JANUARY 1979

PPPL-1511
UC-20d

ENERGY STORAGE FOR TOKAMAK REACTOR CYCLES

BY

C. H. BUCHANAN

PLASMA PHYSICS LABORATORY

PRINCETON UNIVERSITY
PRINCETON, NEW JERSEY

This work was supported by the U. S. Department of Energy Contract No. EY-76-C-02-3073. Reproduction, translation, publication, use and disposal, in whole or in part, by or for the United States Government is permitted.

[illegible]

*Present Address: General Electric Company, Schenectady, New York

I Energy Transfer Mechanism

The heat transfer mechanism from the blanket to the electric power grid involves four energy transfer "loops" (see Fig. 1). The plasma reaction vessel is surrounded by a molten salt (flibe) blanket. Distributed throughout the flibe is a flibe/helium heat transfer grid of pipes through which helium flows to cool the flibe. The hot helium, in turn, is circulated through helium/steam generators to produce steam. The steam powers steam turbine generator units which deliver electric power to the power grid.

Inherent in the heat transfer mechanism is some significant energy storage capability. The blanket has heat storage capability (assuming a 100°F temperature drop) corresponding to approximately 35% of the total thermal storage requirement of 920 GJ (872 × 10^6 Btu). There is some nuclear afterheat which amounts to approximately 5% of the total requirement. There is additionally some storage in the helium and steam volumes whose contributions are assumed to be negligible.

A. Flibe Loop

The four energy transfer loops of the hybrid reactor present a variety of possibilities for energy storage. The flibe loop offers the possibilities of storage in an extra volume of flibe or in a volume of a less expensive salt via an additional heat exchanger.

B. Helium Loop

The helium loop offers the potential for incorporation of a variety of heat storage devices such as ceramic refractory blocks, fluidized beds, or steel tubes, referred to generally in this report as "hot rocks".

C. Helium/Steam Interface

The interface between the helium and steam loops offers the possibilities of integrated heat transfer and energy storage utilizing either the fluidized bed or the flash steam approach.

D. Steam Loop

The steam loop offers the possibility of storage of steam itself.

E. Electrical Loop

The electrical loop offers the potential for utilization of mechanical/electrical energy storage in the form of rotating machines incorporating flywheels, hydraulic storage in the form of pumped storage, magnetic field storage in the form of superconducting coils or electric field storage in the form of capacitors. A further possibility is modification of power grid operating procedures (and possibly configuration) to permit inherent compatibility with the reactor cycles.

II Constraints/Assumptions

The constraints and assumptions guiding this energy storage study are:

1. Electrical output to the power grid must be maintained constant at approximately 2500 MW (except for power company operating procedure discussion).

2. Steam temperature change at the steam turbine inlet cannot exceed 50^{o}F. This constraint derives from data applicable to the 1000 MW steam turbine generator units used presently in nuclear power plants. Utilization of 250 MW units might permit a relaxation of this requirement. Designs of these smaller machines have been developed to permit temperature and load cycling.

3. For metallurgical reasons, the helium temperature at the hottest helium loop point in the reactor should be limited to 600°C (1113°F). To allow a reasonable margin, a helium hot spot temperature of 550°C (1022°F) is postulated.

4. Allowable helium and flibe temperature change during the reactor downtime is judged to be 100°F. This judgment is based on the probability that flibe and helium mass flow rates can be controlled to limit the steam change to the 50°F required by the steam turbines. The helium loop cool side temperature must be maintained no cooler than 710°F to prevent flibe solidification.

5. Implementation of the energy storage concept will be achieved by methods closely approached by state-of-the-art to the extent that no breakthroughs are required.

III Energy Storage

Various energy storage methods incorporated into the flibe, helium, steam and electrical loops, and in the helium/steam interface were investigated. The preferred method, the flash steam approach is one which constitutes the helium/steam interface and which incorporates the energy storage function as well as the basic energy transfer (steam generator) function.

One disadvantage is common to several of the approaches. It is identified in the ensuing discussion as "insufficient temperature difference" and it is based on the fourth assumption/constraint which assumes a 100°F temperature excursion for the flibe and the hot side helium, and a 50°F excursion for the steam. When energy is transferred across a heat exchanger alternately in both directions (i.e., hot rocks are heated by, and then heat the helium) and when the temperature differential is small (cannot be more than 100°F, probably closer to 50°F), the heat exchanger must necessarily have a very large heat transfer area. Size and cost are consequently large.

A. Flibe Loop

Energy storage in the flibe loop appears to be relatively easy, albeit expensive, but the energy retrieval appears to present some rather severe difficulties.

1. Extra Flibe Storage

Energy storage in an extra quantity of flibe (see References 1 and 2 and Fig. 2) seems, at first glance, to be attractive. Further consideration, with particular attention to the typical flow rates, raises some question as to the retrievability of the stored energy.

Retrieval must occur within the 100-second downtime. One pass of the entire inventory of molten energy storage material is assumed. The molten salt flow rates discussed in Reference 1 speak of a normal inherent blanket one-pass time of 30 minutes (page 257) and a reduced one-pass time (page 487) of 12 minutes during reactor downtime. Incorporation of the indicated extra flibe (page 487 $\simeq$ 2 times the inherent flibe) means that it would require 3 × 12 = 36 minutes to pass all the flibe through the reactor once.

Reference 2 (page X-E-4) speaks of molten sodium flows and amounts that are equivalent to one pass of all the molten sodium through the sodium loop in 5.5 minutes. The molten sodium loop in this case incorporates the energy storage function in extra molten sodium. Normalization of the 5.5 minute one-pass time to the Reference 1 equivalent power and downtime requirements yields a 14.3 minute one-pass time, assuming constant flow.

It is significant that the typical flows of References 1 and 2, when normalized to one passage through the loop in 100 seconds, yield values from 8.5 times (Reference 2) to 22 times (Reference 1) the flows considered. It is unlikely that increasing the flow rates by these factors would be practical from either the flow characteristic or the pumping power standpoints. Redesign of the flibe system to incorporate many parallel paths, each path consisting of a pump, inherent flibe, and extra energy storage flibe could achieve the necessary one-pass time, but the pumping power requirements would be essentially the same as for the 8.5 times and 22 times flow rates.

Since the hybrid reactor flibe is radioactive, a further complication is the shielding of the extra energy storage flibe. The cost of the extra energy storage flibe alone, exclusive of the storage containers and shielding, is estimated to be of the order of 640 million dollars. The foregoing uncertainties and cost encourage exploration of other energy storage methods.

2. HTS Storage

A variation of the foregoing approach incorporates (see Fig. 3) the function of the extra energy storage flibe in the form of a far less expensive industrial type molten salt designated as HTS. This approach, however, requires an additional heat exchanger for the flibe/HTS heat transfer. The required flibe and HTS flow rates would be well above the typical flow rates of References 1 and 2. A further disadvantage of this scheme involves the insufficient temperature difference factor discussed earlier in paragraph 4 of Section II.

B. Helium Loop

Energy storage in the helium loop can be achieved using many materials and configurations, series or parallel energy retrieval paths, and special high-temperature storage heating loops.

