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PROGRESS AND PLANS

The first phase of ITER Conceptual Design Activities — the Definition Phase — was successfully concluded as planned by the end of 1988. Plans for the Design Phase in 1989–90 include the following activities and milestones.

— Throughout 1989 and 1990, seven ITER engineers and scientists will remain at Garching, facilitating project communication and co-ordination.

— Implementation of the R & D Plan by the Parties will continue throughout this 2-year period.

— Through May 1989, assigned design tasks will be performed by ITER scientists and engineers, working at their home institutions.

— A design review workshop will be held at Garching for four weeks in February–March 1989.

— Full-force joint work at Garching will resume on June 2 and continue for twenty weeks, through October 20, 1989.

Design Phase work is scheduled for completion in 1990

— Progress in design will be reviewed by ISTAC and the ITER Council in June and July 1989. The ISTAC will meet on 26–28 June and the Council on 12–13 July.

— Results of the 1989 joint work will be summarized in an intermediate report and presented to ISTAC and the ITER Council in November, 1989.

— Joint work sessions in 1990 will be nine weeks beginning in January and twenty weeks from July into November.

— Technical results of the ITER Conceptual Design Activities will be presented at the 13th IAEA Conference on Plasma Physics and Controlled Thermonuclear Research at Washington in September 1990.

— The Final Report on ITER Conceptual Design Activities will be written by the end of the 1990 joint work on November 16, 1990.

— After reviews and appropriate actions by ISTAC and the ITER Council, the Conceptual Design Activities will be concluded by December 31, 1990.

NUCLEAR ENGINEERING ASPECTS OF ITER
by G. Shatalov, Group Leader

The Nuclear Engineering Group has the responsibility during the ITER Conceptual Design Activities from 1988 through 1990 for the following areas: design of plasma-facing components, shield and blanket; consideration of tritium fuel cycle; development of the nuclear testing programme in ITER; definition of objectives, performance and operating conditions of in-vessel components; and definition of the major R & D tasks required in support of the nuclear engineering of ITER. During the Definition Phase in 1988, this work was conducted by a group of people stationed at the ITER site at Garching, with strong support of the hometeams of the four Parties. The main physical and technical results are presented below.

Erosion of plasma-facing components is a critical issue

Plasma-Facing Components -- The plasma-facing components are the first wall and the divertor plates. They must be designed to function reliably for reasonably long service times despite extraordinarily high local energy deposition rates and erosion by the plasma, which will occur during normal operation but will be especially severe during plasma disruptions.

Calculations showed that local heat fluxes to the first wall can be as high as 0.5 to 1.0 MW/m^2. Peak heat flux to the divertor plates was predicted to be up to 15–25 MW/m^2 (assuming 20-degree inclination of the plate to the separatrix) during ignited operation in the physics phase and driven operation with $Q = 10$ during the technology phase of the test programme.

The chosen material for the first wall is solution-annealed, austenitic stainless steel (Type 316). The first wall will be cooled by low-temperature (≤ 100 C), low-pressure (≤ 1 MPa) water and be fully protected by armor tiles. Design options under active consideration in the conceptual design include either poloidal or toroidal orientation of coolant channels, with or without double containment of cooling water, either mechanical attachment or brazing of graphite tiles 15 to 20 mm thick cooled by radiation or conduction.

The basic concept of the divertor plates consists of 5–10-mm thick carbon tiles brazed onto a water-cooled heat sink of an alloy of copper or molybdenum. Preliminary analyses showed that tolerable static heat fluxes would be about 7 MW/m^2 if continuous, but by sweeping of the separatrix across the plates with an amplitude of about 20 cm and a frequency of 0.1–0.2 Hz the allowable peak flux may be increased by about a factor of two, close to the design objective.

Erosion of the carbon armor is a critical issue. If there were no redeposition, erosion rate of carbon from the divertor plates might be on the order of several meters per burn-year, not including erosion during plasma disruptions. This latter was estimated at 0.01 and 0.1 mm per disruption for the armor on the first wall and and divertor plates respectively. However, there is reason to expect that the net erosion rate may be reduced significantly by carbon redeposition, separatrix sweeping, and use of improved materials with lower chemical erosion and lower radiation-enhanced sublimation. Nevertheless, a major critical issue for the divertor plates continues to be the lifetime of the carbon armor. It is foreseen that in the physics phase of the test programme, after about 100 major disruptions the plates may have to be replaced. During the technology phases, although it is assumed that there will be very few disruptions, the carbon armor will not survive as long as desired unless the net erosion can be reduced by about a factor of one hundred below the prediction without redeposition and separatrix sweeping. For this phase of the test programme, the backup option of plates with high-Z armor is being considered.

