higher inherent sensitivity of the film and because time integration accumulates delayed as well as prompt fission gamma rays. Furthermore, photographic film has well-characterized relationships between density and exposure, making the results much less subject to nonlinearities of the type often found in active electronic instrument systems that are operated outside their normal range.

The other integral effect reported in Ref. 1 is an axial flux tilt, which appears in both the pinhole film and the monitor wire tabulations. The 5% tilt shows up when an axial fission density ratio is formed from the data collected during two extreme positions of control rod T1. This tilt might be real; in a pair of comparable single-pin experiments, the hodoscope observed an extreme transient background flux tilt of 5%. In any event, the integral data presented are not sufficiently definitive or relevant to constitute confirmation of a strong previously unrecognized flux anomaly during the PINEX-3 transient.

TREAT Power Coupling. An assortment of flux-related candidate explanations is offered[1] on behalf of the pinhole anomaly—control rod effects, Doppler broadening, fuel density changes, capsule heating, core temperature rises, and spectrum hardening. The integral steady-state data could be accounted for[7] by physical effects that depend on control rod core location and axial movement, but the pinhole transient data lack specific theoretical foundation; it might be entirely spurious, or it might be a small flux tilt magnified out of proportion.

Transient-correction factors in the TREAT program have long been recognized, and calibration experiments are routinely performed to make integral corrections. Even so, coupling-factor adjustments have little or no bearing on many measured properties: time or magnitude of temperature, flow, or pressure; hodoscope determination of time, location, and velocity of fuel motion; and quantitative estimates of fuel motion involved in transients. Interpretation, modeling, and intercomparisons based on fission energy deposition must, of course, take into account the method of instrumentation and normalization. Outside the limits of other systematic and statistical errors, any "misinterpretation"[1] of tests at TREAT would more likely result from inadequate understanding of test results and insufficient verification of pinhole instrumentation performance.

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August 20, 1982

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[7] A. DeVOLPI, "Neutron-Flux, Power-Coupling, and Transient-Correction Factors at TREAT" (in preparation).

Response to "Unjustified Interpretation of Flux Anomaly at the Transient Reactor Test Facility"

In the preceding Letter,[1] DeVolpi asserts that our identification of the flux anomaly in the Transient Reactor Test Facility (TREAT) "is based on selected data, omits contradictory results, misplaces physical phenomena, and ignores the alternative of nonlinearity in the pinhole instrumentation response as a cause of the anomaly." He also makes a number of other, scientifically unfounded statements regarding our Note[2] and invokes hodoscope data as the contradictory evidence.

We welcome the opportunity to discuss any of the technical issues. In fact, we strongly feel that a thorough examination of these issues would be beneficial for all who interpret TREAT tests—be they experimenters, analysts, or diagnosticians, or those necessarily removed from immediate technical involvement. In our opinion, the potential for serious misinterpretation of data as a consequence of reactor physics related effects[3,4] is a most crucial issue for the entire fast reactor safety program.

It appears to us from the tone and content of DeVolpi's Letter that he does not understand the PINEX technique, does not recognize the value in internal, real-time calibration, and does not appreciate the advantages in characterizing and monitoring 4 instruments [the 4 television (TV) cameras of the PINEX] as opposed to 300 (the 300 plus hodoscope channels). We are reluctant to delve into inadequacies of the hodoscope system in this forum but feel that, because DeVolpi seeks to support his accusations by appealing to the hodoscope data, some discussion must be made.

We have prepared a lengthy, documented rebuttal to DeVolpi's ubiquitous, negative statements about our experiment. Such a lengthy discussion is perhaps inappropriate for a Letter to the Editor. Hence, we have summarized what, in our opinion, are the major issues. A full text dealing with all of the points, paragraph by paragraph, is available upon request.

First, we address the assertions that DeVolpi makes about our diagnostic system and its calibration. He claims that our TV camera tube had a matrix of discrete silicon diodes that exhibit a supralinear response, and that a pulsing light in the image scene would not provide a real-time gain monitor. The system we used in the experiment employs an antimony trisulfide target that is *not* a silicon matrix and has a sublinear transfer curve as shown in Fig. 1 (see DeVolpi's Ref. 5), a fact that has been known for years, and whose system gain has been shown to be characterizable by our pulsed light method.[5]

His statement that ". . . the performance of the pinhole instrumentation has not been verified under the relevant dynamic conditions" is simply incorrect.

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[1] A. DeVOLPI, *Nucl. Sci. Eng.*, **83**, 316 (1983).

[2] A. H. LUMPKIN and G. J. BERZINS, *Nucl. Sci. Eng.*, **81**, 477 (1982).

