Appendixes

Non-Electric Applications of Fusion[1]

The baseline D-T fusion reactor discussed in chapters 4 and 5 produces energetic neutrons as its immediate output. In an electric generating station, the energy of these neutrons would be recovered as heat and used to generate electricity. Other possible applications of D-T fusion technology might use the neutrons themselves to produce fission or fusion fuels or to induce nuclear reactions that change one isotope or material into another. Applications of fusion as a neutron source and other non-electric applications of fusion energy are discussed below.

Fusion as a Neutron Source

Each D-T reaction in the plasma produces one neutron, which is needed to breed tritium to replace that used in the reaction. However, additional neutrons can be generated by neutron multipliers i n the reactor blanket.[2] These "excess neutrons" are available to make up for losses as well as for other purposes, such as the production of materials in the reactor blanket. Therefore, fusion reactors could be used as neutron sources in addition to sources of electricity.

If it produced a sufficiently valuable product, a fusion neutron source would not need to generate net electric power to be cost-effective. In practice, however, few if any such products exist; system studies show that a fusion reactor serving as a neutron source will probably also need to produce electric power to be economically viable. (A possible exception, tritium production, is discussed below.)

Fusion-reactor neutron sources could have significant advantages over fission reactors, the major existing large-scale sources of neutrons. A suitably designed fusion reactor would generate only about one-sixth the heat of a fission reactor with the same neutron output. Furthermore, the energy of the fusion neutrons is several times higher than the energy of fission neutrons, thus permitting applications that are not possible with fission.

Tritium Production

One application of a fusion-reactor neutron source would be production of tritium beyond that needed to fuel the fusion reactor.[3] As discussed in chapter 4, tritium self-sufficiency is a key issue for a fusion electric power reactor;[4] it is especially difficult to design a power-producing reactor capable of producing substantial amounts of excess tritium. However, tritium production can be enhanced at the expense of electricity generation.

Tritium has several industrial, medical, and military applications; its largest user is the nuclear weapons program. Tritium is radioactive, with 5.5 percent of the tritium stockpile decaying each year. Therefore, the tritium supply for nuclear weapons requires constant replenishment even if no additional weapons are built. Four fission reactors are operated for the Department of Energy (DOE) in Savannah River, South Carolina, to produce tritium for nuclear weapons. These reactors are currently about 35 years old, and they will soon need replacement.

A recent National Research Council study found that **although fusion reactors have promising features for breeding tritium, fusion technology is not yet sufficiently advanced to expand or replace the Savannah River facilities.**[5] The engineering development and testing needed to create reliable fusion tritium-breeders cannot be completed by the time decisions must be made concerning the Savannah River reactors. Nevertheless, the study also concluded that fusion has potential for producing tritium, and that DOE should "undertake a program that analyzes and periodically reassesses the concept, including design studies, experimentation, and evaluation, as fusion development proceeds."[6]

Fusion technology could be applied to tritium production without necessarily altering the technical course of the civilian magnetic fusion research program. However, if use of fusion technology for tritium production were to precede its commercial application as a civilian electricity generating technology, the fusion research program nevertheless could be pro-

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[1] Much ot the material in this appendix is drawn from K. R. Schultz, B.A. Engholm R F Bourque, E.T Cheng, M J. Schaffer, and C. P.C. Wong, *The Fusion Applications and Market Evaluation - "FAME" - Study*, by GA Technologies, Inc San Diego, CA, 1986 This study was done under contract to the Department of Energy's Office of Fusion Energy

[2] Neutron multipliers are discussed in ch 4, box 4-B

[3] Tritium-produc i ng fusion breeders are discussed i n N ationa l Research Council, Committee on Fusion Hybrid Reactors *Outlook for the Fusion Hybrid and Tritium-Breeding Fusion Reactors* (Washington DC National Academy Press, 1987), pp. 94-110. See the following section of t h i s appendix for definitions and discussion of fusion hybrid reactors,

[4] See the section "The Fusion Blanket and First Wall" in ch 4

[5] National Research Council, *Outlook for the Fusion Hybrid and Tritium-Breeding Fusion Reactors*, op cit , p 16.

[6] Ibid

foundly affected. On one hand, the nuclear weapons program would shoulder some of the development costs and would provide a near-term motivation for supporting fusion research. Furthermore, associating fusion R&D with the nuclear weapons program would ensure it a higher national priority.

On the other hand, **associating fusion power with the nuclear weapons program could also become a severe liability in terms of public acceptance.** Moreover, since the technical requirements for breeding tritium and producing electricity are different, features of the tritium-breeder design would not necessarily be applicable in an electric power reactor. The institutional experience gained in developing, building, and operating a military tritium-breeder may be even less transferable to a civilian power reactor than the technical experience because, at present, regulatory mechanisms for the two are so different.[7] For all of these reasons, adopting the technological or institutional framework from a military tritium-breeder to the civilian fusion program could seriously compromise the future acceptability of fusion power.