The neutron wall loading that can be achieved without exceeding the limits on heat fluxes to the divertor plates and first wall were determined for various plasma scenarios. Results are as follows.

Predicted Limits on Neutron Wall Loading* (MW/m^2)

	Ignited Operation	Driven Plasma Operation	
	$Q \simeq \infty$	$Q \infty 10$	$Q \infty 5$
Limited by allowable:			
1. Divertor heat flux, with effective sweeping	1–1.3	0.7–0.9	0.4–0.5
2. First wall heat flux, allowing 3.10^4 pulses	1.4–1.7	1.2–1.5	1–1.2

* The range of values indicates the worst and average case of radiated power to the first wall.

Thus it is evident from the analyses during the Definition Phase that the performance of ITER may be critically constrained by the allowable conditions at the divertor plates, particularly during operation with a driven plasma.

Candidate blanket concepts are being evaluated

Blanket and shield — After consideration of a wide range of options for the blanket, three concepts, which are believed to have the potential to meet ITER's goals, have been selected for more detailed studies over the next year. These are:

— aqueous-salt concept
— solid-breeder concept
— lithium-lead concept

The first option offers potential for ITER design simplification but has limited reactor relevance. The other two are supported by a reasonable world-wide R & D programme, have more reactor relevance, and are judged to have acceptable risks. Each concept has its own particular advantages and disadvantages. Choice among them will be made during the design phase of ITER project.

Shielding will limit heating and radiation damage

The radiation shield of ITER is designed to protect TF magnet materials and to provide side shielding for the larger penetrations in the blanket and vacuum vessel (e.g. NBI ports, RF launchers, pumping ducts). The limiting criterion during the Physics Phase is the total nuclear heating in magnets. In the Technology Phase it is local radiation damage of electrical insulating material.

Within the constraints of the reference design, 85 cm is available on the inboard side of the plasma between the first wall and the TF magnet coils. Current design parameters for the TF coils are maximum insulator doses of $\sim 2 \times 10^9$ rads and total nuclear heating rates of 10–15 kW (assuming a thicker outboard shield/blanket). In principle, the shield thickness could be reduced either by accomodating higher nuclear doses and heating in the coils or by including in the shield substantial amounts of a heavy material like tungsten with its disadvantages of cost, afterheat and difficult fabrication.

Preliminary consideration was also given to the design of local shielding around major penetrations for vacuum pumping and plasma heating systems. A typical port cross section is 1 m $\times$ 3.5 m and will require a minimum shielding of 40–50 cm near the back of the shield and 70 cm or more in the near-plasma region.

Tritium fuel will be contained and recycled

Fuel cycle — The ITER facility must provide for recovery and reuse of tritium and other hydrogen isotopes in a closed cycle. It will include fuelling and plasma exhaust processing, blanket tritium recovery and processing, processing of various liquid and gaseous streams, and solid wastes. Fuelling for ITER will be based on gas puffing, likely in the upper divertor region. Pellet injection will be provided for control of edge density profile and to assist fast ramp-up of the density. Typical pellet injector parameters would be: velocity 1.5–2.0 km/s, repetition rate 1.0–3.0 Hz, and pellet radius 0.2–0.5 cm.

The effective pumping speeds for He at the divertor exit must be in the range of 300–700 m^3/s. Duct diameters, especially in the divertor region, must be as large as possible.

Key issues in tritium recovery were identified for the three proposed blanket concepts. For self-sufficiency, about 130 g of tritium per day must be recovered from the blanket during continuous operation. The technology for plasma exhaust processing is in an advanced state and can be demonstrated within the ITER project design phase time-frame.

Nuclear testing — ITER will provide the first opportunity for testing fusion nuclear components in the actual fusion environment. ITER is considered a crucial step in fusion technology to accomplish the following objectives:

1. Provide fusion integrated testing data to calibrate results from non-fusion facilities and to verify theoretical models and design codes.