[3] A. H. LUMPKIN and G. J. BERZINS, "Test Reactor Physics Effects on Fuel Motion Diagnostic Data Interpretation," *Proc. Int. Topl. Mtg. Liquid Metal Fast Breeder Reactor Safety and Related Design and Operational Aspects*, Lyon, France, July 19-23, 1982, European Nuclear Society (to be published); see also LA-UR-82-2028, Los Alamos National Laboratory (1982).

[4] A. H. LUMPKIN, "Further Comment on the Time-Dependent Neutron Flux/Spectrum Anomaly at the Transient Reactor Test Facility," Los Alamos National Laboratory (in preparation).

[5] G. J. YATES, Los Alamos National Laboratory, Private Communication (Sep. 1982); see also G. J. YATES and V. H. HOLMES, Jr., "Typical Vidicon Responses to Short-Duration Pulsed Light and Fast Single-Field Readout," LA-7026, Los Alamos National Laboratory (Mar. 1978); G. J. YATES and B. W. NOEL, "A 256-Line, 2.8-ns Field Duration TV Camera," LA-6407, Los Alamos National Laboratory (Nov. 1976).

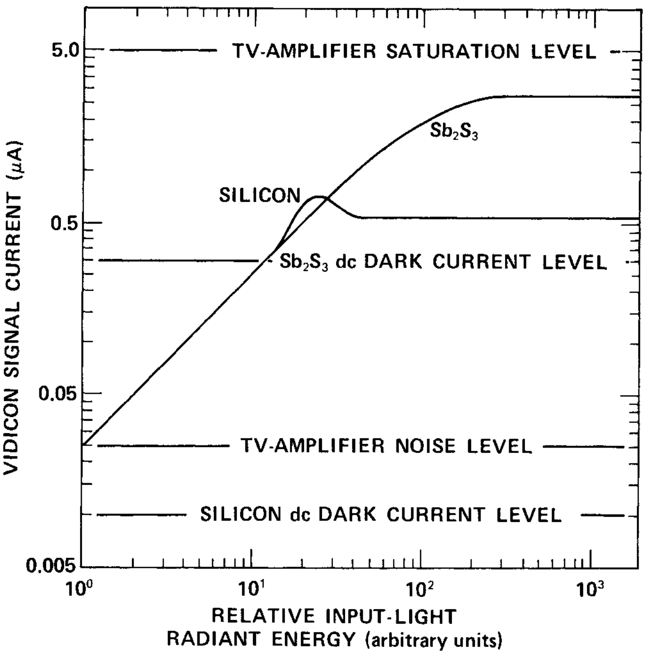

Fig. 1. Comparison of the transfer curves (signal out versus light input) for silicon and Sb_2S_3 targeted vidicons. (Data shown by permission of authors of DeVolpi's Ref. 5.) DeVolpi's thesis rests on the supralinear behavior of the *silicon* target. In fact, we used Sb_2S_3-type vidicons. The smooth curve for Sb_2S_3 shown above is representative of those measured for our cameras and exhibits *no* supralinearity.

The instruments were verified under the relevant dynamic conditions as follows:

1. Light sources of controlled, variable intensities were used to sweep the cameras through the full dynamic range of the system.

2. Video signals were then referenced to the power range in the reactor during low-power (~50-MW) reactor transients.

3. Final verification was achieved by operating the system during a standard TREAT calibration transient whose power follows the required profile for the final transient, but which uses a dummy capsule in the test section.

Thus, all parts of the image except for the (absent) pin contain signals representative of (but not necessarily identical to) those in the final transient.

Second, the only information that apparently contradicts the evidence for our hypothesis of a time-dependent flux tilt is that attributed to his own hodoscope data interpretation: "The hodoscope data . . . did not show–to a precision of a few percent–any time-dependent local perturbation correlated with transient rod motion" including the experiment in Ref. 2.

We are somewhat puzzled by DeVolpi's claimed "few percent" precision when we read the appendixes in his Ref. 3 (our Ref. 6) on the hodoscope. Supralinearity corrections for the hodoscope are quoted as typically "a factor of 2," as varying from transient to transient and from detector to detector. Supralinear response is a measured count rate increase at a faster rate than the reactor power.

In Ref. 6 he also states that there is a second nonlinear term, a drift in the detector count rate that is most noticeable when the power level is "constant." "The maximum magnitude of the drift correction is ±50% at the end of a 20-s transient." He also argues that *if* (our emphasis) the correction is well understood, then the resulting systematic error will be small.

