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13. ABSTRACT (Maximum 200 words)

This research effort addresses the production process of ion clusters with binding energy per ion as low as =2.78eV from a plasma source characterized by high energy density (.kJ/cm^3, i.e., 0.2keV/particle) and electron temperatures T_e 0.4 keV.
Particle-flow and magnetic structure of the plasma current sheath affect the emission of ion clusters and superclusters in plasma focus discharges. Part of the tests summarized here address methods and means for achieving controlled variations of the curretn sheath 9CS) structure via electrode geometry modifications. CS parameters are monitored with multiple magnetic probes in the case of cylindrical - and - open funnel electrode geometry.

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Self-Field-Dominated Plasma

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Final Progress Report

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SELF-FIELD-DOMINATED PLASMA.
SOURCES OF MeV ION CLUSTERS AND SUPERCLUSTERS

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Summary.

This research effort addresses the production process of ion clusters with binding energy per ion as low as $\simeq 2.78$ eV from a plasma source characterized by high energy density (> 1 kJ/cm^3, i.e., >0.3 keV/particle) and electron temperatures $T_e \geq 0.4$ keV.

Particle-flow and magnetic structure of the plasma current sheath affect the emission of ion clusters and superclusters in plasma focus discharges. Part of the tests summarized here address methods and means for achieving controlled variations of the current sheath (CS) structure via electrode geometry modifications. CS parameters are monitored with multiple magnetic probes in the case of cylindrical- and open-funnel electrode geometry .

Beam composition and energy spectrum above 100 keV of the ions emitted along the electrode axis ($\theta = 0°$ direction) are determined with a Thomson spectrometer. The energy spectrum of the ion trapped in the self-field dominated plasma of CS, of the pinch and of CS fragments after the pinch disintegration, is determined from measurement of plasma reactivity in deuterium plasma doped with high-Z nuclei, characterized by different energy threshold reactions. Cluster emission dominates over single ion emission at all angles. The data reported here indicate that this is true also for θ approaching the 0° direction, where single ion emission has peak intensity. The total ion cluster emission above 100 keV at 0° is higher by a factor $\simeq 10$ than the total particle emission measured in previous tests at 67° and 80°. The structure of the parabolic patterns of etched ion tracks on the Thomson analyzer targets provides basic information on cluster-in-flight disintegration modes.

Signals from scintillation detectors at different angular locations and variable distances (15 cm to 6 m) from the source provide energy spectrum and emission pulse shape at the source of particle reaction products, after implementing powerful numerical methods for signal processing.

[redacted]

Compact Source of Relativistic Electron Beams Above 10 GW And Microwaves Production in Plasma Filled BWO

by Compton R&D Laboratories, New York 10301-1739

Summary

A high-density relativistic electron beam is generated in the plasma diode formed during the pinch disintegration of a MA focused discharge, and is injected in a resonant cavity for generating a high-power microwave pulse (HMP). The REB has net current ≥ 10 kA, sharply-peaked electron energy, with peak location variable between ~0.3 MeV and ~1 MeV, beam diameter at the source $\simeq 0.2$ cm, propagation direction along the axis of the REB-source hollow anode, pulse duration $\simeq 20$ ns. The REB source is an advanced plasma focus machine (APF-50) with a powering capacitor bank of energy W optimized for operation in the interval W = 15 kJ - 50 kJ. The beam is injected in a slow wave structure (SWS) with a rippled profile and a magnetic field. A second (service) plasma focus machine (APF-10) is used to generate microwave pulses with the electric field polarized along the collinear electrode axis of the two APF's. These broad-band microvave pulses propagate backward inside SWS and are expected to stimulate the REB interaction, particularly at selected frequency values. Consistently, a variety of operation modes of the backward wave oscillator (BWO) becomes available. The proposed effort includes (i) the characterization of the REB and of the backward waves available from the service APF, (ii) the matching of APF-50 with APF-10, (iii) the verification of the microwave gain in terms of absolute power measurements with microwave calorimeters, (iv) the optimization of the BWO performance in terms of high power microwave (HPM) output (probed up to ≥ 100 - 200 GHz), by changing a variety of controlling parameters of REB and BWO.

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Compact Source of Relativistic Electron Beams Above 10 GW And Microwaves Production in Plasma Filled BWO

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[redacted]

The relativistic electron beam (REB energy 0.3 - 1 MeV, current $\geq$ 10 kA) generated in the plasma diode of a MA focused discharge in H_2 or D_2 will be injected in a resonant cavity with a rippled structure for generating high power microwave pulses. The REB source is an advanced plasma focus machine (APF-50) optimized for electron beam production over a wide interval of the energy W of the powering capacitor bank. The high electron density of the "cold" REB pulse of typical 20-ns-duration is expected to probe the performance of a backward wave oscillator under conditions not investigated so far in other laboratories. Different modes of operation of the BWO with a magnetostatic axial field (5 to 20 kG) will be tested. A first group of experiments will simply use the oscillation excited by the REB in the slow wave structure (SWS) entered by the beam, with variable magnetic field and fill gas at different pressure values. A second group of experiments will use a backward wave, with tunable frequency values over a wide frequency band, generated by a smaller unit (APF-10) coaxially matched with the beam source. The microwave power output will be monitored in a sequence of tests up to a frequency of $\simeq$ 200 GHz.

The proposed work program is summarized by the following tasks.