Fissionable Fuel Production or Use

In a *fission/fusion hybrid* reactor, excess fusion neutrons are used to breed fissionable fuel or to induce fission reactions within the fusion reactor blanket. There are, correspondingly, two different types of fission/fusion hybrid: one that uses fission reactions in its blanket to multiply the energy generated in the fusion core, and one that suppresses blanket fission reactions to generate fissionable fuel for use i n pure fission reactors. The former type, the "power-only" hybrid, does not produce fissionable fuel. The latter, or "fission-suppressed" hybrid, does not produce much of its own power from fission reactions; instead, it transforms "fertile" materials that are not readily fissionable into fissionable fuels such as uranium or plutonium. In both types of hybrid, the total energy released (or made available) is much larger than that available from fusion reactions alone. [8]

Since most of the energy generated in a power-only hybrid is due to fission reactions, the amount of fusion power generated by such a device need not be large. Therefore, the fusion core of a power-only hy-

brid would not need to achieve as high a level of performance as the core of a pure fusion power reactor in terms of parameters such as energy gain. [9]

In combining the fusion process with fission, a hybrid reactor could also combine their liabilities. Since hybrid reactors involve the production and/or use of fissionable fuels, their environmental, safety, and proliferation concerns are more serious than those of pure fusion reactors; many of the environmental and safety concerns of nuclear fission, both perceived and actual, could be transferred to the hybrid. Furthermore, a complete evaluation of the fuel-producing hybrid must include the client fission reactors. **If the incentive for pursuing fusion research is to provide an energy alternative that is environmentally or socially preferable to nuclear fission, then combining fusion with fission in a fission/fusion hybrid reactor might not accomplish that goal.**

The economic justification for hybrid reactors is weak at present because the price of uranium fuel is so low. According to the National Research Council hybrid study, uranium prices must rise by a factor of between 6 and 20 for a fission/fusion hybrid to be economically attractive.[10] The study concluded that accelerated use of fission reactors in the United States, coupled with policy decisions requiring U.S. reactors to be fueled with domestic uranium supplies, could increase the domestic price of uranium by a factor of 10 by the year 2020. However, a more likely rate of fission growth would cause prices to reach this level sometime between 2020 and 2045, and relaxing the constraint on domestic supply would delay such a price increase for an additional 30 years. Therefore, the NRC study concluded that fission/fusion hybrids will probably not be economically justified in terms of increased uranium price before the middle of the next century.

Several additional factors besides the price of uranium affect the economic viability of fission/fusion breeders. First, advanced-converter fission reactors that use uranium much more efficiently than present light-water reactors would be less sensitive than present reactors to the price of uranium. Development of these more efficient reactors would further delay the time when breeders would become attractive. Second, any discussion of hybrid breeders must compare them to pure fission breeders, which can also produce fissionable fuel. Such a comparison is beyond the scope of this study.

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[7] Weapons-related DOE facilities are not now subject to the same process of Nuclear Regulatory Commission and National Environmental Pol Icy Act review that governs civilian nuclear facilities. However, publ Ic pressure for Increasing the regulation of military reactors is growing.

[8] Energy multiplication occurs because a fission reaction releases about 10 times as much energy as a fusion reaction. Each excess neutron that induces a fission reaction In the blanket releases many times more energy than it originally carries. (The same energy multiplication occurs when fissionable material produced In a fusion reactor is removed to fuel external reactors, except that the additiona l energy IS released In the externa 1 reactors and not in the fusion blanket.)

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[9] Energy gain is discussed I n the section of ch. 4 titled "Sclentklc Progress. '

[10] National Research Cou ncil, *Outlook for the Fusion Hybrid and Tritium-Breeding Fusion Reactors,* op. cit., p 8. The study estimated fission/fusion breeders to become economically viable when the price of uranium oxide reaches from $100 to $300 per pound; the price currently is $17 per pound

Other Isotope Production

With the possible exception of tritium and fissionable fuels, no materials have yet been identified that would justify building a fusion reactor for the sole purpose of producing them. To be economically worthwhile, high-value materials would have to be produced from inexpensive ones through reactions with fusion neutrons. In addition, extraction of the desired isotope from the fusion blanket could not be too expensive. Furthermore, the amount of the material produced in a fusion reactor must not be so large compared to the demand that it would saturate the market, driving down the price and destroying the value of the material.

it would be much easier to justify producing special materials or isotopes in a fusion reactor if electricity were produced at the same time. A recent study has identified cobalt-60 (^{60}Co) as an isotope that might be economically produced in a fusion electric generating station.[11] However, demand for ^{60}Co would have to be much greater than it is now for this process to be viable, since the amount of ^{60}Co that could be produced annually in a single fusion reactor is much larger than the present annual demand.