1. Hot Rock Bed (Series)

A hot rock bed (ceramics, fluidized bed, steel tube bundle, etc.) placed in series on the hot side of the helium loop (see Fig. 4) is penalized by the insufficient temperature difference discussed above.

2. Hot Rock Bed (Parallel)

One possible approach (see Fig. 5) to improvement of the insufficient temperature difference problem is to connect the hot rock bed in parallel with the hot side of the main helium flow. By appropriate valving, and by incorporation of a special high-temperature helium heat exchanger (using special materials) in the hot portion of the flibe blanket, especially hot helium can be used to heat the hot rock bed to a higher temperature than could be attained with the main flow helium. The increased temperature differential permits reduction in the size and cost of the bed, but at the expense of the special high-temperature heat exchanger and the helium flow valving.

3. Steel Tubes

In either one of the foregoing hot rock bed approaches, the use of a pebble bed or a fluidized bed introduces the need for some kind of impurity separator to maintain gas cleanliness. A possibility that eliminates the impurity separation requirement is the use of steel tubes bundled in an outer shell, the steel itself serving as the heat storage medium (see Reference 3).

C. Helium/Steam Interface

Energy storage as an inter-loop function, integrating the interfacing of the helium loop and the steam loop, suggests two somewhat similar approaches. Both approaches incorporate dual functions into the hardware. Both the helium/steam energy transfer and the energy storage are achieved by the same equipment.

1. Fluidized Bed

The fluidized bed approach (see Fig. 6) utilizes two heat exchangers immersed in the bed, one for helium/bed transfer and one for bed/steam transfer. A separate, closed-loop helium system fluidizes the bed. The mass of bed material (graded sand) required for the heat transfer during burn is expected to be somewhat inadequate for the required energy storage. However the bed material constitutes a very small percentage of the total fluidized bed cost so the incremental cost of the energy storage feature is judged to be negligible.

The fluidized bed approach appears presently to require both technology and physical size development to become a really viable energy storage candidate. It is very probable, however, that its development may parallel that of tokamak reactors to the extent that both will mature into the hardware stage at the same time.

2. Flash Steam

a. Concept

The flash steam concept (see Fig. 7) stores energy in containers that are filled with a water/steam combination at a temperature determined by regulation of the boiling point by pressure. The containers are essentially fire tube boilers with the boiler and tube axes oriented vertically. The hot helium passes through the tubes and transfers its heat through the tube walls to the water/steam combination which occupies the spaces between the tubes and the boiler shell.

The boiler complement constitutes a series element in the heat transfer system, all of the helium/steam energy being transferred via the flash steam medium. Further, the boiler complement integrates the two functions of helium/steam heat transfer and the required downtime energy storage and recovery. During the 1000-second reactor burn, the helium transfers more energy to the water/steam combination than is demanded by the steam turbine generator units. Therefore there is an increase in the pressure, and hence the temperature of the boiler contents. A pressure regulator function governs the steam delivery to the steam turbine units. During the 100-second reactor downtime, the pressure regulator demands constant steam, thereby depleting the steam in the boilers and reducing boiler pressure. The reduced pressure lowers the boiling point of the boiler water, some of which immediately flashes into steam and lowers the boiler contents temperature. The pressure and temperature reduction continue until the next reactor burn occurs. The flashed steam drives the steam turbine generator units for constant electrical output.

b. Preliminary Design

Twelve boilers are required, each being 105 feet high and 17 feet in diameter and incorporating 4000 one and one-fourth inch tubes for an active surface area of 125,000 square feet. Each boiler is rated 250 MW electric.

Water partially fills the boiler, immersing the tubes to the 54 foot level, the remaining height being occupied by steam. Although the boilers are 105 feet high, only 95 feet of height is tubes. The remaining 10 feet of boiler is manifolding at top and bottom. Hence, 41 feet of the tube height is immersed in steam. Approximately 39 feet of tube at the bottom heats liquid water while the next 15 feet constitute the region where the steam is formed. The top 41 feet act as a superheater, perhaps making a moisture separator unnecessary.

c. Cost

The basic uninstalled cost of the helium/steam energy transfer system is estimated by Foster-Wheeler (boilers) and Leslie Company (pressure regulators) to be $145,000,000. The incremental cost of the energy storage function is perhaps nonexistent in view of the fact that the compelling factors determining the boiler design are the steam generation factors rather than the energy storage factors.

D. Steam Loop

Direct storage of steam itself necessarily calls for a much greater volume than does the flash steam approach since steam density at the pressure and temperature involved is less than 5 percent of that of water. The additional boilers re-

quired for this approach eliminate it from further considera-
tion.

E. Electrical Loop

Energy storage in the electrical loop offers possibilities ranging from mechanical/electrical storage in rotating flywheel machines to changes in power company operating procedures. Between these two extremes lie techniques to store energy in electric fields, magnetic fields, and elevated water.

Any approach to energy storage in the electrical loop is predicated on the ability to throttle the steam turbines back to some load (perhaps 20%) which permits them to ride through the reactor downtime on the energy stored inherently in the reactor energy transfer system. Although the design of the presently available 1000 MW turbine units does not permit such throttling, there are 250 MW designs that do tolerate this kind of operation. In view of the fact that twelve boilers, and associated pressure regulators, would match twelve 250 MW steam turbine units one for one, it is possible that the final plant configuration could consist of twelve 250 MW systems paralleled at the helium loop on the source side and at the electrical loop on the load side.

1. Flywheel Machine

The flywheel machine approach (see Fig 8) to energy storage in the electrical loop utilizes vertial shaft ac machines with added flywheel effect. Frequency conversion between the machines and the power grid permits the necessary machine speed excursions for energy storage and recovery. Machines similar to those procured for Princeton'a TFTR program are applicable. Ninety machines in parallel are required at a typical cost of six million dollars each, for a total machine cost of 540 million dollars.

The frequency conversion function between the machines and the power grid is estimated at $130/kW for a total conversion cost of 312 million dollars. The combined cost approaches one billion dollars, a value which encourages investigation of other approaches.

Use of homopolar machines and half the conversion (ac to dc instead of ac to dc to ac) might result in lower cost, but only if homopolar machine development is presumed to have been accomplished.

2. Superconducting Coils

Magnetic field energy storage (see Fig. 9) presumes s perconducting coils as the storage devices. Thyristor bridges are required to convert the dc of the coils to the power grid frequency. At 0.1 cent per joule of stored energy, the cost of magnetic field storage is 250 million dollars.

3. Capacitors

Electric field storage in capacitor banks has been shown in other studies to be one of the most expensive ways to store large amounts of energy.

4. Pumped Storage

Pumped storage (see Fig. 10) can be employed by integration of Pelton or Francis hydraulic turbines with the steam turbine generator units. In this case 250 MW units are considered because the extrapolation of presently available turbines and/or gears to 1000 MW units appears to be impractical within the time frame considered.

