LETTERS TO THE EDITOR

RADIATION EFFECTS ON THERMOCOUPLES

Dear Sir:

We on the NERVA program have lived with the problem of radiation effects on instrumentation in general and thermocouples specifically. The following is a critique of the article "Direct Radiation Effects on Thermocouples," by Leonard and Hunkar.[1]

1) The design of the experiment was poor and did not eliminate all possible sources of error (witness the pretest offset in Fig. 2). The test results, therefore, are questionable and are definitely contradictory within themselves. As a result, the conclusions reached by the authors relating to radiation effects on thermocouples are unsupportable.

2) The interconnection of the two water tanks guarantees neither equal temperature in the two baths nor homogeneous water compositions.

3) The secondary junctions of Chromel-compensated lead wire were uncontrolled and the use of such lead wire in precision experiments is poor.

4) Figure 1 shows the circuit for the grounded thermocouples and reveals that the Alumel/Chromel/Alumel circuit is in fact Alumel/Chromel in parallel with Inconel and Aluminum/Alumel. The calibration of such a loop is uncertain and definitely not that of Chromel/Alumel. Temperature gradients within the structure could account for the voltages recorded since the structure is made a part of the circuit.

5) The test on p. 722 indicates that the reference junction is formed at the measuring instrument. This is poor design and can yield serious measurement errors.

6) The test results shown in Fig. 2 cannot be considered valid when the pretest portion of data shows a large temperature offset that is not explained.

7) During test number one, the appearance of a large thermoelectric drift was coincident with the appearance of a radiation field. During test number two, the appearance of a large thermoelectric drift was coincident with the disappearance of a radiation field. This must cast doubts on the validity of either or both tests.

8) The text on p. 721 and Fig. 3 purport to demonstrate radiation effects. The only relationship appears to be a transient response related to reactor startup. If this were, in fact, a radiation effect, then there should be a change upon subsequent reactor shutdown or startup. There is none. These data are, therefore, suspect and cannot be used to support the authors' position.

9) The authors, on p. 724, postulate large effects at small doses that grow smaller with increasing doses. To postulate such an occurrence is questionable. This would presume that the maximum radiation effect exists with no radiation.

10) The authors, on p. 724, discuss the care taken in eliminating extraneous sources of error; yet, the design of the experiment is, at best, poor and introduces many gross uncertainties into the measurements.

11) In item 3 of p. 725, the authors state that transient decalibration effects would not be detectable in thermocouple tests involving only pre- and postirradiation calibrations. However, most of their conclusions are based upon the large postirradiation drift illustrated in their Fig. 5.

12) The authors, on p. 725, indicate that shunting of thermocouple circuits reduces the voltages recorded. The amount of reduction should have been presented in order to permit evaluation of the results.

13) On p. 725, the statement is made that the voltage variations are radiation induced, and Fig. 5 is used to support this statement. Inspection of Fig. 5 reveals no radiation effect possible other than gamma heat during the first reactor power cycle. It is only after the cessation of radiation that a voltage variation occurs. Resumption of reactor power shows a change in voltage; however, the third cycle does not. These results are within themselves and cannot be used to support any conclusion concerning radiation effects on thermocouples.

14) The authors state, on p. 726, that transient radiation-induced thermoelectric alterations appear upon exposure cessation and are produced by the self-annealing of radiation induced "scattering centers." If this were the true drift mechanism, some evidence of drift should appear upon any exposure cessation. However, Fig. 5 clearly demonstrates the complete absence of postirradiation drifting after the termination of the second radiation cycle.

15) In summary, it is my opinion that the basis for the experiment design is questionable and that the results cannot be used to support the premises.

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REFERENCES

1. JAMES H. LEONARD and DENES B. HUNKAR, "Direct Radiation Effects on Thermocouples," *Nucl. Appl.*, 3, 718 (1967).

Nuclear Engineering Program

Dear Sir:

It is gratifying that our article on direct radiation effects on thermocouples has been evaluated sufficiently to warrant comment by Mr. Gilles, who is concerned with instrumentation aspects of the nuclear rocket program. This program constitutes one important application in which thermocouples are used in the presence of time-variant radiation fields. It was with such applications in mind that we undertook to investigate whether thermocouples are insensitive to direct radiation effects, as generally believed.

In our initial experiment, absolute temperature calibration was not feasible because of the unconventional thermocouple connections employed, as our article stated. Gilles' comments 2, 4, and 6 would be pertinent to absolute temperature calibration, had that been attempted, but could not account for temporal changes in emf observed upon variation of reactor power level while the boiling water baths (and surrounding structure) were maintained at constant temperature. Our article conceded the difficulty of interpreting data from the initial experiment by itself except for recognition of a timewise emf variation possibly related to radiation exposure. However, the results were included along with those from the more conventional second experiment because both experiments considered together yielded information about more experimental parameters (tabulated on p. 725 of the article) than could be derived from either experiment alone.

As cited by Gilles in comments 3, 5, and 10, the second experiment employed sheathed thermocouples conventionally connected to compensated lead wire with the reference junction formed at the measuring instrument terminals. These features (necessitated by mechanical aspects of the reactor facility) could not be responsible for the observed emf variations of $>400\,\mu V$, which were shown in Fig. 5, p. 724, to be associated with reactor power level changes. The temperature of the reference junction was found by independent thermometer measurements to have varied during the course of the experimentation $< 1.5°F$, resulting in an emf variation of at most $\sim 35\,\mu V$. Prior to in-pile testing, the secondary junctions between the sheathed thermocouple leads and the compensated lead wires were temporarily heated with a torch until the exposed junctions rapidly increased from room temperature to well above 250°F. This severe test caused $< 30\,\mu V$ of emf variation. Whatever adjectives Gilles may choose to describe the quality of the experiment design, the observed effects were definitely not attributable to these design features, and must therefore be presumed to have been radiation-induced.

The remainder of his comments relate to reconciliation of the several test results emphasizing differing degrees of emf variation during, and after, successive exposure cycles. Such behavior may be difficult to accept in terms of intuitive expectations, but a mechanism of the nature hypothesized in the article could account for differing effects at various exposure levels, if not for the exact variations observed. Certainly, thermoelectric materials are not immune from radiation damage, and it would seem surprising if direct radiation damage (in addition to known transmutation effects) did not in some way affect thermoelectric power. References 4 through 7 of our article each contain predictions of such effects.

Our article disclaimed completeness and suggested that more extensive investigations of possible direct radiation effects on thermocouples are needed. Hopefully, others (perhaps including reader Gilles) have relevant experimental data that could be published to provide more pertinent information. The key features of any such experiments must be 1) an absolutely assured constant temperature environment (including the hot junction) while radiation level is varied, and 2) continuous monitoring of thermocouple output during and after exposure (which was not the case in previously published work involving calibration before, and long after, irradiation). Only after more experimental information obtained under these necessary conditions becomes available will it be possible to consider the exact mechanism involved. Until such time, we reassert that the experiments indicate that radiation can directly affect thermocouple calibration.

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