2. Provide data for comparison of candidate concepts for nuclear components; the data should be definitive enough to permit selection of the best reactor relevant concepts for the devices beyond ITER.

3. Demonstrate tritium self-sufficiency.
4. Demonstrate performance levels that extrapolate to reactor conditions.
5. Demonstrate adequate level of reliability for the fusion nuclear components.

Neutron flux from ITER plasma will support testing and demonstrations

ITER parameters could satisfy most of these objectives. The first wall load on the level of 1 MW/m^2 provides conditions which adequately simulate temperature gradients, thermal stresses and nuclear reaction rate in the blankets being considered for later demonstration reactors. The nuclear scoping study requires approximately 1 Mwa/m^2 of neutron fluence which corresponds to the ITER operational goal, to provide significant data. However, if the possibility exists to operate ITER to about 3 Mwa/m^2 (which is the ITER design goal), concept verification studies can also be carried out.

The design of ITER should, to the maximum practical degree, incorporate different types of testing devices ranging from submodules to full outboard sectors and provide the ability to exchange modules in a short period. At least eight modules with dimensions 1 m × 2 m × 0.5 m and two outboard sectors would be necessary for adequate testing of blanket/first wall options and materials considered as reactor-relevant.

SYSTEMS ANALYSIS FOR ITER
by H. Iida, Group Leader

The responsibilities and activities of this Group are quite diverse, including parametric analysis, cost analyses, and consideration in the ITER design of safety and environment, reliability and availability, site criteria, plant layout, etc. Such a wide variety of activities requires experts from many fields to perform the associated tasks. The Group consists of eight persons, two from each ITER Participant. Although the members of this group tend to be generalists with a broad knowledge of fusion science and engineering, they can be divided into two categories. One category includes the areas of parametric and cost analysis; in this group, the experts have in-depth understanding of the present tokamak physics and engineering and use "systems" computer codes as powerful tools in their work. The second category includes participants who have a broad scientific and engineering knowledge not only of the basic tokamak but also of the total fusion plant and associated systems.

Systems analyses aided choices of ITER parameters

In the Concept Definition Phase, the Systems Analysis Group had the exciting task of helping to guide and define the particular device parameters most appropriate for ITER. Accordingly, most emphasis was placed on the parametric analysis work. International activity on parametric analysis studies in INTOR workshops demonstrated that each of the four ITER participants had developed a computerized "systems" code particularized to the needs of their national programme. Working together on ITER during the five-months Definition Phase, we learned and demonstrated that the parametric analysis codes produce quite similar results when given the same assumptions and input. Such comparable output was not only encouraging, but essential for convincing non-systems code advocates.

The task of selecting a region of desirable design space required that the ITER device be capable of achieving the sequential objectives of ignition and steady-state burn. Based on present understanding of plasma confinement and associated models for scaling to the ITER conditions, it was found that a meaningful formulation for discussing the design space was in terms of the plasma current, I, and aspect ratio, A (major radius/plasma radius). A typical example is shown in Fig. 1, which samples the design space for a range of plasma current from 10 to 30 MA, and aspect ratio from 2.5 to about 4.8.

Constraints on the design space are established by several different considerations. Interpretation of all confinement scaling evidence suggests that the enhancement factors (improvement factors) of energy confinement required for self-ignition might be at most 2.0. This requires that ITER be located to the right of this constraint curve in Fig. 1. A second constraint is dictated by considerations of reasonable radial build of the tokamak; i.e. that sufficient space be allowed for the central solenoid and inner leg of the TF coil. The resulting constraint (not precisely defined since there is some arguments of choice here) provides a reasonable lower limit to the aspect ratio one can choose; therefore the desirable space lies below the radial build constraint region shown in Fig. 1. These are additional considerations. The total fusion power is judged best to be less than 1 GW. For steady-state operation, additional considerations are: 1) to achieve a neutron wall loading, (>0.8 MW/m^2), that provides the desired environment for testing, 2) to achieve a minimum Q (>5), and 3) to limit the required power needed to drive the current, (<100 MW). Curves of reasonable choices for these constraints are also indicated on Fig. 1. Finally, to limit the overall cost of the device, the size should be as small as other considerations permit.