There are two possible approaches, both requiring development. Steam turbine generator unit operation is at 1800 rpm. Pelton or Francis turbine operation is in the 100 to 450 rpm range. Development is required to produce either an 1800 rpm hydraulic turbine or a 250 MWe gear.

A pumped hydraulic storage source is required to provide the typically 1000 to 2500 feet of head. A compressed air equivalent of the typical head requires a pressurized volume of water and air not unlike that utilized for the flash steam energy storage approach.

Uninstalled cost of a pumped storage complex, considering only the costs of gears or turbines (after development has been completed), pumped storage pressure tanks and pumps amounts to 75 to 100 million dollars.

5. Power Company Operating Procedures

Imaginative investigation of power company operating procedures and capabilities could result in determination of system overload capability such that the hybrid reactor downtime, with its associated reduction of output power, could be tolerated by the power grid. It is true at present that instantaneous load assumption or rejection of 1000 MW is tolerated.

6. Tokamak Commutation

An alternative possibility is installation of a sufficient number of tokamak reactor plants so that, if ten plants can carry full load, an eleventh one is provided, and the plant cycles are controlled so that no more than one plant at a time is in its downtime. The cost of this approach, per plant, is 10% of the cost of the eleventh plant, or 350 million dollars.

IV Summary

Table I summarizes the estimated costs of the various energy storage approaches considered. Many of the costs represent only a part of the energy storage hardware, but the values are high enough to indicate that other approaches should be pursued.

V Conclusions

Two conclusions result from the foregoing investigation:

1) Energy storage to ride through reactor downtime can be provided inexpensively.

2) The flash steam approach appears to be the one to pursue.

Table I. Estimated Costs of Energy Storage Approaches

	Estimated Cost Millions	Comments
Flibe Loop		
Extra Flibe	$640	Flibe Only
HTS	–	
Helium Loop		
Hot Rock Bed	$100	
Helium/Steam Interface		
Fluidized Bed	Negligible	ΔCost for storage feature (basic cost $50 million)
Flash Steam	Negligible	ΔCost for storage feature (basic cost $145 million)
Electrical Loop		
Flywheel Machines	$850	
Superconducting Coils	$250	Coils Only
Capacitors	Prohibitive	
Pumped Storage	$100	Gears/turbines, pressure tanks, pumps only
Power Company Operating Procedures	Possibly Negligible	
Hybrid Plant Commutation	$350	

NOTE: All Costs Uninstalled

References

[1] A Fusion Power Plant, R. G. Mills, ed., Princeton Plasma Physics Laboratory Report MATT-1050 (1974).

[2] B. Badger et al., UWMAK-III, A Noncircular Tokamak Power Reactor Design, University of Wisconsin Report UWFDM-150 (1976).

[3] K. Sako, Design Study of a Heat Reservoir System for the Tokamak Reactor, Japan Atomic Energy Research Institute Report JAERI-M 6099 (1975).

Acknowledgment

This work was supported in part by the U.S. Department of Energy Contract No. EY-76-C-02-3073.

Figure Captions

Fig. 1. Tokamak Reactor Energy Transfer.

Fig. 2. Tokamak Reactor Energy Storage Systems Flibe Loop.

Fig. 3. Tokamak Reactor Energy Storage Systems Flibe Loop.

Fig. 4. Tokamak Reactor Energy Storage Systems Helium Loop Series.

Fig. 5. Tokamak Reactor Energy Storage Systems Helium Loop Parallel.

Fig. 6. Tokamak Reactor Energy Storage Systems Helium/Steam Interface.

Fig. 7. Tokamak Reactor Energy Storage Systems Water/Steam Interface.

Fig. 8. Tokamak Reactor Energy Storage Systems Electric Loop.

Fig. 9. Tokamak Reactor Energy Storage Systems Electric Loop.

Fig. 10. Tokamak Reactor Energy Storage Systems Electric Loop.