For the experiment in question, the hodoscope analyst reported that his axially summed power monitor array average agreed with the TREAT power monitor, Safety-1 (S1), within 5% over the whole transient *after* he had applied *their supralinearity* corrections.[7] It appears probable, then, that the reactor physics related phenomena, which are observable as a test section count rate increase that rises faster than the TREAT monitor instrument S1, are masked in the hodoscope electronic supralinearity and the associated correction technique that relied on a TREAT instrument at some stage. Furthermore, we believe that properly analyzed hodoscope data would reveal these reactor physics effects. In our opinion, the effect is present even in the corrected hodoscope data for the experiment in the Note. We have stated so in DeVolpi's Ref. 4.

Third, DeVolpi says that the flux tilts due to control rod motion are only "a few percent" as determined by hodoscope measurement and that there is no specific theoretical foundation for the effects appearing in our transient data—even if there are integral steady-state data effects. He also discounts our "assortment of flux-related candidate explanations."

As a further test of our thesis, we have recently reported[3] our results obtained on the "constant power" transient performed shortly before the final transient of Ref. 2. Figure 2 shows that we observed an ~20% increase in the test section signal from early to late in the "constant power" transient. No subtractions have been done, and the digital profiles are matched at the camera dark-current. (The hodoscope also operated during this transient.) The T-1 rod motion was ~30 cm (12 in.) but had a pattern similar to a portion of the transient in our Note. We are preparing a comparison of the model to these data.[4] Implications of the actual axial position of S1 may be involved.

Other than our own deductions described in Ref. 3 and in the Note, where among other things we used the flux wire and fuel pin irradiations as a function of T-1 positions in steady state to approximate transient rod motion in a transient, we quote results from recent, independent TREAT modeling.[8,9] (This is in addition to Graff's study,[10] which we discussed in Ref. 2.)

In contrast to DeVolpi's statement, a recent study by Hart et al.[8] of TREAT states ". . . rod position changes cause power-coupling changes during the course of a transient. . . . The magnitude of the effect is such that rod pair T-1 causes a 25% change in power coupling as it moves from its fully inserted to its fully withdrawn position. Similarly,

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[6] A. DeVOLPI, C. L. FINK, G. E. MARSH, E. A. RHODES, and G. S. STANFORD, *Nucl. Technol.*, **56**, 141 (1982).

[7] G. E. MARSH, Argonne National Laboratory, Hodoscope Report to HEDL, May 1, 1980, Information Exchange.

[8] P. R. HART, G. KLOTZKIN, R. W. SWANSON, and L. J. HARRISON, "Power Coupling Dependence on Rod Position During Transient Operation," Argonne-West Memo, Argonne National Laboratory (Aug. 23, 1982).

[9] R. W. SWANSON, G. KLOTZKIN, and L. J. HARRISON, "Power Coupling Dependence on TREAT Core Temperature," Argonne-West Memo, Argonne National Laboratory (May 25, 1982).

[10] D. L. GRAFF, "A Study of the Transient Correction Factor Used in TREAT Reactor In-Pile Experiments," ANL-78-31, Argonne National Laboratory (1978).

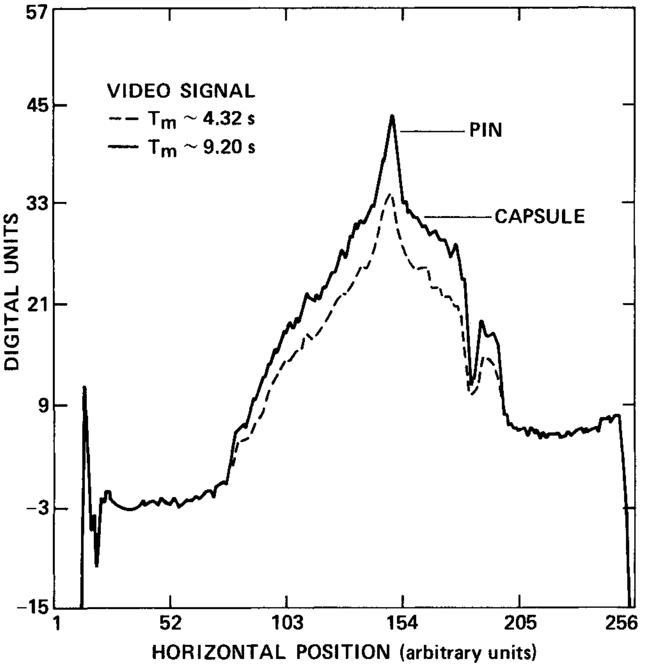

Fig. 2. Fuel pin-plus-capsule profiles obtained for an axial segment about one pellet long and located 10 cm below the midplane. The profile at an early median time, T_m = 4.32 s, represents $\sim$20% less signal strength than that at the late median time, T_m = 9.20 s, during a "constant power" transient at TREAT.

rod pair T-2 causes a 16% change." Based on this TREAT analysts' study of available experimental flux wire data, the power coupling should change at the midplane by $\sim$17% due to T-1 and 5% due to T-2 from the beginning of the flattop to the peak of the transient of our Note. In that experiment, T-1 moved 71 cm (28 in.) and T-2 moved 29 cm (11.5 in.) out of a maximum 101 cm (40 in.) of travel for each rod pair. This power coupling is based on a reference to S1 or Integrator-1 and a specific steady-state configuration of the rods. This total of $\sim$22% expected change in the power coupling is also several times larger than DeVolpi's few percent hodoscope experimental limit.