- Characterization of the electron beam for two different energy levels W of APF-50 operation, 15 kJ $\leq W \leq$ 20 kJ (APF peak electrode current $I \leq 1$ MA) and 25 kJ $\leq W \leq$ 30 kJ (APF peak electrode current $I \leq 1.5$ MA).
- Determination of the starting energy and starting current of the beam for initiating oscillations in the SWS with substantial microwave power emission, for different modes.
- Measurement of the peak microwave power as a function of the beam current for a specific choice of SWS parameters and of the magnetostatic field value B. These tests are expected to discriminate cyclotron resonance effects from other causes of high-power microwave emission.
- Experimental test on best choice of rippled waveguide (with different values of the corrugation period z_s) and of B lower bound in order to maximize millimetric wave output (> 100-200 GHz) for a chosen beam current.
- Comparison of millimetric power emission with and without the backward injection of excitation microwaves from the service APF for different values of λ_{APF}.
- Upgrading of APF-50 with repetition of Tasks if positive results are obtained at the starting W levels of APF.

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1. Introduction: Innovative Points

The use of highly-focused relativistic electron beams (REB) of power > 10 GW may substantially improve the efficiency, via novel, dominant collective effects, for generating high-power microwave pulses above 100 GHz, e.g., from a backward wave oscillator (BWO) [Ref. 1]. REB characteristics, such as the high-density of the beam, which are unique of the plasma-diode-formed REB in a MA focused discharge, are expected to strongly bear on the interaction REB-BWO. A slow wave system (SWS) with tunable geometric-and-magnetic-field parameters, in which the high-density REB is injected, can provide a clear evidence of the novel-collective-effect bearing on microwave efficiency generation. An axial magnetic field of 10 to 30 kG and the rippled field component of the undulator in the SWS is easily created by a current pulse in an external coil and by ferromagnetic elements of variable spacing L, without interference with the REB source proposed here.

Plasma focus machines (PF), and particularly advanced plasma focus machines (APF) when powered at energy levels 5 kJ $\leq$ W $\leq$ 100 kJ, have an outstanding performance as compact pulsed generators of REB's (the typical REB energy spectrum is sharply peaked - i.e., each REB is cold - in the interval $E_b \simeq 0.25$ MeV to 1 MeV, with an observed energy spread < 10%). The REB for W $\geq$ 7 kJ, has a pulse duration $\tau_{reb} \simeq 20$ ns to 80 ns, with a typical net current $i_{reb} \geq 10$ kA in the background plasma where the REB-emitting plasma diode forms. The beam diameter at the source matches the plasma virtual cathode of diameter $\simeq$ 2 mm and, depending on the boundary conditions after extraction from the APF diode region, the REB may spread to a typical annular structure of radius close to the drift chamber diameter (typically from 2 mm to 3 cm) and thickness up to 2 mm [Ref. 2]. At a chosen value of W the APF efficiency is $\geq$ 1.5 times higher than that of a PF optimized for REB production, up to $\simeq$ 15 % of W.

The proposed effort would address:

(i) The characterization of the REB for W $\geq$ 20 kJ, up to W $\simeq$ 100 kJ in term of net current (via Rogowski coil signals), primary electron current, space distribution and electron density (via electron deposition in calibrated-breakdown collectors), REB energy spread (via electron magnetic-analyzer/spectrometer and phosphor target).

(ii) The demonstration of the emission of high-power microwave pulses from a gas-filled BWO, including power measurement with microwaves calorimeters and time-resolved receiver signals. [By using a calorimeter target of water or of octanol the power level would be reduced to 10 watts or less on the microwave receiver (a second harmonic mixer/whisker contact diode) measuring pulse characteristics as functions of time [Ref. 3]]

The proposed program includes absolute - intensity measurements on microwaves pulses of frequency about 100 -200 GHz expected from the APF-generated REB injected in the BWO. In a first group of tests the REB energy would be not greater than $W_b = 2$ kJ (20-80 ns pulse duration) and the expected microwave pulse of the same duration should carry not more than 0.5 kJ (expected microwave power less than ~2 GW).

The scaling of the REB energy and current for increasing values of W above 35 kJ would be determined in a second group of experiments after the successful demonstration of high-power microwave pulse generation from the REB-BWO interaction.

Substantial achievements were obtained in recent experiments with BWO's using relatively-low density REB's and in experiments using higher-density REB's by partially by-passing REB space-charge limitations with gas-filled BWO's [Ref. 4]. The APF-generated REB at power levels above 10 GW, has order-of-magnitude-higher electron density than in the experiments reported so far. This is expected to further clarify the leading processes of the beam-wave coupling, and, hopefully, to further increase the gain in the sought-after energy transfer.

General reasons why the gain-controlling processes in the REB-wave interaction considered here differ from those involved in laser gains are reported in the literature [Ref. 5]. From all reasonable points of view one can adopt on this matter, the bearing of the REB density on the gain is expected to be strong. This is one of the main points of the proposed program along with the other unique, yet not fully exploited, characteristics of the APF-generated REB. Other innovative points are: (i) The use of a second APF, to be matched with the first APF used as REB source, as a powerful source of strongly polarized microwaves [Ref. 6] useful for activating the BWO and of highly collimated ion beams which can be injected in the BWO to stimulate [or to affect in controllable manners] the REB-wave interaction inside the BWO [Ref. 7]. (ii) The compactness, the low operation cost and the availability of several APF generators operating at different W levels, between 100 kJ and 10 kJ, suitable for rapidly implementing the proposed program.