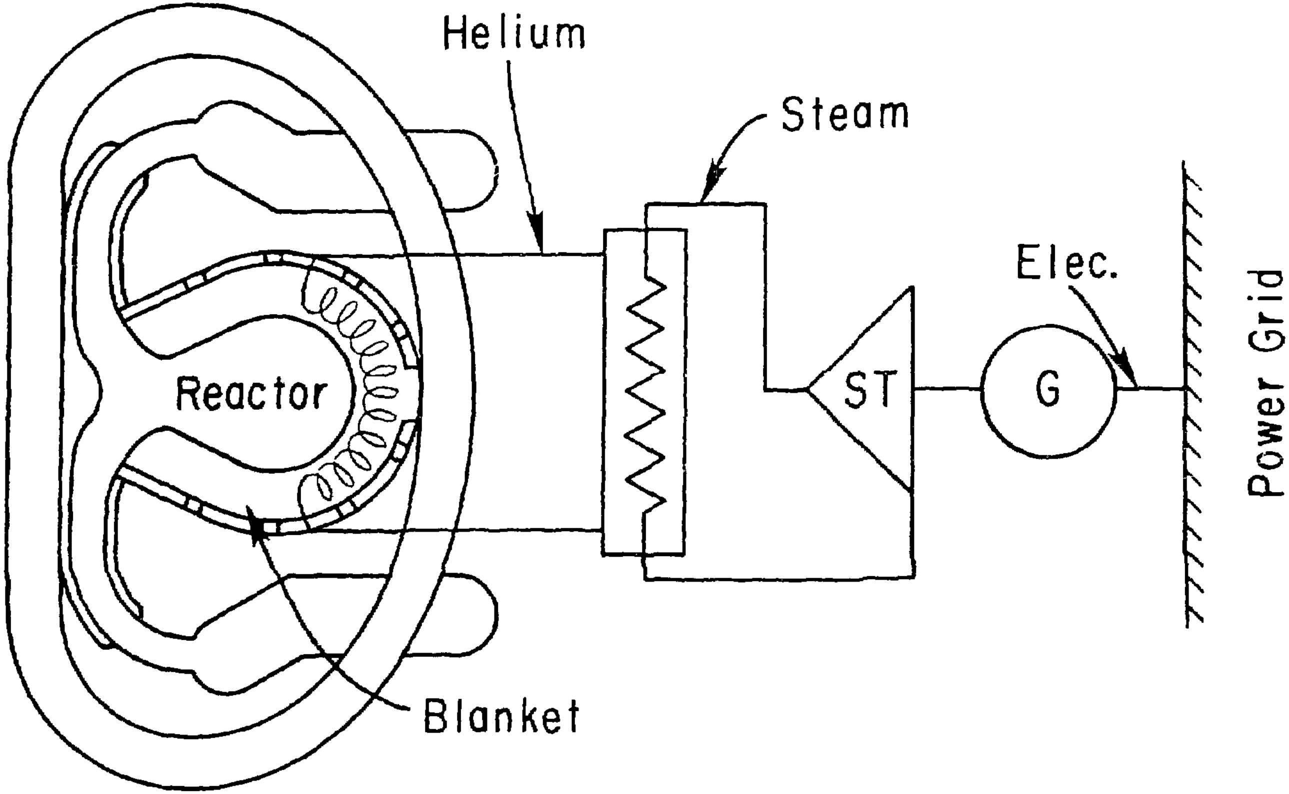

Fig. 1. 788023

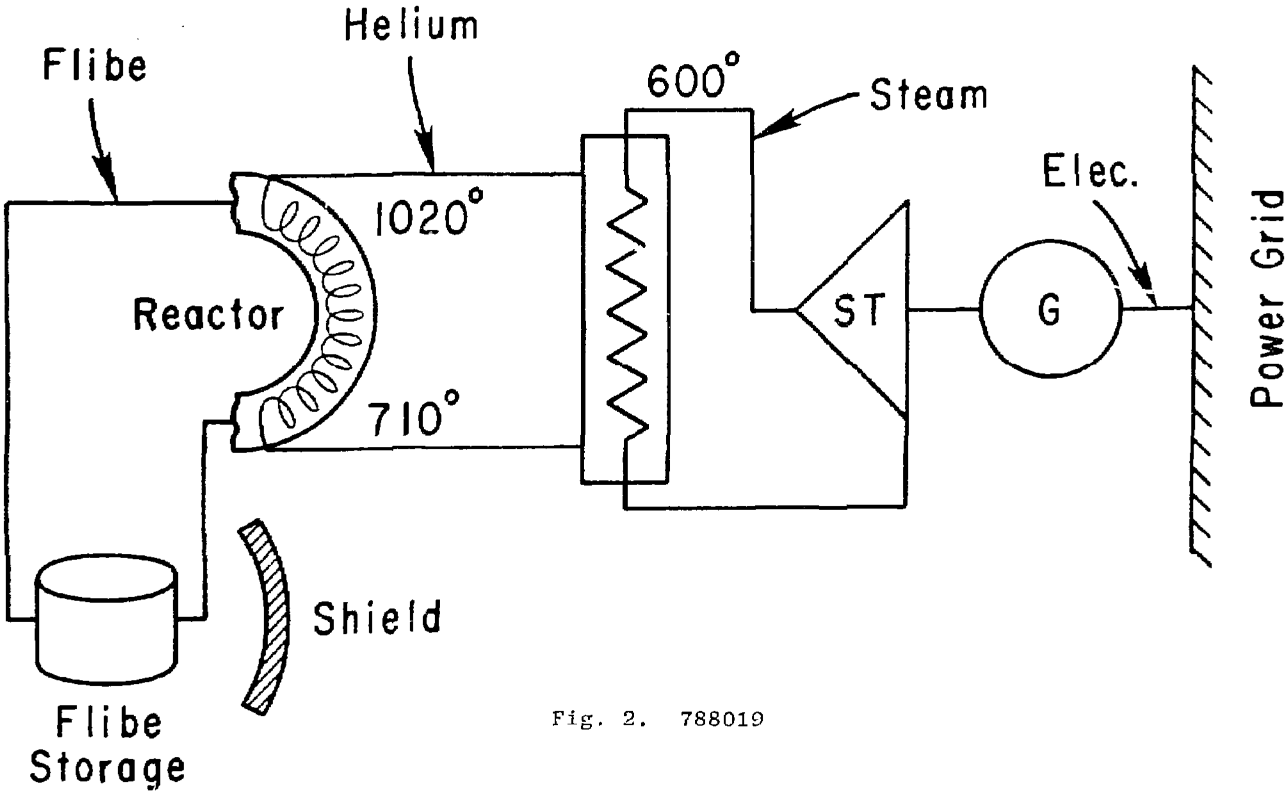
Flibe
Helium
600°
Steam
Elec.
Power Grid
1020°
Reactor
ST
G
710°
Shield
Flibe Storage

Fig. 2. 788019

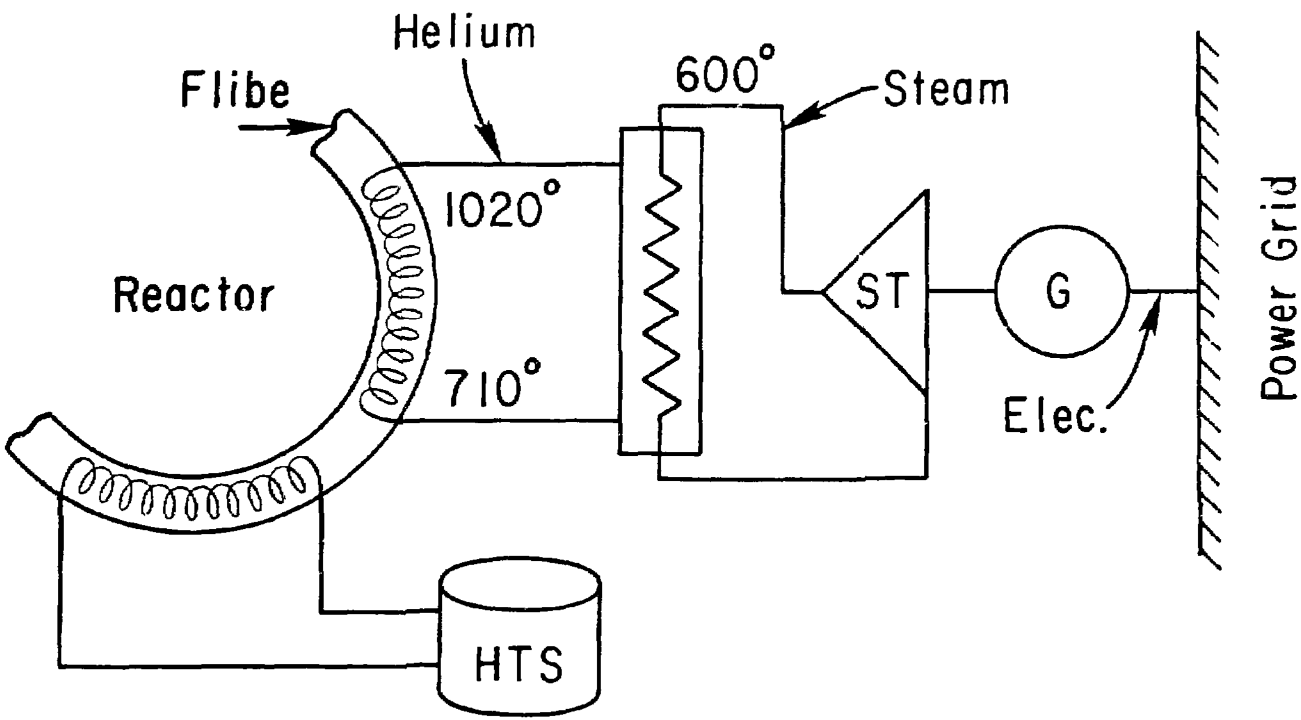
Flibe
Helium
600°
Steam
1020°
Reactor
ST
G
710°
Elec.
Power Grid
HTS

