

gave the final talk, on dissipative ballooning modes in tokamaks. In the resistive MHD model, the electrostatic branch is stabilized by the finite value of the ratio  $(C_s/C_A)^2$ , so the second stability zone should exist for dissipative ballooning modes. The kinetic theory allows the consideration of the magnetic drift: it has also a stabilizing effect.

Xavier Llobet

Centre de Recherches en Physique des Plasmas  
Association Euratom-Suisse  
21 avenue des Bains, CH-1007  
Lausanne, Switzerland

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## SUMMARY OF "ANOMALOUS NUCLEAR EFFECTS IN DEUTERIUM/SOLID SYSTEMS," AN INTERNATIONAL PROGRESS REVIEW, PROVO, UTAH, OCTOBER 22-24, 1990

An international gathering of 160 scientists met at Brigham Young University (BYU) to scrutinize observations of small nuclear effects associated with deuterium loaded into various solids. The workshop was sponsored by the Electric Power Research Institute, the U.S. Department of Energy, and BYU. Nuclear physics and geophysical experimental data were emphasized, and theoretical issues were also explored. Calorimetry and electrochemistry were discussed only as adjuncts to investigations of nuclear reaction products.

Nearly 70 papers were presented, with discussions divided into five broad categories with chairs as indicated:

1. *Neutron Measurements*: W. Meyerhof (Stanford University), K. Nagamine (University of Tokyo), A. Vitale (University of Bologna), K. Wolf (Texas A&M University), F. Scaramuzzi (Frascati Research Centre), H. Menlove [Los Alamos National Laboratory (LANL)], and V. Tsarev (Lebedev Physical Institute)
2. *Charged Particle Detection*: J. Ziegler (IBM) and E. Cecil (Colorado School of Mines)
3. *Geophysical Considerations*: F. Goff (LANL), E. P. Palmer (BYU), and G. McMurtry (University of Hawaii)
4. *Tritium/Helium Studies*: G. Miley (University of Illinois), N. Hoffman (Rockwell International), and M. Srinivasan (Bhabha Atomic Research Centre)
5. *Theory*: J. Rafelski (University of Arizona), V. Belyaev (Dubna), Y. Kim (Purdue University), and E. Tabet (Istituto Nazionale di Fisica Nucleare).

### NEUTRONS

Significant improvements in neutron detectors and signal/noise ratios were reported. Techniques now include plastic and liquid scintillators often used in conjunction with neutron capture detection using lithium-doped glass or  $^3\text{He}$ -filled proportional counters. Time-of-flight and pulse digitization techniques are also employed. Groups in the United States [S. Jones (BYU), H. Menlove and T. Claytor (LANL), K. Wolf], Italy [A. Bertin (University of Bologna), F.

Scaramuzzi, and F. Celani (Frascati Research Centre)], Argentina [J. Granada (Centro Atomico Bariloche)], and China [R. Zhu (Institute of Atomic Energy)] reported on neutron studies in deep underground locations. Observations of neutron emissions from  $\text{D}_2$  gas-loaded metals,  $\text{D}_2\text{O}$  electrolysis cells, and deuterium ion-implanted metal foils in low-background environments (very low cosmic-ray fluxes particularly) and with redundant detectors confirmed earlier observations, with rates broadly consistent with the early Jones et al. report.<sup>1</sup> Neutron bursts of the order of a few hundred neutrons produced in  $\sim 100 \mu\text{s}$ , consistent with early observations of Menlove et al.,<sup>2</sup> were also reported in detectors of various types, including segmented neutron counters in underground locations.

Neutron bursts were measured in an underground lead mine at Leadville, Colorado, with both temperature-cycled titanium deuteride samples and a palladium electrolysis experiment (S. Jones, H. Menlove, and K. Wolf). Frequency and magnitude of large burst events were consistent in the mine and aboveground at an altitude of 10 000 ft (gas-loaded titanium only aboveground) in Leadville. These experiments evidently rule out neutron cascading from cosmic nuclei as a possible explanation of neutron bursts. R. Anderson discussed the need for redundant detectors and exclusion of cosmic-ray effects based on negative experiments carried out at LANL a year ago. In fact, redundant detectors, exclusion of cosmic rays, adequate hydrogen controls, and improved reproducibility based largely on controlled sample preparation techniques were of paramount importance in recent experiments.

### CHARGED PARTICLES

Several experimenters reported searches for energetic charged particles from deuterium-loaded metal foils. E. Cecil, G. Chambers (Naval Research Laboratory), and R. Tani-guchi (ARL, Japan) observed charged particles having a few mega-electron-volts energy using silicon surface-barrier detectors, while K. Wolf has not yet found any evidence. X. Z. Li (National Tsing-Hua University) reported numerous ion tracks in etched plastic detectors exposed to deuterided palladium and showed a dramatic slide of etched tracks that had the appearance of arising from a localized "burst" of ions.