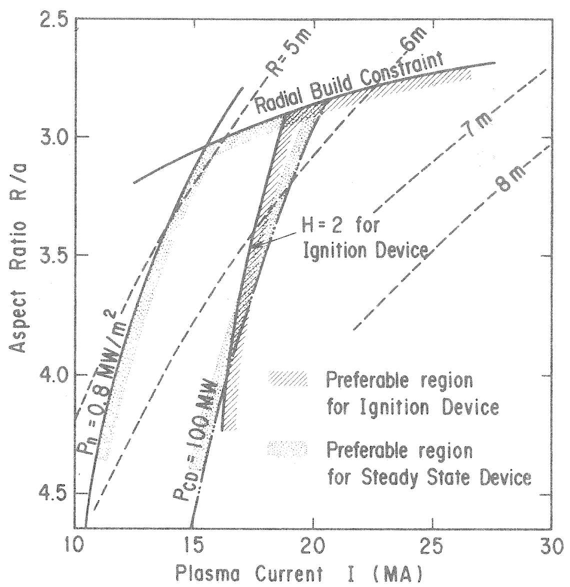

Fig. 1 Preferable parameter regions for Ignition and Steady State Device

ITER dimensions meet needs for both ignition and steady burn

When all of the data are examined, the best compromise from the point of view of attaining ignition with a reasonable power level and with a reasonable cost is for a device with parameters near I = 20 MA and A about 3. As indicated, these parameters also turn out to be a reasonable design point for steady-state operation.

Although considerable emphasis was placed on the parametric analysis effort during the Definition Phase, substantial progress was made in the other Systems Analysis areas to define the programmatic needs and to establish initial foundations for the later Design Phase work. Such foundations were established in the cost analysis area by creating a comprehensive cost center breakdown. With regard to safety and environment, world-wide input was obtained on radiation protection and targets were established for use in ITER. In the area of reliability and availability, a first plant evaluation was performed to develop a priority ranking of the key components judged to contribute most to the overall unavailability of the plant. Plant services provide mostly an auxiliary function to the basic tokamak, but are very significant to the overall cost; in addition, they may put additional constraints on the design of the main reactor systems. During the Definition Phase, initial plant considerations were developed and initial estimates made for a number of important plant services system.

The Definition Phase was a very useful, productive, and enjoyable time for the Systems Analysis group. Creative and effective progress was made in all areas of responsibility and the foundation was established organizationally and technically for the important work of the Design Phase.

Editor's Note

The extended period of joint work at Garching in 1988 was for many fusion scientists and engineers an introduction to life abroad. As foreshadow of the much larger international community that would have to be involved in detailed design, construction and operation of ITER, the favourable experiences were valuable in themselves. In keeping with the ITER Council's policy for the Newsletter — to depict personal and institutional involvements as well as technical facts — the impressions of an articulate spouse were solicited. The result is the following personal article by the British wife of an American physicist at Garching.

REFLECTIONS OF AN ITER SPOUSE
by Joy Perkins

Thermonuclear fusion may be the most difficult technological challenge facing mankind, but getting used to another country's plumbing can be quite a challenge too!

Families were accommodated at Garching during joint work

The ITER team that worked from May through September in Garching comprised scientists and engineers from the European Community, Japan, the USA, the USSR and Canada. Many of them were joined by their families for all or part of the five months. Our housing was provided by the Max-Planck-Institut für Plasmaphysik so, thanks to Frau Dietrich and all at IPP, we moved into spotlessly clean, fully equipped (even the phones and electricity already worked) guest apartments.

For the team members there were some initial problems, such as establishing computer links between home and host sites; but they had the benefits of being all together in the ITER building, with all team members able to use English as a working language. For the ITER spouses, spread all over Garching and facing the necessity of using German as our working language, our first problem was learning to be a "Hausfrau". Often we saw one another in the local supermarket, with our phrase books, trying to translate labels with intimidating compound words, such as "Rindfleischgeschnetzeltes" (stewing beef) into Japanese, Russian or English. (Yes, I know you think we all spent our summer absorbing great art and architecture and studying the German philosophers but actually it was rather different!)

Many of us were already well-travelled as tourists but ill-prepared for spending two mornings a week trying to outsmart a German washing machine. They seem to want to pre-wash and then boil, producing what is probably the cleanest wash in the world but taking 1 3/4 hours to do it. Thus the laundry room was another likely gathering place for ITER people — armed with our phrase books again, of course.