Fig. 3. 788022

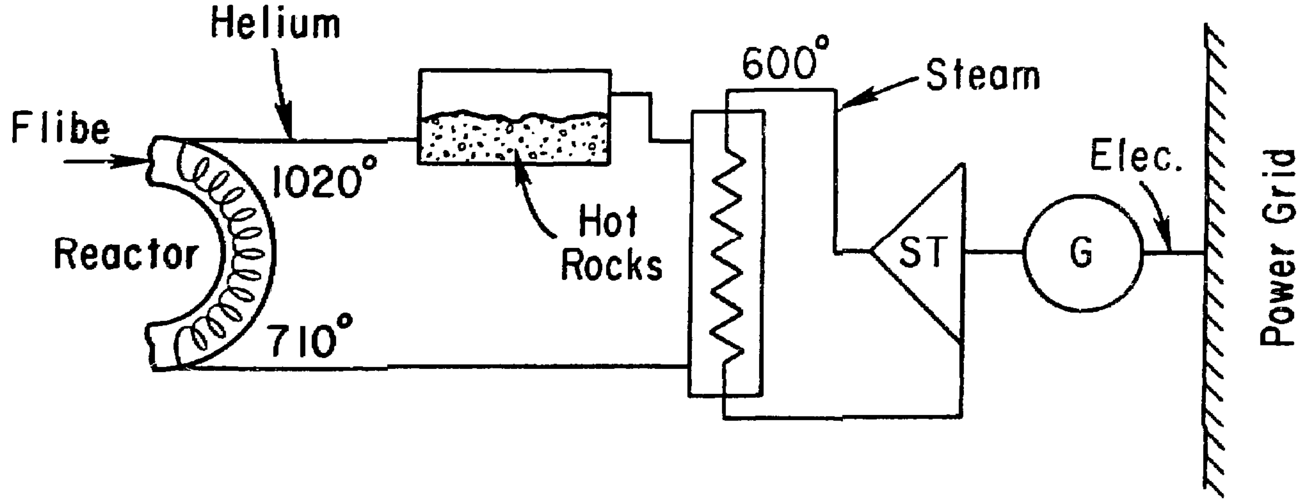
Helium
Flibe
1020°
Reactor
710°
Hot
Rocks
600°
Steam
ST
G
Elec.
Power Grid

Fig. 4. 788014

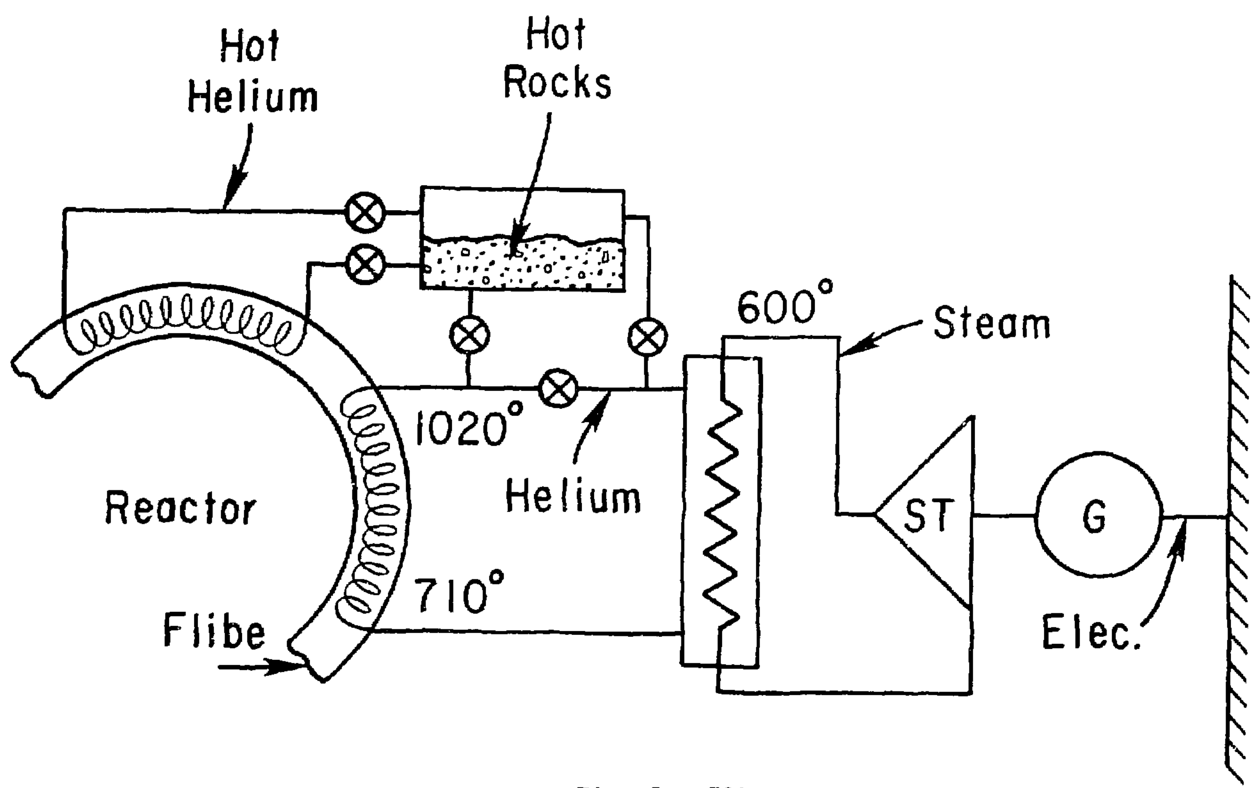
Hot
Helium
Hot
Rocks
600°
Steam
1020°
Helium
Reactor
ST
G
710°
Flibe
Elec.
Power Grid

Fig. 5. 788024

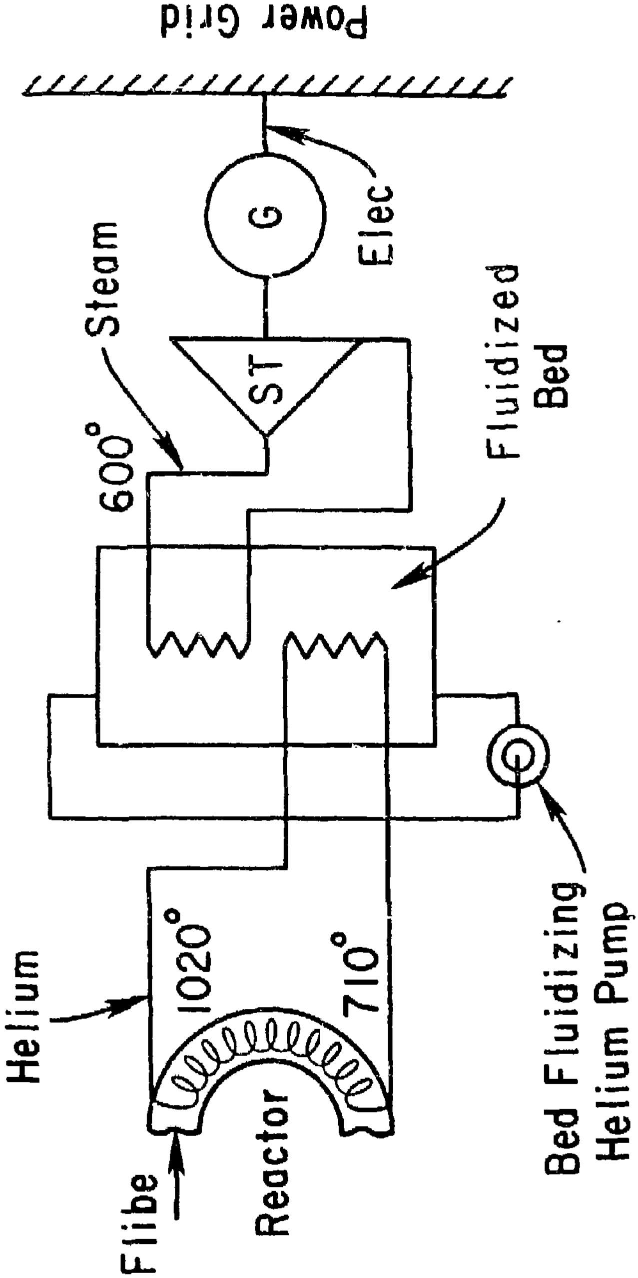
Power Grid
Elec
G
ST
Steam
600°
Fluidized Bed
Helium
1020°
710°
Flibe
Reactor
Bed Fluidizing Helium Pump