### GEOPHYSICAL INVESTIGATIONS

P. Britton (Reiss Foundation) reported evidence for increasing  $^3\text{He}$  and tritium with depth in boreholes in the Hamilton shear zone. E. P. Palmer reviewed the geophysical "cold fusion" hypothesis, which was responsible for the inception of cold fusion experiments at BYU in 1986. F. Goff presented evidence for several tritium units in "magmatic" water from Mount St. Helens. He and G. McMurtry collected samples from the Pu'u O'o vent of the Hawaiian volcano Kilauea that will be analyzed for tritium content. Their adventure was the subject of a most interesting after-banquet slide and video talk by McMurtry at Robert Redford's Sundance Resort on the second night of the conference.

### TRITIUM/ $^4\text{He}$

Reports of tritium production from deuterided metals and of tritium contamination in metal samples generated considerable discussion. The possibility of tritium contamination

leading to false readings emerged as a drawback of this technique, and K. Wolf in particular reported the presence of tritium contamination in as-received palladium samples. Noting that he had not seen evidence for tritium production for many months, E. Storms (LANL) showed experimental evidence that tritium loaded into palladium diffuses out almost exclusively to the gas phase under cathodic potential in an electrolytic cell, whereas several experiments finding tritium show significant amounts of tritium in the electrolyte. Preliminary results from experiments carried out at the National Cold Fusion Institute of the University of Utah were originally interpreted as evidence for low-level tritium production in electrolytic cells, but this turned out to be due to a calibration problem for colored solutions. However, M. Srinivasan, T. Claytor, and O. Matsumoto (Aoyama Gakuin University) continue to find evidence for tritium production. In addition,  $^4\text{He}$  production in a molten salt electrolytic cell was reported by B. Liebert (University of Hawaii), with two caveats: a control with light hydrogen had not yet been done and the amount of  $^4\text{He}$  above that in the as-received metal was too small to account for observed "excess heat" by a factor of  $\sim 10^8$ .

## THEORY

Lines of thought relevant to the very puzzling observations of low-level nuclear reactions in deuterided metals include micro hot fusion or fractofusion, electron screening, low-energy nuclear resonances, neutron transfer (Oppenheimer-Phillips) reactions, coherent fusion mechanisms, nucleation centers in metal lattices, reactions associated with phase changes, formation of metallic deuterium, and fusion catalyzed by di-quarks or new particles.

A few participants, notably P. Hagelstein (Massachusetts Institute of Technology) and A. Takahashi (Osaka University), explored the novel concept that nuclear reactions other than two-body deuteron-deuteron ( $d-d$ ) fusion might account for observations of neutrons and charged particles having energies  $>3$  MeV reported at the workshop. Such models also allow for a large tritium-to-neutron ratio (roughly  $10^8$  is reported by some researchers) without invoking an anomalous branching ratio for  $d-d$  fusion favoring the tritium channel.

## CONCLUSIONS

Several features emerge from the ensemble of studies presented at the workshop. Evident nuclear particle emissions are observed episodically, with episodes typically lasting minutes or hours. Rates of particle emission vary greatly from episode to episode, with some observed rates now several orders of magnitude above the instrumental sensitivity. Detectors dedicated to the study of these effects are improving, as are signal/noise ratios. However, an immediate "trigger" mechanism remains elusive, as does a coherent model for the observations. Observed effects seem to be related to *changing*

temperatures and deuterium/metal ion ratios (highly non-equilibrium conditions); very little evidence has emerged for a correlation between nuclear effects and high deuterium/palladium loading ratios.

Negative experiments were discussed at the meeting, many of which pursued the notion that high deuterium/palladium loading was essential. Still, it was recognized that observations must be checked in sensitive detectors by skeptical observers. In this spirit, an offer was extended by Y. Totsuka (University of Tokyo) for use of the deep underground Kamiokande detector, a 4500-t water-Cerenkov system now used for neutrino studies. S. Jones and colleagues accepted the offer on condition that several weeks (rather than days) be allotted to the tests. The tests are expected to be completed in summer 1991.

It is clear that a robust community intends to pursue the study of anomalous nuclear effects in deuterium/solid systems. The sensitivity of detectors is expected to improve further, accelerating progress in experiments. The interaction between theorists and experimenters should lead to increased understanding and corresponding control of what appears to be a new and intriguing regime for nuclear reactions.

This summary endeavors to share the flavor of the workshop on nuclear effects in deuterium/solid systems. The full proceedings will be available from the American Institute of Physics as proceedings no. 228.

*Steven E. Jones*

Brigham Young University  
Department of Physics and Astronomy  
Provo, Utah 84602

*Franco Scaramuzzi*

ENEA  
CP I-00044  
Frascati (Rome), Italy

*David Worledge*

Electric Power Research Institute  
Palo Alto, California 94303

*Nate Hoffman*

Rockwell International Corporation, ETEC  
Canoga Park, California 91304

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