2. Experimentals. REB Source

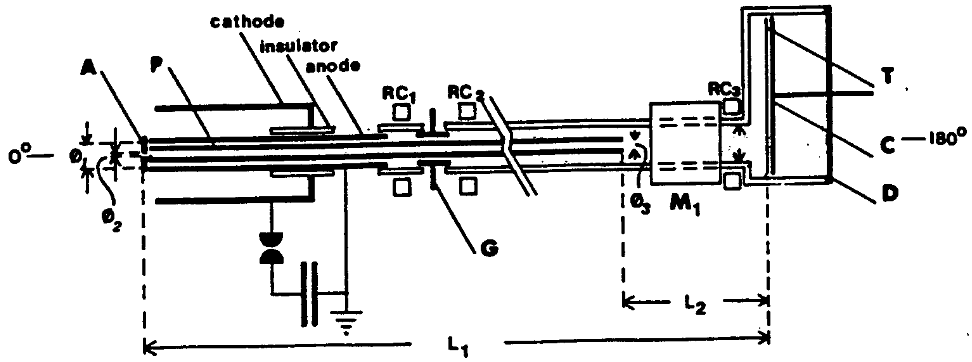
The REB is ejected from the plasma diode formed in thedisintegrating pinch and extracted from the APF-50 discharge chamber via the APF hollow anode. The plasma (virtual) cathode is at a distance of about 0.5 cm from the aPF anode the The front side of the anode can be fully open or can be sealed by a disc with a central circular hole of diameter $\phi_2 \geq 2$ mm from which the focused REB is extracted. The REB drift chamber has initially a maximum inner diameter equal to the anode inner diameter, or a smaller diameter $\geq \phi_2$. The schematic of the REB generator with standard diagnostics, including Rogowski coils monitoring the REB characteristivs, is reported in Fig. 1 (A). The REB pulse characteristics are reported in Fig. 1 (B). A simple method based on dendride formation is used in parallel with two other methods for recording (i) the dominant electron energy, E_e, of the REB and (ii) the sharpness, $1/\Delta E_e$, of the energy distribution peak (ΔE_e = full width at half maximum of the energy spectrum peak). The dentride method is implemented by inserting a Plexiglas hollow cylinder which shaves the outer edge of the REB inside the drift chamber.

The typical dendrite length, $|\zeta| \simeq$ "electron penetration in the Plexiglas", from the exposed surface of the Plexiglas, determines E_e. The distribution of the dendrite origin inside the Plexiglas determines the REB energy spread ΔE_e ($\Delta E_e/E_e < 10\%$), [Ref. 2]. These time integrated records of E_e, ΔE_e, well agree with the E_e, ΔE_evalues from magnetic analyzer data, and from the relative delay Δt of signals from two Rogowski coils at a mutual distance $|\zeta|$ along the drift chamber before SWS. With obvious notations, $E_e \simeq [m(v_e) - m_0]c^2$; REB axial velocity $v_e \simeq |\zeta| / \Delta t$; $\Delta t \simeq$ "delay between Rogowski signal peaks". Under the chosen conditions, the corrections due to REB absorbtion in the drift chamber gas and to signal-peak deformations related to ΔE_e do not appreciably affect the value of Δt defined above [Fig. 1 (B)].

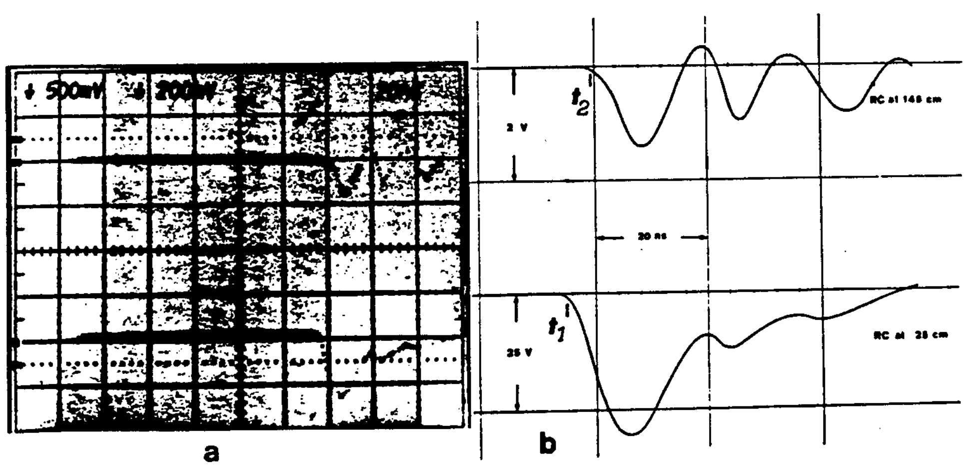
Variations of characteristics of the APF beam can be implemented under well controlled conditions with the same method (change of the APF electrode geometry) as implemented in Ref. 8.

APF-beam collective-field acceleration of ions occurs in the background gas to an energy, E_i, up to several MeV, depending also on the drift chamber characteristics. The higher the ratio (ion charge)/(ion mass) the higher is the observed E_i. This provides the means for evaluating if ion focusing of the electron beam [Ref. 7] has a substantial bearing on the BWO performance.