Similar conversations occurred in many homes as couples compared their day's achievements:

He: "Hey, I got my international computer link working today!"

She: "That's nice, dear. I got the washing machine to pump out the water instead of my emptying it with a cup!"

or:

He: "This is nice, dear. Is it chicken?"

She: "Er,... probably".

Learning led to pleasurable experiences and acquaintances

It was not long, however, before most of us got the hang of day-to-day living and found we had time to get to know our neighbours and the other ITER spouses. The village of Garching has a Newcomers Club for this purpose. Although it closed down for the summer, we were able to attend the last few meetings - enough to make us realize we needed to organize ourselves better. Many of us rented bikes so we could explore rural Munich and started to enjoy ourselves here. Suddenly, we found our time over for the first (definition) phase of ITER. We realized that we would miss the glorious Bavarian summer flowers, the street cafes and beer gardens — not to mention the ease of travel on the fast Autobahns.

So...what did we learn? Will we do it again next year? What will we do differently? Most of the spouses wished they spoke better German. Although the Germans are used to foreigners and try to be helpful, with language limitations one's conversations with neighbours remain superficial and frustrating. Tourist German is fine for ordering two coffees and an ice cream but not sufficient for asking the "Hausmeister" to mend a dripping tap or the "Friseur" to trim just one centimeter (and no more) off all round with any degree of confidence.

Many of the ITER spouses also wished they'd gotten to know one another earlier. One practical incentive is the ability to network information, such as where to buy familiar items from home: such as maple syrup, soy sauce, caviar, peanut butter, seaweed and the like. Of course, you can find things on your own but you are very often wasting time "re-inventing the wheel". Secondly, it is more fun to do something in a group — especially if you have young children and need help to get around.

Experience will help future participants

If anyone reading this is considering coming in 1989 or 1990, you would be well advised to talk to someone from the 1988 team before packing. The "meaning of life" may have kept philosophers worried for thousands of years but the "quality of life" — in all its day to day trivia — deserves a few hours consideration too! For example, if you know ahead of time that it is customary to bring a gift ("Mitbringsel") whenever you visit here you can pack some items from your home country that your host will really enjoy. Likewise, some traditional stationery for "Thank you" or invitations. Your own cook-books and measuring cups would be useful, but be prepared for surprises — some of us found the sugar here gave results very different from what was expected! Maps and guide books in your own language need to be purchased at home. Also, reading material in your own language is something you'll really appreciate; bring it with you — it is hard to find here. It may be fun to have a vacation where you don't look at a newspaper for two weeks but you'll be surprised how much you miss it after three weeks! Personally I've always had the horrors of a British tourist who is forever searching for a "decent cup of tea" or the US equivalent who wants to find a McDonald's next to every ancient monument. However, if you're moving here to live, you'll find the comfort of your own pillow, your own brand of deodorant or your own washcloths to be very important to your feelings about the quality of your life. Bringing them with you saves wasted time searching for them here. This gives you the chance to make friends with your neighbours and the ITER participants and to enjoy your stay in Bavaria.

ENHANCED ITER SUPPORT THROUGH USE OF EXISTING BILATERAL ARRANGEMENTS

by Michael Roberts, Director of International Programmes, Office of Fusion Energy, U.S. Department of Energy

Existing programmes help meet ITER R&D needs

The ITER Conceptual Design Activities involve all four major fusion programmes and all elements of tokamak fusion science and technology. The same programmes and elements are also involved in other international arrangements, both bilateral and multilateral. Experience with these arrangements and with the IAEA's quadrilateral INTOR workshop series was invaluable in the establishment of the firm programmatic basis for the successful joint work on ITER. Now these other arrangements are proving very helpful in addressing ITER R&D needs, longer-range as well as near-term.

From the beginning of ITER planning, it was foreseen that existing arrangements would be employed in co-operation on those R&D tasks that are necessarily an integral part of the ITER Conceptual Design Activities in 1988–90. The Terms of Reference say that such R&D "will be performed ... using existing bilateral and multilateral arrangements ..." A further significant development in the first months of joint work on ITER, moreover, is the increasing utilization of those existing bilateral and other multilateral arrangements to support ITER more broadly.