Fig. 6. 788015

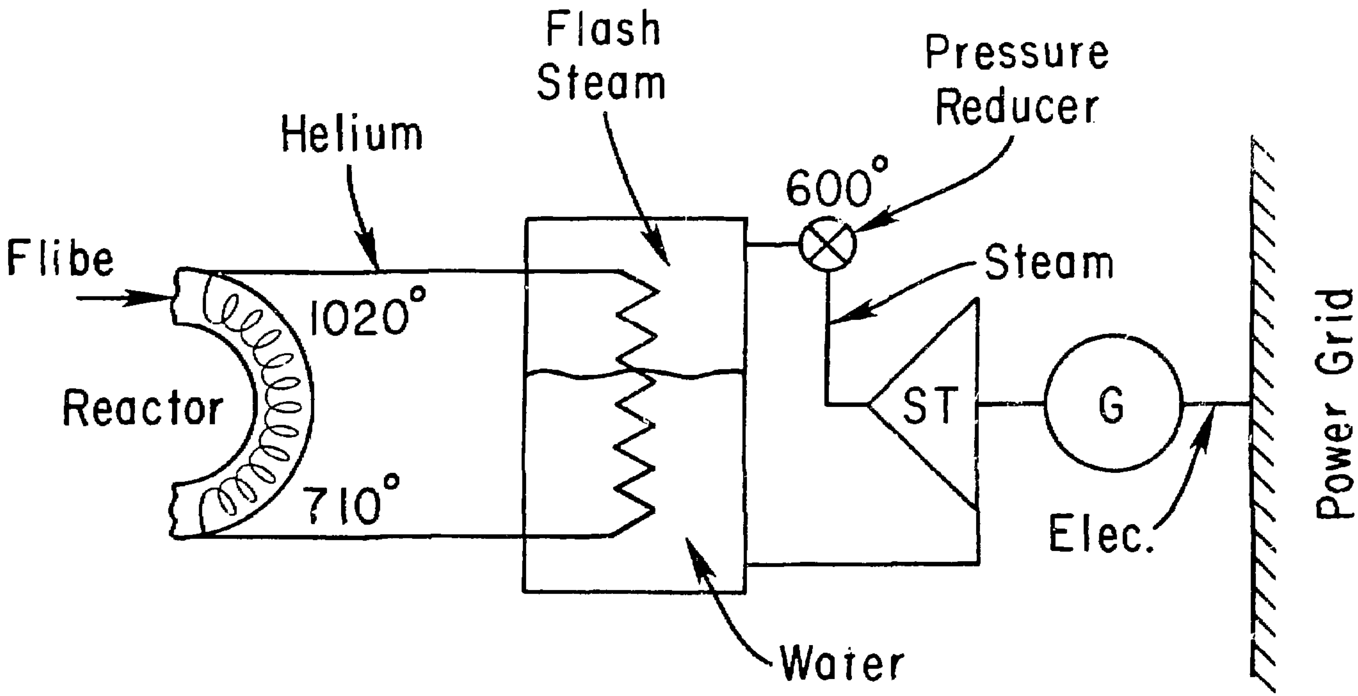
Flash
Steam
Pressure
Reducer
Helium
600°
Flibe
Steam
1020°
Reactor
ST
G
710°
Power Grid
Elec.
Water

Fig. 7. 788020

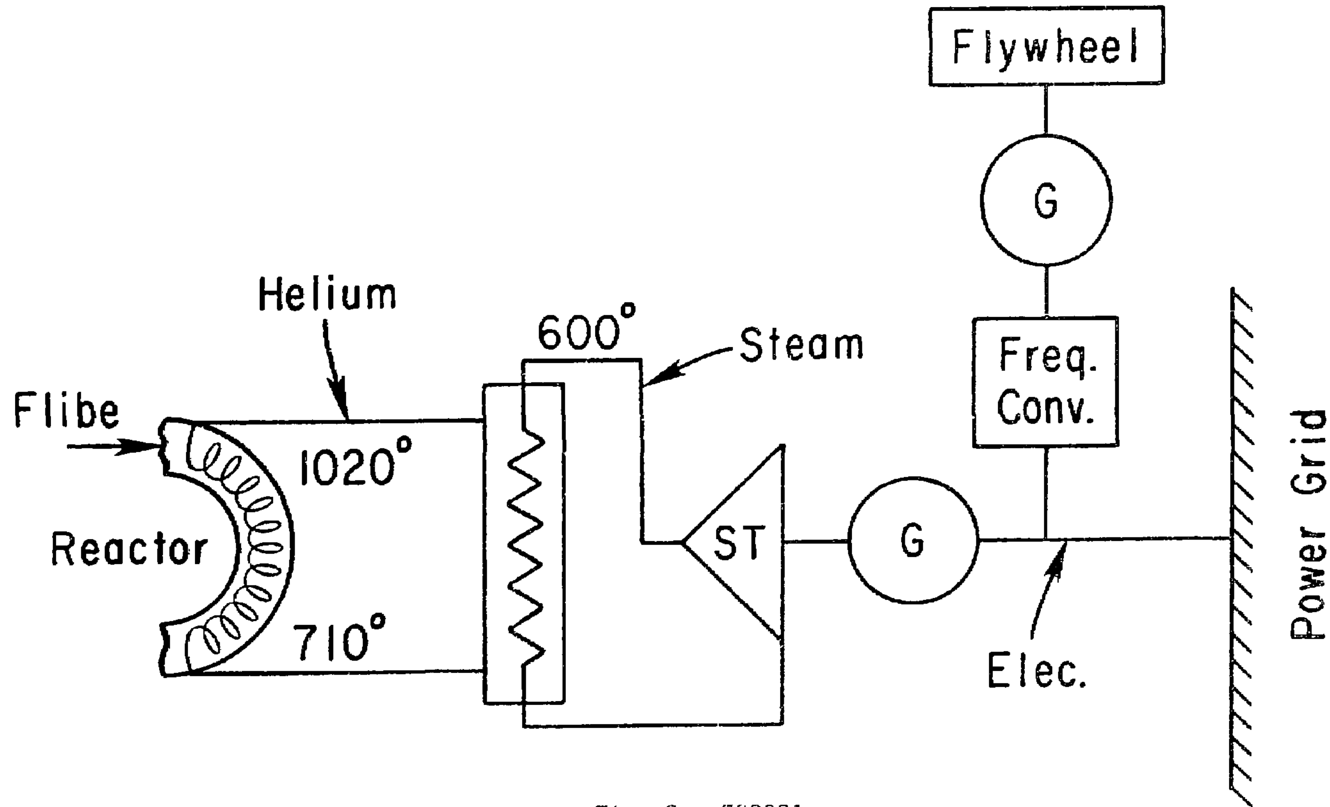
Flywheel
G
Helium
600°
Steam
Freq.
Conv.
Flibe
1020°
Reactor
ST
G
710°
Elec.
Power Grid