Fig. 1. (A). Schematic of Advanced Plasma Focus electrodes with circular knife edge (KE) and of typical arrangement for REB extraction at 180°. The REB current measured from Rogowki coils RC_1, RC_2, RC_3 does not depend on the diameter ϕ_2 of the REB extraction aperture [on the sealing disk at the front end of the anode] by increasing ϕ_2 above $\phi_2 = 2$ mm. This gauges the high focalization of the REB ejected from a localized region of the APF pinch at a distance d = 0.5 cm-to-1 cm from the REB extraction aperture. M_1 is a magnetic analyzer. Capton foils of thickness 10 μm along the drift chamber are used to establish different values of the gas pressure along the drift chamber.



(B). Typical i_{reb} signal from RC_1 and RC_3 (at 25 cm and 145 cm, respectively from the REB source) in a single PF discharge at 6 Torr of H_2; charging voltage of the PF capacitor bank V = 16 kV; W < 6 kJ; Tektronix 7844 display in (a); drawing of the same oscilloscope traces in (b). The value of the REB propagation speed $v_{reb} = 120$ cm/$(t_2 - t_1)$ = 0.75 c, is obtained from the RC_3 signal delay; t_1, t_2 = time from sig
nal onset from RC_1 and RC_3, respectively. A highly collimated ion beam of energy $\simeq$ REB energy is ejected at 0° with a corresponding current of the order of $\geq$ 1 kA [Ref. 2]. A sequence of about 10 microwave pulses in a single discharge are also generated from electron beams formed at the outer side of the PF/APF pinch, which circulated in the pinch azimuthal magnetic field at a distance greater than 2 mm from the electode axis, i.e., outside the axial REB-generating region.



Conceptual Design of HPM Generator

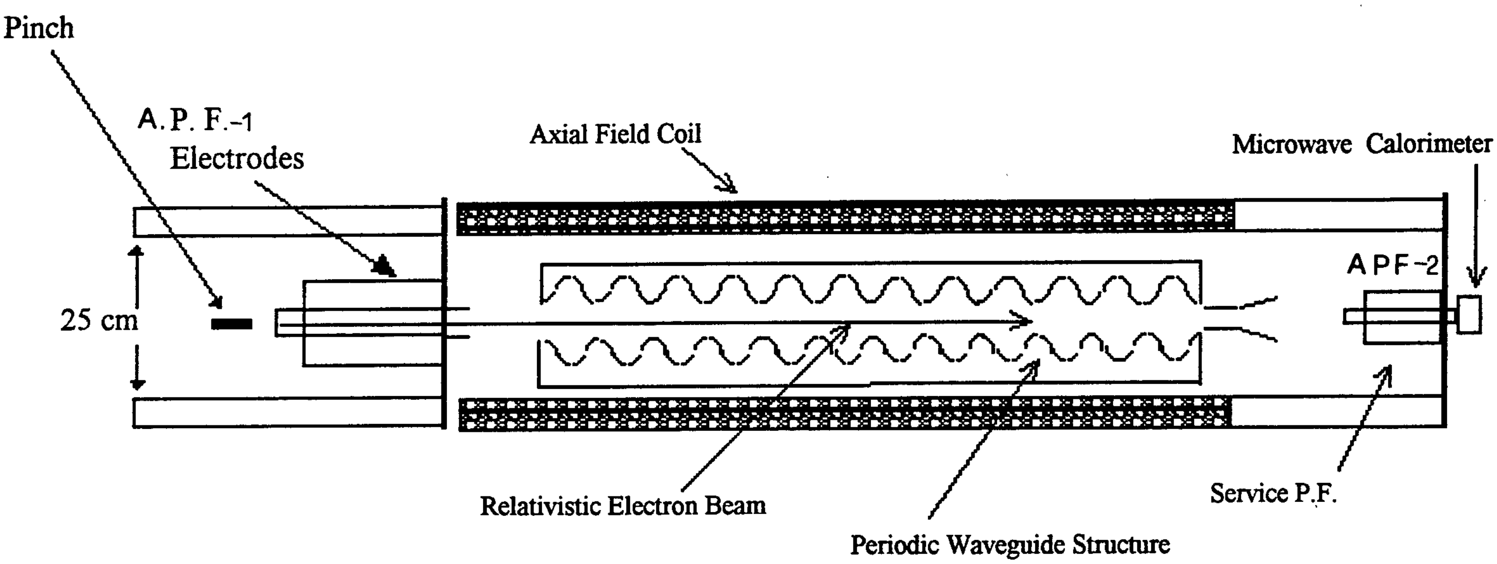
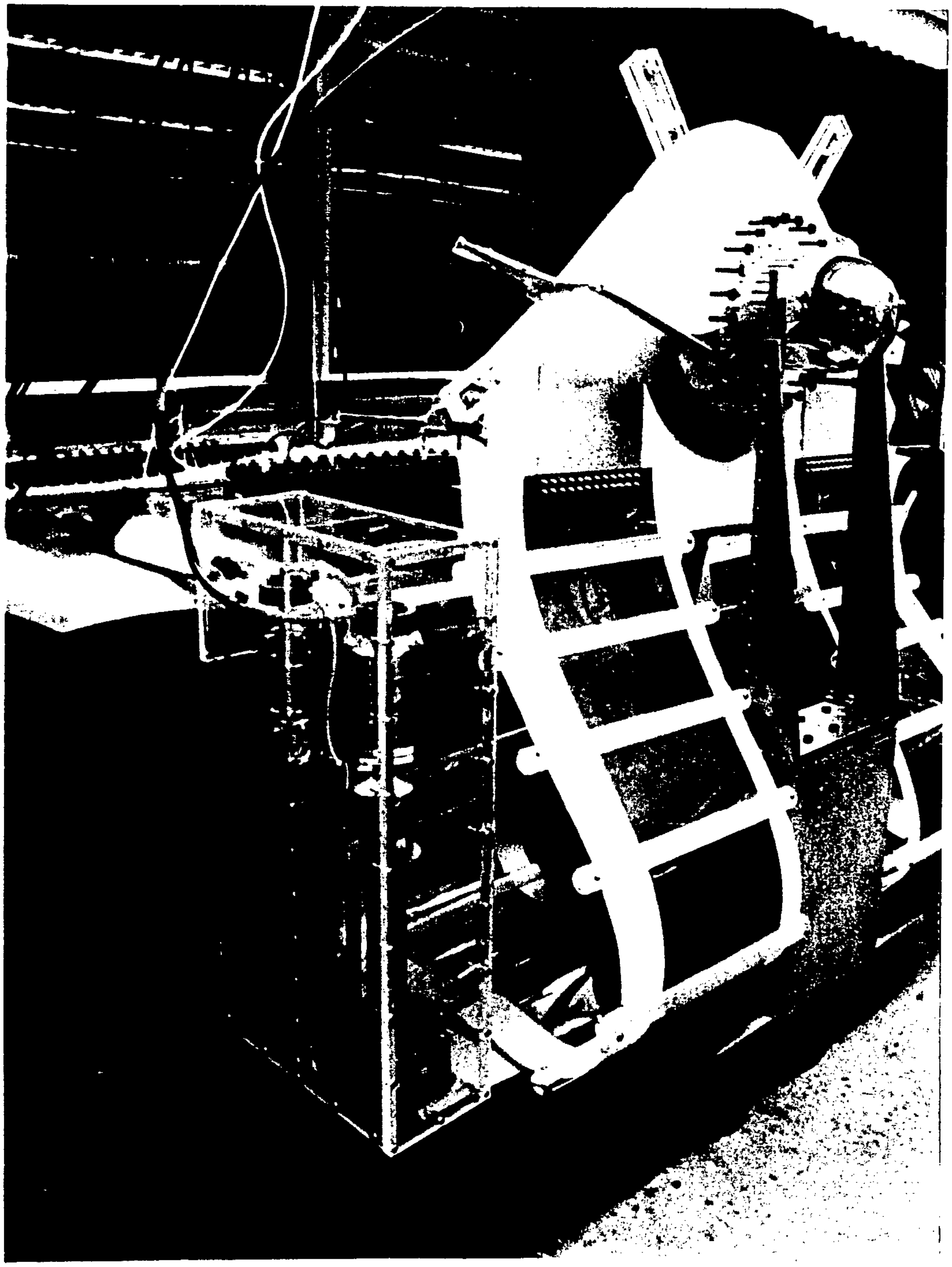