Formal bilateral or multilateral programme plans for broad support of ITER are generally not yet in place. This is primarily because most senior programme policy groups overseeing these international agreements meet on an annual cycle and so have not yet had an opportunity to address specific proposals for such ITER support based on the completed Definition Phase work. Nevertheless, pertinent statements by fusion programme leaders in the records of discussions at recent bilateral meetings clearly indicate interests and intentions which have led or are expected to lead to enhanced support for ITER. Following are some notable examples.

From the record of the April 1988 US/EC Fusion Co-ordinating Committee Meeting:

"Ch. Maisonnier observed that the recent development of the ITER activity offered the two fusion programmes a useful means of improved focusing of co-operative activities."

This observation led to a broader discussion of how use of the ITER process could be of benefit to fusion work generally. It further led to a discussion on how to deal with the larger body of required R&D not within the three-year horizon of the present ITER agreement. The net outcome of this and similar discussions in other bilateral fora was the recent Council agenda item dealing with co-ordination of voluntary R&D, provided on a best-efforts basis.

From the record of the April/May 1988 Meeting of the US/USSR Peaceful Uses of Atomic Energy Co-operation Joint Committee:

"The Joint Committee then recommended that the (subordinate, US/USSR) Joint Fusion Power Co-ordinating Committee (JFPCC) use bilateral efforts to be supportive of ITER to the greatest extent possible in both the 1988 and 1989 programmes."

This policy guidance led to agreement at the October 1988 JFPCC meeting to entertain the invitation of scientists from the other ITER Parties to selected bilateral US/USSR activities as appropriate. As an example of appropriateness, the Summary Report from a US/USSR fusion materials technical workship that was held just before the JFPCC meeting contains the following point:

"Task 6 provides for research on the reference materials for ITER, including materials for various categories of ITER applications as may be mutually agreed."

The JFPCC meeting record acknowledges this by stating:

"The joint planning in the area of controlled fusion materials is mainly oriented to the solution of practical R&D problems for ITER."

From the record of the May 1988 meeting of the Japan-US Co-ordinating Committee on Fusion Energy:

"Professor Miyajima emphasized that the importance of R&D based on international collaboration has increased greatly as the research equipment has grown larger. In particular, he spoke about the significance of the new ITER activity in aiding further collaboration." "In Dr. Clarke's remarks, he stressed the unifying focus ITER was bringing to the international fusion co-operative programmes worldwide which would enhance the effectiveness of overall fusion resource use." "The Executive Secretaries were asked to follow through on these points: ... The concept of providing relevant information on bilateral activities to the ITER Newsletter was endorsed."

This policy guidance led to the idea of developing articles such as this one and to the idea of providing to the ITER community knowledge about relevant bilateral meetings which could be used in an effective manner to enhance ITER work.

The practical outcome thus far of these supportive statements by programme leaders has been: impetus for improved co-ordination of voluntary R&D for ITER, sharpened focus of bilateral activities on ITER needs, and increased awareness of all ITER Parties of relevant bilateral technical meetings.

ITER Management Committee is informed of pertinent meetings

Bilateral topical meetings are usually held throughout the year. Each of the bilateral groups has agreed to inform the ITER Parties through the IMC and the ITER Newsletter concerning meetings pertinent to ITER. The IMC may then inform the bilateral meeting hosts of its interest and desires for invitations.

Recent and current one-to-two-week bilateral workshops that are relevant to ITER include the following.

US-Japan

P129	Radiation Damage: Theory and Calculation	Japan

Q103	Evaluation Study on Tritium Breeding Design of Near-Term Reactor	US
P134	First Wall In-Vessel Materials for ITER and Beyond	Japan
Q106	Tokamak Physics Issues/Structure of Boundary Plasma	US

US-USSR

I.8	Design Review of Electromagnetic Systems for Tokamaks	USSR
II.5	Comparison of Liquid Metal Blanket Approaches and Experiments	US

Contacts for further information are the Executive Secretaries of the various bilateral agreements:

for the United States:	M. Roberts, USDOE
for the European Communites:	E. Canobbio, CEC
for the Soviet Union:	B. Kuvshinnikov, SCAE
for Japan:	A. Oikawa, STA and M. Honma, Monbusho

In addition to the bilateral agreements referenced above, there may soon be others that could offer additional opportunities for ITER R&D support. There is shortly to be a new fusion bilateral agreement between the EC and Japan.

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