During Phase III, more than 200 cells were assembled and tested to examine the effects of electrode geometry, seal configuration, and sulfur container material. In October 1978 a durability test of a group of 20 cells representing the best combination of variables was begun. Early in their life these cells delivered ~120 W h/kg at 90 mA/cm^2 at an efficiency of ~80%. Tests of these cells continued in Phase IV.

The Phase IV work encompasses continuing cell development leading to selection of a cell design for the pre-BEST Qualification Test which is to begin by the end of Phase IV. In this phase the overall designs and control systems will be developed for both systems.

More than 250 exploratory and Mark I cells utilizing a 34 mm dia., 250-mm long β''-alumina solid electrolyte have been built and tested in the last 18 months under the referenced Phase III and Phase IV contracts. Of these, presently 60 cells are undergoing electrical testing. Eleven of these have been operated for over 400 cycles. Discharged at 90 mA/cm^2 to 1.4 V and charged at 50 mA/cm^2 to 2.6 V, 46 cells of the improved Mark I design exhibited the following mean performance: energy, 208 W h; energy density, 109 W h/kg; capacity, 119 A h; utilization of sulfur ($S^0 \rightarrow NaS_3$), 86.7%; efficiency, W h_o/W h_i, 81.6%; discharge time, 5.0 h; overall cell impedance (ohmic resistance plus polarization), 10.6 mΩ.

During the remainder of 1979 and early 1980 an improved cell will be developed. A compact hermetic seal will replace the present bulky mechanical seal. A more durable sulfur container will be developed. Multicell tests will be continued. System analysis of conceptual batteries is being performed.

SODIUM–SULFUR BATTERY DEVELOPMENT, PHASE IV

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The Ford portion of this program has the following objectives: (1) the development and evaluation of advanced sodium–sulfur cells which offer increased volumetric energy density, improved cell safety, and improved freeze–thaw characteristics; (2) the analysis of EV battery requirements and coordination of EV battery design efforts; (3) the completion of sodium–sulfur battery technology transfer to Ford Aerospace and Communications Corporation, Aeronutronic Division. The program objectives will be achieved by conducting an on-going research effort in cell design, fabrication, analysis and evaluation and *via* system studies to determine EV battery requirements and characteristics.

Design and analysis of electric vehicle cells using plate and multitubular electrolytes was initiated. A small, plate-type cell was designed and parts ordered. Fabrication of the β''-alumina electrolyte by a Ford-financed project is in progress.

Preliminary design optimization of a volume efficient battery incorporating multitubular cells (several tubular electrolytes in a common sulfur container) indicates volume savings of 30% or greater over a battery utilizing single cylindrical cells. Battery volume sensitivity to various parameters is presently under study.

A load-leveling size test seal fixture, incorporating a "double OD" radial compression seal, operated successfully for 111 days at constant cell operating temperature and is now being thermally cycled to room temperature with no apparent problem. Work is in progress to test this seal in several cells.

Tests of two long-life cells which were fabricated in Phase III were terminated. One, a load-leveling cell of standard Mark-I configuration, operated for 17 months and 1000 cycles. Cell failure occurred as a result of an overdischarge caused by malfunctioning equipment. The other, an electric vehicle cell incorporating a splined-type sulfur electrode, operated for 16 months and 730 cycles. Failure occurred suddenly, 45 cycles after a freeze/thaw cycle (caused by equipment malfunction) had occurred.

Recent publications

1 A. Topouzian and R. Harlow, The sodium–sulfur battery: a progress report, *28th Power Sources Symp. June 12 - 15, 1978, Atlantic City, NJ.*

2 A. Topouzian and R. W. Minck, Sodium–sulfur batteries, *Second Annu. Battery and Electrochem. Technology Conf., Arlington, VA, June 6, 1978.*

3 M. Mikkor, R. W. Minck and L. E. Unnewehr, Pulse characteristics of sodium–sulfur cells for electric vehicle propulsion, *13th IECEC Conf., August 20 - 25, 1978, San Diego, CA.*

4 M. Pulick, Sodium–sulfur electric vehicle demonstration program, Electric and Hybrid Vehicle Program Contractors Meeting, June 26 - 28, 1978, Germantown, MD.

5 R. W. Minck and R. A. Harlow, Sodium–sulfur batteries for electric vehicles: status of the DOE–Ford program, presented to the *ACS/CSJ Chem. Congr. Symp., "Batteries for Electric Vehicles," April 2 - 3, 1979.*