Fig. 2. Schematic of APF(1) used as REB source connected to SWS. A second APF(2) can be used as a source of polarized microwaves (polarization with electric field in the direction of the electrode axis, see [Ref. 6]) suitable for exciting the BWO, and of ion beams for microwave amplification in the ion-focused regime [Ref. 7]. The ions from APF (2) with energy $E_i < 0.5$ MeV are streaming in the opposite direction of the APF-(1) REB and can be easily stopped with a mylar foils of thickness ~ 50 µm. On the other hand, the background gas ions accelerated by the REB collective field have much higher energy ($E_i > 5$ MeV) and can be used to analyze different modes of the ion-focused regime. Microwaves and ion beams can be launched in the SWS by adopting the arrangement as described. The REB source APF(1) is expected to operate at twice the energy level W of the auxiliary APF(2), or higher, up to 100 kJ.

Fig. 3. APF-50 to be used as REB source for the first series of tests with the BWO. This, and other APF machines of greater as well as of smaller size, presently operate at the Compton Laboratories.



3. BWO and Expected Microwave Output

The REB enters the sinusoidally corrugated SWS of mean diameter $D \leq d_a$ (d_a = 50 mm is the inner diameter of the REB-source hollow anode) as reported in Fig. 2. Greater values of D can be selected depending on the gas density in the SWS, on the REB energy E_e and on the observed HPM power level. Smaller values of D can also be selected after verification of the SWS performance in terms of internal RF breakdown occurrence. The SWS gas pressure can be decoupled from the REB source chamber by one (or several) capton foil(s) of thickness $\simeq$ 10 μm located near the Rogowski coil axial positions z_{r1}, z_{r2}. The capton foil is not appreciably affecting E_e, but weakly changes (increases) the observed net REB current I_e [Ref. 2]. Alternatively, the same relatively-high pressure of the REB-source chamber, up to $\simeq$ 5 Torr, can be mantained by fully-open connections throughout the systems, also to increase the ionization level in SWS.

