seems little doubt that a central organization could help immediately with many problems, but until it is shown that it can play a vital role in the European development of fusion that cannot be played by the larger national centres, such as establishing more extensive facilities for fusion research, the difficulties in setting it up may prove insuperable.

2. There should be set up regular scientific discussion meetings, to be held in rotation at the main European laboratories working on fusion problems.

In the USA the six-monthly AEC fusion meetings have proved to be most valuable, and something similar is required in Europe. The attendance at these meetings should be limited to about sixty people, and they should be discussion meetings, not large conferences. The Study Group has spent at least half of its time discussing general and specific fusion problems, and it is agreed that this has been extremely useful, especially for the newer groups in this field. The size of the Study Group is about thirty people and twice this size would be a maximum for a discussion meeting.

3. Encouragement should be given to schemes by which staff can work at other laboratories apart from their own.

The reasons for this recommendation have already been explained at length above (see III.3).

4. Particular attention should be paid by all laboratories and national institutes to the training of staff and the education of graduates in the universities.

This point has been dealt with under (III.3) above.

5. Laboratories should set up as soon as possible exchange schemes for reports on fusion problems.

6. Close collaboration should be maintained with the laboratories in the USA and USSR, and exchange schemes for reports set up.

This point has been dealt with under (III.5) above. It has been most useful for the Study Group to have as a member Dr. Amasa S. Bishop who has been so closely connected with the AEC programmes. Also Dr. Arthur E. Ruark, the present Chief of the Controlled Thermonuclear Branch of the AEC Division of Research, has been keenly interested in the work of the Study Group and has greatly helped in making immediately available declassified reports of Project Sherwood to the CERN library. Both Dr. Bishop and Dr. Ruark have expressed the wish for close cooperation between the AEC and European fusion work in the future. Through some common organization this problem would be simple, but it is no doubt difficult for the AEC to maintain close contact with up to thirty separate laboratories in Europe.

## PART V. Proposals of the Study Group.

In considering the draft of this report, which ended with the Recommendations given above in Part IV, the Study Group thought it advisable to make proposals on how such recommendations might be realized in practice.

The Study Group was set up by CERN, in whose Council are represented the twelve European member states. Although the members of the Study Group could no doubt go on meeting as a scientific body, this link with the Governments, now provided by the Council of CERN, would be lost should CERN withdraw its support at the termination of the present task, and the Study Group felt that some formal access to the European Governments was essential.

Three proposals covering these points are put forward by the Study Group:

1. <u>That CERN be asked to continue its sponsorship and support of the Study Group</u>.

The majority of the members of the Study Group preferred this solution and the advantages are obvious enough. However, it was recognized that although CERN set up the Study Group, its Council might feel that, since fusion research did not form part of the programme of CERN, it could not continue to sponsor the Study Group in the future. To cover this eventuality two other proposals were suggested.

2. <u>That a new Society be set up to continue the work of the Study Group</u>.

Again the majority of the members of the Study Group were in favour of proposing that a new Society be set up to continue the work of the Study Group should CERN withdraw its support. There already exists in Europe a Society called the European Atomic Energy Society, whose aims and objectives are very similar in the field of fission to the recommendations listed above for fusion research. Consequently, the Statutes of the E.A.E.S. were modified to suit the needs of fusion research and are presented in Appendix I as suggested Statutes for a European Society for Controlled Thermonuclear Research. The recommendations of the Study Group appear as the aims of this new Society.

3. <u>That the European Atomic Energy Society be asked to expand its aims and interests to cover fusion research</u>.

A small minority of the members of the Study Group preferred that,

instead of setting up a new Society, the E.A.E.S. be asked to expand its aims and interests to cover fusion research. This is a possible solution, but not one preferred by the majority of the members of the Study Group who felt that, failing the support of CERN, it would be better to set up a new Society with the problems of fusion as its sole interest.

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J.B. Adams
Chairman

Encl. Appendix I

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# EUROPEAN SOCIETY FOR CONTROLLED THERMONUCLEAR RESEARCH

## S T A T U T E S

I. Aims of the Society.

The main aim of the Society is to promote cooperation in controlled thermonuclear research and development. To achieve this aim the Society will:

a) Arrange regular international meetings of scientists and engineers working in the field of controlled thermonuclear research and development.

b) Promote the circulation of reports and other information between European laboratories.

c) Promote the exchange of information and reports with other countries outside Europe and, if possible, establish a centre of information for such reports somewhere in Europe.

d) Establish a centre of information on the availability of equipment and materials for C.T.R. work.

e) Promote the exchange of staff between laboratories engaged in C.T.R. work.

II. Membership.

1. The founding of this Society is suggested by the "CERN Study Group on Fusion Problems", a list of whose members is given in Part I, Section 3 of the "Report of the CERN Study Group on Fusion Problems".

2. Invitations to join the Society may be issued by the Council (see Section III) to European laboratories which, in its opinion, have established controlled thermonuclear projects. In each country the invitation is to be sent to the Agency recognized by its Government to be the central agency for controlled thermonuclear research. If no such agency exists, the invitation can be sent to any organization recognized by the Government as entitled to represent the country in the Society. Invitations to join the Society can only be issued if the invitation is approved by unanimous decision of the Council and this provision of the Statutes can only be altered by the unanimous decision of the complete Council.

3. The Council can institute Associate Membership for countries outside Europe and for countries without established thermonuclear projects.

## III. Administration.

1. The work of the Society shall be directed by a Council. The Council will consist of one Delegate appointed by each Member. In all matters requiring a vote, each Delegate will have one vote.

2. There will be a Working Group to conduct the business of the Society between meetings of the Council. Each Member will nominate a Delegate to the Working Group.

3. The Council will, from its Delegates, elect annually a President, an Executive Vice-President and one or more Vice-Presidents as may be thought desirable. The Executive Vice-President will be Chairman of the Working Group.

4. The Secretariat of the Society will be provided by the Chairman of the Working Group.

5. The Council may formulate Bye-Laws on any matters not covered by these Statutes.

IV. Meetings of the Council.

Council Meetings will be called by the President, or, in his absence, the Executive Vice-President. The Council will normally meet once a year. The President must call a meeting of the Council if so requested by at least one third of the Members.

V. Finances.

The Members will cover current expenses incurred in connection with their work in and for the Society.

VI. Modifications to the Statutes.

Any Member wishing to propose changes in these Statutes shall notify the Secretariat at least three months before a Council Meeting. Notice of proposed changes in the Statutes shall be sent to the Members at least one month before a Council Meeting. No change shall be made in the Statutes except at a Council Meeting and with the approval of at least two thirds of the Delegates, subject to the reservations made in Section II, paragraph 2.

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