system was developed further so that the resolution of the detector was not degraded by the processor. During this period, the Ge(Li) detector surpassed the scintillator in resolution, and its use in research applications became widespread. These detectors, however, had to be manufactured and operated at very low (cryogenic) temperatures.

Research on the development of Ge(HP) detectors was initiated at LBL and General Electric (GE). The first high-purity germanium detectors were sold by GE in 1974. These detectors still needed to be cooled during operation but not during manufacture and storage. Manufacturing and operating costs fell as a result.

The ability to work with the germanium at room temperature also permitted the construction of multidetector systems. By connecting as many as ten detectors to a single processing unit, the efficiency of the germanium detector array can be increased without sacrificing resolution. These multidetector arrays are ideally suited to situations such as medical research and power plant environmental monitoring. Between 1975 and 1982, OHER funded development of these multidetector arrays at LBL.

Benefits Gamma-ray spectrometers are used primarily for gamma radiation monitoring and elemental analysis of radioactive or neutron-activated materials. Accordingly, gamma-ray spectrometer users fall into four main categories:

1. Nuclear power plants use gamma-ray spectrometers to monitor the content of gas and liquid effluents and the environment of the plant and to measure the condition of the reactor fuel elements.
2. Laboratories (National, university, and commercial) use spectrometers to monitor the environmental conditions of the laboratory and to perform elemental analyses.
3. Resource exploration companies use spectrometers in serial and ground surveillance and mapping and in wellhole logging.
4. Environmental monitoring organizations (such as state and local environmental protection agencies) use spectrometers to monitor levels of radiation being emitted into the environment.

For users of gamma-ray detectors and spectrometers who require a high level of resolution, the only alternative in these applications is time-consuming chemical separations. The real choice to be made by users, therefore, regards the degree of resolution required. None of the competing detectors has the resolving power of a Ge(Li) or Ge(HP) detector.

Discussions with representatives of gamma-ray spectrometer systems and detectors indicated that the market is approximately $7 to $8 million annually. One major manufacturer offered a distribution of units by type of user:

User	Percent of units
Public utility	<10
Laboratories	75
Resource exploration	5
Environmental monitoring	10

The major manufacturers of Ge(Li) and Ge(HP) detectors are Canberra Industries, EG&G Ortec, and Princeton-Gamma Tech Inc.

The use of germanium detectors is most often justified by the need for fast, high-resolution measurements. Fairly short scan times are reported for Ge(Li) detectors, ranging from 100 to 1000 seconds. The time for radiochemical analysis to perform the same analyses ranges from one-half day to several days.

Cost savings associated with using germanium detectors were estimated based on discussions with the staff of approximately 20 utilities operating power reactors. Based on this survey, the annual cost saving in 1982 was estimated as $21.2 million. Past savings were estimated as $230 million (present value). Almost all of these benefits represent cost savings associated with measurements for which the alternative is radiochemistry.

It appears that other important, but difficult to quantify, benefits are being realized. For example, much of the scientific work in nuclear physics could not be performed without the germanium detector. Interestingly, a number of isotopes have been discovered by scientists using the Ge(Li) detector. The device is currently being used to determine whether the neutrino has mass. Also, the germanium spectrometer is now a primary method of gamma-ray spectrometry in astronomy.

Industrial Hygiene Monitors The expertise and methods in measurement sciences accumulated in the nuclear energy program served the Nation well in the 1970's when complex chemical mixtures became an area of vital concern in exploring the potential of synthetic fuels from coal. Lapel and pocket dosimeters for monitoring exposure to polycyclic aromatic hydrocarbons [(PAHs), known carcinogens] were developed to meet the needs of industrial hygiene. Sensitive instruments to measure skin contamination and spill spotters able to measure previously undetectable amounts of chemical contamination also emerged from the OHER Program. In addition to monitoring devices, scientific procedures such as biodirected chemical analysis were developed to measure the carcinogenic and mutagenic properties of complex mixtures of chemicals derived from coal liquefaction and gasification.

As part of the efforts aimed at detecting toxic chemicals, a survey of instrumentation for environmental monitoring was published, and an instrument for monitoring concentrations of PAH compounds, a hydrogen fluoride monitor, and a portable elemental survey meter were developed. The three monitors are in the prototype stage of development. A handbook *The Survey of Instrumentation* for Environmental Monitoring* has been in use for

*LBL, Environmental Instrumentation Group, Vol. 1(4), 1972–1980, John Wiley and Sons.