Hydrogen or deuterium will be used in the REB source chamber because this maximize the beam current. By using the same gas filling (H_2, or D_2) in the SWS, a shift is expected for the peak microwave power as a function of the fill pressure toward higher values of the fill pressure, if compared to the corresponding quantities for He and Ar fillings [Ref. 4-III].

An axial magnetic field B = 5 kG to 20 kG is generated by an external coil in the SWS for testing the dependence of the beam current on B and its bearing on the observed peak microwave power output.

In some of the proposed tests, the SWS will be excited by a microwave beam entering SWS from the rear end, where a smalller (service) APF-10 is coaxially located and performs as a microwave source. The service APF has a strong emission, particularly in the wave length interval λ_{APF} = 10 cm - 2 cm, (down to much smaller λ_{APF} values; [Ref. 6-III]) with the wave electric field polarized along the electrode axis (z-axis) [Ref. 6-II]. The different process involved for the APF microwave emission at different wavelength values λ_{APF} are described in Ref.s 6-I, 6-III]. A calibrated directional coupler (located between service APF and SWS) will select λ_{APF} for the backward wave entering SWS. The choice of the sinusoidal (or quasi-sinusoidal) structure of the SWS rippled wall with period z_s will be tested in particular for $z_s/\lambda_{APF} \leq 1$.

The microwave output from the BWO is expected to be strong [a substantial fraction (~ 10-25%) of the beam power] not only at the BWO estimated oscillation frequency (< 20 GHz), but also in a much higher frequency interval (> 100 GHz), if a suitable choice is made for the backward (excitation) wave λ_{APF} from the service APF.

The major objetive of the proposed effort is to determine the possible advantage, in terms of BWO power output, of the high electron density ($\geq 10^{14}$ cm $^{-3}$) characteristic of APF-generated "cold" beams. In the case of positive system performance, microwave power emission at the GW level can be expected on a time interval $\simeq$ beam duration.

A microwave calorimeter is properly built by using an organic target (rather than water) as octanol-1, a long-chain-molecule alcohol (oily, not toxic) with outstanding absorbtion characteristics (14-15 db/cm). After reducing the power lewel, P, of the BWO output to a few watt (or to mwatt), the time characteristics of the microwave pulse are detected by a diode/receiver, at the rear side of the calorimeter, as in Fig. 2. RF breakdown is a frequent occurrence at the calorimeter surface for the long pulses (~ 50 millisecond) at the ~ 0.5-1 MW level for the source reported in Ref. 3. In the tests proposed here, RF breakdown at the calorimeter surface may not occur even at higher power levels P_{BWO}, because of the relatively short duration ($\simeq$ 50 ns) of the expected microwave pulse, and because the calorimeter can be inserted in a low pressure chamber. The power reduction by a suitale factor R_f (as required to avoid breakdown) can be estimate from the equation $R_f P_{BWO} = sE_{br}^2/Z$

where s is the microwave beam cross-section, Z = 377 Ohm , E_{br} is the breakdown field (30 kV/cm on material surface in air at 1 atmosphere. The short pulse length of 50 ns appromatively doubles this breakdown limit to 60 kV/cm). A desired R_f can be implemented by reducing the aperture leading to the calorimeter (in Fig. 2, the APF-10 hollow anode of diameter 34 mm, is accordingly reduced to size by a centrally perforated disc that partially closes the anode). Avariety of methods and instrumentation are based on measurements of the energy leaked from a small hole. Useful considerations on a different approach to burst generation of high-power microwave pulses are presented in Ref. 9.

4. Proposed Tasks

1. Characterization of the electron beam for two different energy levels W of APF-50 operation, 15 kJ $\leq$ W $\leq$ 20 kJ (APF peak electrode current I $\leq$ 1 MA) and 25 kJ $\leq$ W $\leq$ 30 kJ (APF peak electrode current I $\leq$ 1.5 MA).

2. Determination of the starting energy and starting current of the beam for initiating oscillations in the SWS with substantial microwave power emission, for different modes.

3. Measurement of the peak microwave power as a function of the beam current for a specific choice of SWS parameters and of the magnetostaitic field value B. These tests are expected to discriminate cyclotron resonance effects from other causes of high-power microwave emission.

4. Experimental test on best choice of rippled waveguide (with different values of the corrugation period z_s) and of B lower bound in order to maximize millimetric wave output (> 100-200 GHz) for a chosen beam current.

5. Comparison of of millimetric power emission with and without the backward injection of excitation microwaves from the service APF for different values of λ_{APF}.

6. Upgrading of APF-50 with repetition of Tasks if positive results are obtained at the starting W levels of APF.

5. Facility and Equipment

1 Four advanced plasma focus machines 1-5 kJ (one), 6-10 kJ (two) 20 -50 kJ (one) Two plasma focus machines can operate simultaneously at the Compton Plasma Laboratory (4,700 sq. ft. in Kearny, NJ): APF-50 with maximum capacitor-bank energy $W_{Max} = 50$ kJ, complete of power supply, Maxwell rail gap switches (750 kA each, with < 10 ns jitter triggers), trigger generators.

2 One plasma focus machine ($W_{Max} = 100$ kJ) partially assembled with complete set of components (power supply, switches, power transmission plates, etc.), available for operation within six months from decision to upgrade tests to W > 50 kJ.

3 Nanosecond signal digitizer:
Tektronix TDS648 (4 ch.s, digitizer), 500 MHz single pulse,
Tektronix 7912AD (1 ch.), 500 MHz single pulse.
HP-200 MHz (2 ch.s), HP-50 MHz single pulse.