Since we wrote our Note, another study by TREAT's Swanson et al.[9] considered core temperature effects on pin power coupling. Graphs from that work indicated that, for a 300°C core moderator temperature increase, the test pin fissions-to-local core power ratio would increase 20% and the pin fissions-to-capsule absorptions ratio would increase 12%. This core temperature change is approximately that which occurred during the experiment in our Note. This would be a change in the relative pin signal that would *not* be due to fuel motion but is larger than the maximum signal change accommodated by filling the central void of that annular pin.

In addition, we refer to recent relevant work done with the CABRI hodoscope.[11,12] A postirradiation gamma-ray scan of the test fuel measured the relative induced fissions as a function of axial position, and the resulting power profile was then compared with the CABRI hodoscope data. The CABRI reactor does not use transient control rods but can bank the rods. The CABRI measurement of flux depression of 15 to 20% in the upper half of the reactor and a relative flux increase in the lower half of the reactor when the rods were banked partly down into the reactor core, as compared to the completely withdrawn case, is suggestive. If one reverses the sequence and withdraws those rods, there is a relative flux gain in the upper half of the reactor and a loss in the lower half. This flux shift would cause a shift in the pin signal intensity profile and would look like axial fuel motion.

The CABRI measurements were supported by calculations that showed an axial shift in the hottest point of the test pin.[13] For control rod insertion to the midplane, the hot point shifted down by 12 cm relative to the zero insertion case.

In summary, we note that since the writing of Ref. 2, its basic issues have been corroborated by

1. our analysis of other, independent PINEX data[3,4] that were recorded under conditions that allow isolation of several hypotheses
2. independent modeling[8,9] and examination of *other*, existing TREAT data as reported by the TREAT staff
3. measurements[12] performed on the CABRI reactor with the CABRI hodoscope, calculations[13] at CABRI, and other, earlier CABRI studies.[11]

In addition, we had earlier examined the hodoscope data reported in DeVolpi's Ref. 4. In our opinion those hodoscope data, even after supralinearity corrections, drift corrections, etc., also suggest support for the flux tilt.

DeVolpi[1] has helped us to bring three important issues into focus:

1. The traditional view of reactor physics effects as "only a few percent" is not always valid. The "Anomaly at TREAT" as described in Ref. 2 exists in the TREAT reactor because of fundamental nuclear physics and reactor physics phenomena. It exists as an anomaly because investigators such as DeVolpi apparently had an incomplete understanding of these effects and defined "normal" behavior incorrectly.

2. Our choice of the word "misinterpret" seems rather apt. It appears that a self-consistent scenario accommodating the hodoscope and PINEX data together with newer models of reactor behavior[8,9] involves the masking of the reactor physics effects in the hodoscope raw data with detector supralinearity, detector drift, etc. corrections applied to the raw data. These hodoscope data-correction procedures as described by DeVolpi et al.[6] would then include a classic example of a misplaced physical phenomenon.

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[11] K. BOHNEL and H. BLUHM, "First Results of the CABRI Neutron Hodoscope," *Proc. Int. Mtg. Fast Reactor Safety Technology*, Seattle, Washington, August 19-23, 1979, Vol. V, p. 2261, American Nuclear Society (1979).

[12] K. BOHNEL and K. BAUMUNG, Additional control-rod-effect data in *Workshop Meeting on Fuel Motion Diagnostic Instrumentation Related to LMFBR Safety and User Needs*, Cadarache, France, July 26-27, 1982, H. H. HELMICK, Ed., Commissariat à l'Energie Atomique (1982).

[13] J. M. FRIZONNET, Private Communication (July 28, 1982).

3. A thorough understanding of TREAT's core physics is fundamental to the interpretation of simulated accidents. Unless these effects are characterized and applied to test data in a time- and spatially dependent manner, misinterpretation of past, present, and future tests at TREAT is the likely consequence.

We believe that significant progress has been made in the understanding of these problems since we submitted our Note. Further iterations of the new information should be most beneficial.

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October 12, 1982