Fig. 8. 788021

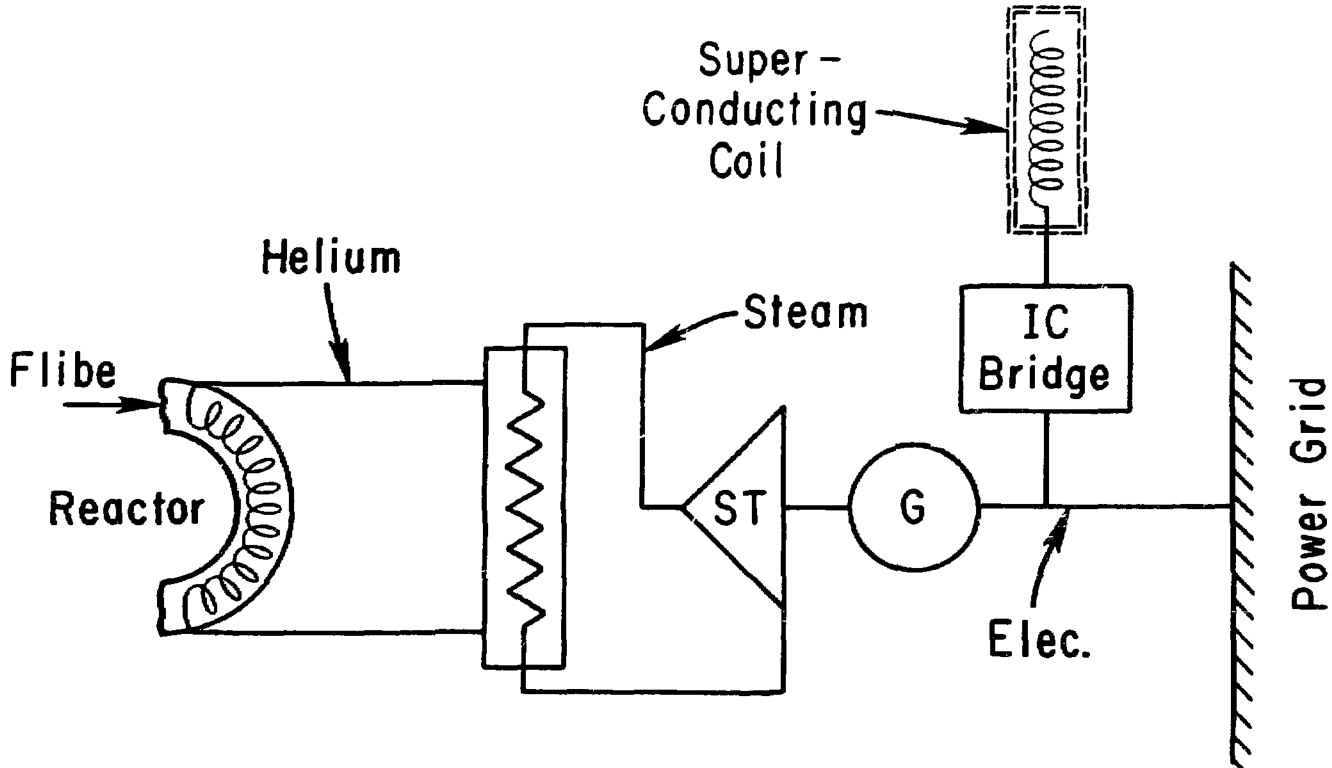
Super -
Conducting
Coil
Helium
Steam
IC
Bridge
Flibe
Reactor
ST
G
Elec.
Power Grid