4 Microwave receivers/diodes, microwaves guides (15 GHz, 3 GHz)
Millitech wave guides with power-limited coupler 75-100 GHz (WR10)
" " " up to 40 GHz (WR28)
Millitech whisker contact diode for operation up to 170 GHz
Millitech power sensors matching HP-432 (ess. voltmeter)
Millitech 2-nd armonic mixer with reduced conversion loss, low noise l., improved dyn. range.
Diode power sensors with power meter.

5 Three complete vacuum systems (including diffusion pump, up 10^{-7} Torr).
One turbomolecular pump with with matching r.p. (fully dry), better than 10^{-8} Torr.

6 Image converter camera, (5 nanosecond exposure, wide frame 3" x 4" image).

7 Scintillation detectors for X-ray, etc. complete of photomultipliers (1 to 3 ns resolution). Detector diameter (solid NE-102, Pilot U, Pilotot B, BC-42, liquid DC-505) is available from 1/2" to 18" (18" dia. for one detector only).

8 Rogowski coils, amplifiers, signal attenuators , REB source imaging systems from X-ray emission, spectrometers for ions and electrons, with matching data recording systems.

9 50 kV Avtech pulse generators with ns rise time, delay lines, pulse power instrumentation.

6. References

[1]. V. L. Granatstein, I. Alexeff: *High-Power Microwaves Sources*, Dedham (Boston, MA), Artech House, 1987.

[2]. W. H. Bostick, et al. (SIT/Compton Lab.): in *Energy Storage, Compression and Switching*, Vol. 2, p. 267-287 (1985), Plenum, NY [Nardi, Sahlin, Bostick, Eds.].
V. Nardi, et al. (Compton Lab./SIT): *Phys. Rev.*, Vol. 22 A, p. 2211 (1980).

[3]. J. Lohr, et al. (General Atomics, Kurchatov I., ENEA, MIT): *Bull. APS*, Vol.42, p. 1976 (1997), paper # I Wep P1 9.

[4]. J. A. Swegle, et al. (LLNL): *IEEE Transaction on Plasma Science*, Vol. 21, p.714 (1993).
K. Minami, et al. (Niigata Univ./J. & MD Univ.): *IEEE Transaction on Plasma Science*, Vol. 23, p.124 (1995).
K. Minami, et al.: *Appl. Phys. Lett.*, Vol. 53, p. 559 (1988).

[5]. H. Motz: in *Energy Storage, Compression and Switching*, Vol. 2, pp. 119 - 129 (1985), Plenum, NY.

[6]. W. H. Bostick, V. Nardi, W. Prior (SIT/Compton Lab.): *Proc. 6-th Europ. Conf. C. F. & Plasma Phys.*, Moscow, Vol. 2, pp. 395-398 (1973).
W. H. Bostick, V. Nardi, W. Prior (SIT/Compton Lab.): *Proc. Int. Conf. Pulsed High-Beta Plasmas*, Oxford, p. 407 (1975) [E. D. Evans Edit.].
W. H. Bostick, V. Nardi, W. Prior (SIT/Compton Lab.): in *Energy Storage, Compression and Switching*, Vol. 1, p. 173, Plenum, NY [Bostick, et al. Eds.].

[7]. D. H. Whittum, et al. (KEK/J): *IEEE Transaction on Plasma Science*, Vol. 21, p. 136 (1993).

[8]. V. Nardi, C. Powell, et al. (Compton Lab./Ferrara Univ.): *Int. Symposium on Research and Applications of Plasmas*, Vol. 2 -Invited Papers, p.78 (1997)

[9]. H. Ikezi, et al. : *Rev. Sci. Instruments*, Vol. 62, p. 2916 (1991). The limitations of the approximate estimate of the electric field E of a microwave beam of cross-section s and power P at the wave-guide/vacuum interface (via $P = sE^2/Z$) are presented in Microwaves Magazine, June 1972, p.103.

KEY PERSONNEL

Dr. V. Nardi is a Physics Research Professor at Compton RDL since December 1994. Dr. V. Nardi received a Ph.D. in physics from the University of Rome, Italy and has served as Research Associate at the University of Rome, Assistant Professor and Professor of Physics at the University of Padua and Professor of Physics at the University of Ferrara. Since 1967, he has permanently immigrated and obtained citizenship in the USA. He came to the USA first as a Fulbright Scholar at the New York University Department of Physics, then as a Visiting Research Scientist at the MFD Division of New York University. He joined Stevens Institute of Technology, New Jersey in 1967 to present as a Research Professor of Physics. Dr. Nardi served as a consultant to the Nat. Inst. Nuclear Physics in Italy until 1966, the Nat. Inst. of Electrotechnics Galileo-Ferraris in Turin, Italy until 1978, and Lawerence Livermore National Laboratory in the USA from 1974-1976. Dr. Nardi had published more than 100 full-length papers on physics, statistical physics, theoretical and experimental physics (shock waves, vorticity, current filamentation in MA plasma current channels, neutron-, ion-, electron- and X-ray diagnostics, relativistic electron beams) in professional referred Journals and International Conference Proceedings, many of which were invited papers. Dr. V. Nardi has been PI and Co-PI of more than 30 projects for DOD, NSF and other government agencies.