Cobalt-60 is an intensely radioactive material whose primary use is in sterilizing medical products, with secondary uses in providing cancer radiation therapy and food preservation via irradiation. Food preservation, in particular, could be a rapidly growing application. Furthermore, ^{60}Co also could be used to treat sewage by sterilizing it, although this application has yet to be commercialized. It is possible, therefore, that ^{60}Co demand might increase substantially.[12]

The worldwide demand for replenishing existing ^{60}C0 stocks is currently estimated to be about 11 megacuries per year,[13] most of which is produced by Atomic Energy of Canada, Ltd. in the heavy-water moderated CANDU reactors operated by Ontario Hydro. A commercial fusion power reactor could produce hundreds of megacuries of ^{60}Co per year with a blanket optimized for ^{60}Co production. Therefore, this application is viable only at greatly increased demand levels; depending on its increased use for food

preservation, the annual growth in this demand over the next several years has been estimated at 6 to 25 percent.[14]

Radioactive (Fission) Waste Processing

In theory, the neutrons from a fusion reactor could be used to change radioactive fission wastes into shorter lived materials that would decay more quickly, posing less long-term hazard. However, **several studies in the 1970s analyzed fusion's capabilities to process radioactive waste from fission reactors, and the results were not promising.**[15] These studies determined that extremely high levels of fusion reactor performance and decades of neutron irradiation would be required, along with advanced isotope and chemical separation processes. Even if these requirements were met, it was unclear whether this approach offered a net advantage over waste burial. The benefit of reducing the long-term hazard associated with fission wastes would have to be balanced against the technological difficulties associated with transforming them, as well as the short-term risk of releasing these wastes i n an accident at the processing facility.

Other Possible Nonelectric Applications of Fusion

Synthetic Fuels

Currently, about two-thirds of all energy used in the United States is consumed directly by users in the form of fossil fuel; only one-third is used to generate electricity, Although the trend in future energy use is towards increasing electrification, many requirements for non-electric sources of energy such as liquid or gas fuels will likely remain.

It may be possible to take advantage of the high temperatures present in fusion reactors, along with the electricity generated by them, to generate hydrogen gas by decomposing water into hydrogen and oxygen. Hydrogen has applications either directly as a fuel or in the synthesis of liquid fuels. The GA fusion applications study indicated that fusion might be an economically competitive source of hydrogen i n the long term but did not demonstrate a clear advantage over high-temperature fission-based sources of hydrogen that could also be available by the time fusion is commercialized.

[11]B A. Engholm, E.T. Cheng, and K R. Schultz, "Radlolsotope Production In Fusion Reactors, " GA Technologies Inc. San Diego, CA (undated) This article was prepared as part ot' the "Fusion Applications Studv" by K.R Schultz, et al., 1986.

[12]Ibid., p. 2.

[13]One Curie of an radioactive substance is the amount that produces 3 7 X 10^{10} radioactive disintegrations per second: 1 megacurie is 1 million curies One curie ot pure ^{60}Co would have a mass ot 0.88 milligram, and 11 megacuries w ou Id have a mass of 9 7 kilograms (2 1pou rids) (Actual ^{60}Co sources do not consist ot pure ^{60}Co in practice, less than 10 percent of the cobalt in a ^{60}Co source consists of the ^{60}Co isotope I n 1984, the price ot ^{60}Co w as about $1 00 per curie (Ibid , pp. 2-3)

[14]Ibid., p 3

[15]For a review ot these studies see Schultz, et al , Fusion *Applications Study* Op Cit. pp Y-1 o

Process Heat

Another energy requirement currently satisfied by non-electric sources of energy is process heat. Process heat is less transportable than electricity; it must be used at locations close to the generating site. Moreover, although there are many users of process heat, few require more than a few hundred megawatts each. Essentially all of these users now use fossil fuels. Present fusion reactor designs would produce on the order of 3,000 megawatts of heat (corresponding to 1,000 to 1,200 megawatts of electricity at 35- to 40-percent conversion efficiency), and there would be little motivation to construct such a fusion plant dedicated solely to the production of process heat. There does not even appear to be significant economic advantage associated with recovering waste heat produced as a byproduct of electricity generation. **Process heat does not appear to be an attractive use for fusion reactors as long as fossil fuels are available.** This conclusion is supported by present-day experience with nuclear fission powerplants, which are not used for process heat production in the United States. In the far future, if fossil fuels become too expensive or too difficult to use in an environmentally sound manner, fusion could become attractive as a source of process heat due to lack of an alternative.