Fig. 9. 788016

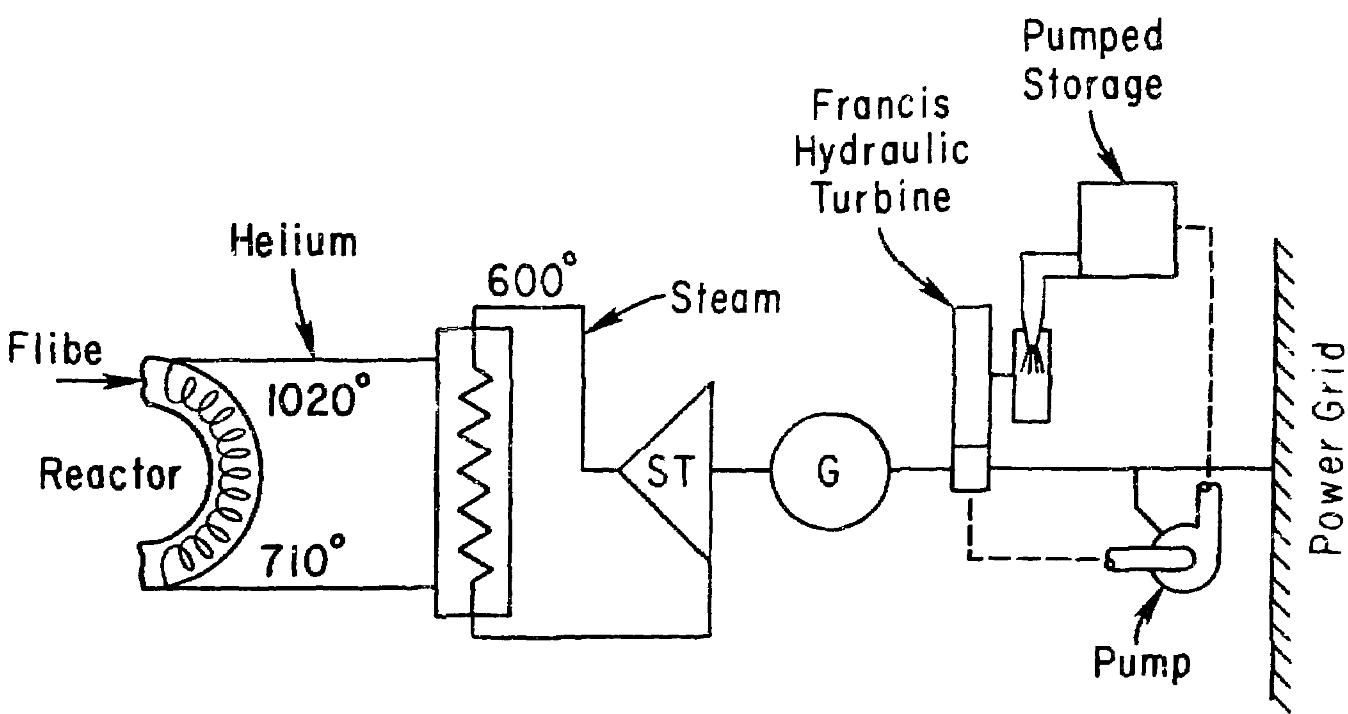

Fig. 10. 788013

EXTERNAL DISTRIBUTION IN ADDITION TO TIC UC-20

ALL CATEGORIES

[illegible], Auburn University, Alabama
S. T. Wu, Univ. of Alabama
Geophysical Institute, Univ. of Alaska
G.L. Johnston, Sonoma State Univ, California
H. H. Kuehl, Univ. of S. California
Institute for Energy Studies, Stanford University
H. D. Campbell, University of Florida
N. L. Oleson, University of South Florida
W. M. Stacey, Georgia Institute of Technology
Benjamin Ma, Iowa State University
Magne Kristiansen, Texas Tech. University
W. L. Wiese, Nat'l Bureau of Standards, Wash., D.C.
Australian National University, Canberra
C.N. Watson-Munro, Univ. of Sydney, Australia
[illegible], Inst. for Theo. Physics, Austria
[illegible] Royale Militaire, Bruxelles, Belgium
D. [illegible], Comm. of Eur. Comm., Belgium
[illegible], Instituto de Fisica, Campinas, Brazil
[illegible], University of Alberta, Canada
[illegible], INRS-Energie, Vareenes, Quebec
[illegible] Skarsgard, Univ. of Saskatchewan, Canada
[illegible], Culham Laboratory, Abingdon, England
[illegible] Library, C.E.N.-G, Grenoble, France
Central Res. Inst. for Physics, Hungary
R. Shingal, Meerut College, India
M. Naraghi, Atomic Energy Org. of Iran
Biblioteca, Frascati, Italy
Biblioteca, Milano, Italy
[illegible] Rostagni, Univ. Di Padova, Padova, Italy
Preprint Library, Inst. de Fisica, Pisa, Italy
[illegible], Plasma Physics Lab., Gokasho, Uji, Japan
S. [illegible], Japan Atomic Energy Res. Inst., Tokai-Mura
Research Information Center, Nagoya Univ.. Japan
S. Shoda, Tokyo Inst. of Tech., Japan
Inst. of Space & Aero. Sci., Univ. of Tokyo
T. Uchida, Univ. of Tokyo, Japan
H. Yamato, Toshiba R. & D. Center, Japan
M. Yoshikawa, JAERI, Tokai Res. Est., Japan
N. Yajima, Kyushu Univ., Japan
R. England, Univ. Nacional Auto-noma de Mexico
B. S. Liley, Univ. of Waikato, New Zealand
S. A. Moss, Saab Univas Norge, Norway
J.A.C. Cabral, Univ. de Lisboa, Portugal
O. Petrus, AL.I. CUZA Univ., Romania
J. de Villiers, Atomic Energy Bd., South Africa
A. Maurech, Comisaria De La Energy y Recoursos Minerales, Spain
Library, Royal Institute of Technology, Sweden
Cen. de Res. En Phys.Des Plasmas, Switzerland
Librarian, Fom-Instituut Voor Plasma-Fysica, The Netherlands
V. E. Golant, A.F. Ioffe Physical-Tech. Inst., USSR
B.B. Kadomtsev, Kurchatov Inst. of Atomic Energy, USSR
The Kharkov Physical-Tech. Inst., USSR
M. S. Rabinovich, Academy of Sci, USSR
Bibliothek, Stuttgart, West Germany
R.D. Buhler, Univ. of Stuttgart, West Germany
Max-Planck-Inst. fur Plasmaphysik, W. Germany
Nucl. Res. Estab., Julich, West Germany
K. Schindler, Inst. Fur Theo. Physik, W. Germany

EXPERIMENTAL
THEORETICAL

M. H. Brennan, Flinders Univ. Australia
H. Barnard, Univ. of British Columbia, Canada
S. Screenivasan, Univ. of Calgary, Canada
J. Radet, C.E.N.-B.P., Fontenay-aux-Roses, France
Prof. Schatzman, Observatoire de Nice, France
S. C. Sharma, Univ. of Cape Coast, Ghana
R. N. Aiyer, Laser Section, India
B. Buti, Physical Res. Lab., India
L. K. Chavda, S. Gujarat Univ., India
I.M. Las Das, Banaras Hindu Univ., India
S. Cuperman, Tel Aviv Univ., Israel
E. Greenspan, Nuc. Res. Center, Israel
P. Rosenau, Israel Inst. of Tech., Israel
Int'l. Center for Theo. Physics, Trieste, Italy
I. Kawakami, Nihon University, Japan
T. Nakayama, Ritsumeikan Univ., Japan
S. Nagao, Tohoku Univ., Japan
J.I. Sakai, Toyama Univ., Japan
S. Tjotta, Univ. I Bergen, Norway
M.A. Hellberg, Univ. of Natal, South Africa
H. Wilhelmson, Chalmers Univ. of Tech., Sweden
Astro. Inst., Sonnenborgh Obs., The Netherlands
N.G. Tsintsadze, Academy of Sci USSR, USSR
T. J. Boyd, Univ. College of North Wales
K. Hubner, Univ. Heidelberg, W.Germany
H. J. Kaeppeler, Univ. of Stuttgart, West Germany
K. H. Spatschek, Univ. Essen, West Germany

EXPERIMENTAL
ENGINEERING

B. Grik, Univ. de Quebec, Canada
P. Lukac, Komenskeho Univ., Czechoslovakia
G. Horikoshi, Nat'l Lab for High Energy Physics, Tsukuba-Gun, Japan
V. A. Glukhikh, D.V. Efremov Sci. Res. Instit.of Elect. App., USSR

EXPERIMENTAL

F. J. Paoloni, Univ. of Wollongong, Australia
J. Kistemaker, Fom Inst. for Atomic & Molec. Physics, The Netherlands

THEORETICAL

F. Verheest, Inst. Vor Theo. Mech., Belgium
J. Teichmann, Univ. of Montreal, Canada
T. Kahan, Univ. Paris VII, France
R. K. Chhajlani, India
S. K. Trehan, Panjab Univ., India
T. Namikawa, Osaka City Univ., Japan
H. Narumi, Univ. of Hiroshima, Japan
Korea Atomic Energy Res. Inst., Korea
E. T. Karlson, Uppsala Univ., Sweden
L. Stenflo, Univ. of UMEA, Sweden
J. R. Saraf, New Univ., United Kingdom