Dr. J. S. Brzosko is a Physics Research Professor at Compton RDL since December 1994. Dr. J.S. Brzosko received a Ph.D. (1968) and habilitation (1971) in nuclear physics from the University of Warsaw, Poland. He has served as Director of the Institute of Physics, Dean of Faculty of Science and Deputy Head of the Science and Research Development for Warsaw University, Bialystock campus. He was invited as a visiting professor to the University of Tubigen in West Germany, the Solford University in Great Britain and the University of Bari in Italy. In J.I.N.R., Dubna, USSR he initiated and led for two years the fast-nucleon radiative capture program of that institution. For many years, he has been PI of government contracts in Poland; in Italy he was Co-PI in several fusion technology projects for EURATOM. Since 1981, he has permanently left Poland and has served as a scientific advisor for the National Energy Agency ENEA, Italy. Since 1985, he has immigrated to the USA and has acquired US citizenship. He joined Stevens Institute of Technology, Hoboken, NJ in 1985 to present as a Research Professor of Physics. Dr. Brzosko has published more than 80 full-length papers on nuclear, gas discharge and plasma physcis.

Dr. C. Powell is a Senior Research Scientist at Compton RDL since December 1994. Dr. Powell received a Ph.D. from Stevens Institute of Technology, Hoboken, NJ. He has served as a Research Scientist for Stevens I. Tech. (1985 to present), Pulsed Power Tech Inc. and AES Dense Plasma Lab. He has a thorough background in both digital and analog circuit design and in FORTRAN programming on DED-10, PRO 350 and VAX computers. He has extensive experience in the design , construction and operation of high power pulsed plasma devices (multi-kJ plasma focus and opening switch research). Dr. Powell has participated with the fabrication and use of plasma diagnostics such as 0.1 GW pulsed ruby laser, X-ray pinhole photography, Rogowski coil measurements and a variety of both time resolved and integrated neutron, ion and electron diagnostic techniques on both steady state and pulsed plasma devices. He also has experience with U.H.V. systems and large superconducting magnets. Dr. Powell has published over 30 papers in professional referred journals and conference procedings.

Selection of Laboratory Member Publications:

- V. Nardi: US Patent No. 4,912,731 (1990) and US Patent No. 5,075, 522 (1991)

- J. S. Brzosko, V. Nardi: High Yield of $^{12}C(d,n)^{13}N$ and $_{14}N(d,n)^{15}O$ Reactions in the Plasma Focus Pinch", Pysics Lett., Vol. 155A, pp. 162-168 (1991).

- A. Bortolotti, , J. S. Brzosko, V. Nardi et al. Inspection of Extended Objects With Fast Neutrons. Numerical Simulation", Nucl. Instr. & Methods, Vol. B-63, 473 (1992)

- J. S. Brzosko, V. Nardi et al.: " Advantages and Limits of 14 MeV Neutrn Radiography", Nucl. Instr. & Methods Vol. B-72, 119 (1992).

- H. Kilic, V. Nardi et al.: "Plasma-Driven Liners", Proc. 1992 Int. Conf. on Plasma Physics, Innsbruck, Vol. 16-C-II, pp. 1253-1256 (1992).

- L. Bilbao, V. Nardi et al.: "Dynamics of Thin Liners Driven by a Quasi-Cylindrical Z-Pinch", Kerntechniik, Vol.57, 330-334 (1992).

- V. Nardi, J. S. Brzosko, C. Powell: Neutron Sources cof the Advanced Plasma Focus Type for Demonstration Tests of Safe Reactors", Invited paper, Proc. Workshop on Plasma Focus Device Utility for Intense Neutron Sources, Los Alamos Nat. Lab. July 21-22, 1992, LANL Rep. LA-UR-8.92.

- H. Kilic, J. G. Linhart, V. Nardi, H. Schmidt: "Plasma-Driven Liners", Proc. of The 19-th Europ. Conf. on Plasma Physics & Nuclear Fusion Research, Innsbruck, Vol. 16-C-II, pp. 1953-56 (1992).

- W.H. Bostick, H. Kilic, V. Nardi, C.W. Powell. "Time Resolved Energy Spectrum of the Axial Ion Beam Generated in Plasma Focus Discharges". Nuclear Fusion, Vol. 33, No. 3 , p. 413-420 (1993).

- V. Nardi, C. Powell, J. S. Brzosko, "Evaluation of the Plasma Focus as a Thruster With Neutron-Lean Fusion Reactions". Public. by Phillips Laboratory Propulsion Directorate, PL - TR - 92 - 3008, pp. 1 - 34 (June 1993).

- J. S. Brzosko, V. Nardi, J. R. Brzosko, D. Goldstein"Observation of Plasma Domains with Fast Ions and Enhanced Fusion in Plasma-Focus Discharges". Physics Letters, Vol. A192, p. 250 (1994).

- K. Melzacki, V. Nardi, "Long-Exposure-Time Schlieren Photography of Plasma Focus Discharges". Rev. Sci. Instrum., Vol. 66, p. 655 (1995).

- A. Bortolotti, P. Desiderio, F. Mezzetti, V. Nardi, C. Powell, "Current Sheet Dynamics in Focused Discharges". Int. Symp. Research and Applications of Plasmas (M. Sadowski, H. Rothkahel Ed.s), Vol. 2 (Invited papers), pp. 78 - 85 (1997).