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RELATIVISTIC HEAVY IONS FOR FUSION APPLICATIONS*

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This is a brief description of what a thermonuclear power generating station might look like in 6-10 years from now. The plant consists of four major systems which differ from conventional stations. One is the thermonuclear reaction vessel, designed to absorb the neutron energy released upon ignition of a pellet of fusile material. The second major system is the pellet compressor system. The third consists of the fuel system, i.e., the pellets themselves. The fourth system, the igniting system, will make up the bulk of this paper, because it is primarily this system which involves accelerator technology. The essential ingredient in this design lies in the fact that no substantial extrapolations of existing technology is necessary to build these components. The component systems can all be designed and built today. Nuclear reactors took more than twenty years to get from a demonstration of feasibility to an economically viable source of energy. It is obviously premature, at this stage in the development, to anticipate all of the problems. Nevertheless, we will review systems bearing costs in mind, only for the purpose of avoiding being led too far astray.

I. Reaction Vessel

The reaction vessel must provide neutron shielding. Therefore, it will require shielding thickness of $\sim$ 3-5 meters, or more. This somewhat sets the scale for the device. That is, an inner radius of an economic boiler will probably be at least 3-5 meters also. Taking a neutron absorbtion of $\sim$ 100 g/cm^2, we see that we have a mass of at least 2×10^8 g to absorb the neutron energy. With a specific heat of $\sim$ 1 J/g/^{o}C, and a 100^{o}C rise/shot, we arrive at $\sim 2 \times 10^{10}$ joules/shot. It is likely that the final solution will wind up between 10^9 to 10^{11} J/shot. Since it is not necessarily more difficult to ignite a large pellet than a small one, consideration of igniter cost push one towards larger boilers. The pellet compressor system will enjoy not having to pulse as often, but will have to expend more work to compress a larger pellet.

II. Compressor System

It requires $\sim$ 600 MJ[1] to ignite a DT pellet at solid density ($\sim 5 \times 10^{22}$/cm^3). This is a formidably large amount of energy. Since the ignition energy drops with the square of the compression factor, an $\alpha = 100$ will result in ignition with only 60 kJ. Since only about 10^{-3} of the beam energy is deposited in the critical mass, an α of 100 $\rightarrow \sim$ 60 MJ of beam stored energy. This is probably a reasonable lower limit on α. There are a number of ways compression $\geq$ 100 may be obtained, using combination of the following methods.

1. Laser compression comes immediately to mind because so much has appeared in the recent literature about attempts to compress pellets for fusion.

2. One can imagine the rapid assembly/compression of the pellet by firing very high velocity subassemblies from high powered "BB" guns.

3. High energy charged ions can produce avalanching shockwaves in a pellet, in much the same way the laser does. This is a novel way of producing shockwaves that is controllable, and relatively insensitive to the properties of the medium in which the shock is generated. Since charged particles will ultimately heat the compressed pellet, it is likely that this method will be useful to obtain some additional compression in any event.

III. Fuel Pellets

The pellet design is not completely independent of the compression and ignition systems. The principal design consideration is the ignition temperature and disassembly time. A heavily tamped pellet might be attractive because of the slower disassembly. Another important consideration, ultimately, will be fuel economy. Pellets may be designed as "breeder" pellets, to produce tritium, say, which may be necessary to get the pellet ignited easily.

IV. Igniter System

The igniter system consists of a large aperture, high energy superconducting storage/accelerator ring, along with its charging system to provide injected beam. Heavy ions may be injected repetitively using stripping foils to achieve very high brightness. If we assume an $\alpha = 100$, we have a 60 MJ beam, and if we additionally assume a pulse every 60 seconds, this leads us to a 1 MW beam power system. Typical costs for such an rf system would be an order of 10 million dollars. Sixty seconds is a reasonable cycle time for a storage accelerator with superconducting magnets. Likely costs for such an accelerator are in the range 50-100 million dollars. The power required to run the igniter system would typically be in the range 10-20 MW.

The two parameters which are of principal concern are the number of particles required for ignition, N_c, and the time τ during which they must be delivered on target. Both of these numbers depend upon pellet design consideration, and upon the compression factor. Roughly, these numbers will be as given in Ref. (1), i.e.

$$N_c \cong \frac{6 \times 10^{21}}{Z^2 \alpha^2} \quad ,$$

$$\tau \cong \frac{1.8 \times 10^{-8}}{\alpha} \quad .$$

For U ions, we get $N = 7 \times 10^{13}$, for $\alpha = 100$, and $\tau = 1.8 \times 10^{-10}$, which corresponds to a 5.4 cm long bunch. This bunch length need not exist in the storage ring, but must at the pellet location. Since, for a tightly bunched beam the space charge limit is proportional to the product of the bunching factor B times the bunch width W, we see that we can obtain tight bunching at the expense of momentum spread without substantial reduction of the space charge limit.

References

1. A.W. Maschke, BNL Inf. Report EP&S 74-3, BNL 19008 (1974).

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