**Final Report
Development of Multielement SQUID Arrays
for Magnetic Source Imaging**

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OCT 06 1995
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June 1995

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Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-ENG-48.

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Final Report

Development of Multielement SQUID Arrays for Magnetic Source Imaging

93-SR-132

FY 1993: \$142,000

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Superconducting quantum interference devices (SQUIDs) were initially developed in the late 1960s as biomagnetic detectors to monitor electrical activity in the body. Research in this area has increased in recent years as electronics and computer diagnostics have improved. The basis of this proposal was to assess: 1) the advantages of using this technique over other technologies and 2) the requirements for development of a complete system that would advance the state of the art. In our assessment of this technology, we collaborated with the Medical School at the University of California, San Francisco (UCSF), General Electric (GE), Biomagnetic Technologies (BTi), and Conductus, each of which has unique expertise in biomedical applications. UCSF is one of the foremost clinical institutions in the US developing imaging techniques. GE is the primary US supplier of medical imaging systems. Conductus is the major US supplier of SQUIDs and BTi is a developer of SQUID array systems.

A major conclusion of this effort was that the application of SQUID arrays to imaging of cardiac activity is medically relevant because about 4% of the population could benefit from clinical evaluations based on a biomagnetic heart-imaging system (BHIS). In addition, magnetic signal strengths from currents in the heart are typically 1000 times larger than those from the brain, making the cardiac application less susceptible to environmental magnetic disturbances. Thus, our primary focus is to develop clinical applications for heart imaging, while imaging of the brain and other biological functions are of secondary

interest. The overall cost to the medical health care community is a crucial issue that may determine if this technology will be successfully applied.

We focused our effort in three main areas. The first was a determination of requirements to develop the BHIS for clinical applications. The second is an assessment to determine the impact of LLNL-based materials fabrication techniques on SQUID detectors. The third is an assessment of the computational requirements for clinical applications.

We identified major elements and outlined a program that should lead to the successful development of a clinical BHIS system. The major elements of such an effort would include the following:

- SQUID system configuration
- SQUID power supply development
- Front-end sensor electronics
- Cryogenics and packaging
- Shielding issues and signal multiplexing
- Workstations, software and database design
- Systems Engineering
- Patient handling and gantry
- Algorithms for inverse problem solutions
- User/physician interface
- Prototype development

In establishing these concepts, it was necessary to develop a memorandum of understanding to promote the free exchange of ideas. Because of a reduction in interest on the part of GE during the course of this work, this effort shifted to an interaction with the BTi company that has prior experience in making SQUID imaging systems. BTi will provide the use of a magnetically and electrically shielded room and one of their instruments for use by UCSF and LLNL for concept testing in the early part of 1994.

We investigated the benefits that LLNL-based materials-fabrication techniques would have on the development of more suitable SQUID-detector systems. Use of the LLNL Electronics Engineering Research Division capabilities for producing extremely precise arrays of conductors is applicable to

development of magnetic-field measurement coils for use as the input to SQUID imaging systems. Very precise magnetic-field gradiometer components would provide a method for reducing the noise caused by ambient magnetic fields, thereby enhancing signal detection capability. If the process is as effective as calculations suggest it will be, use of precisely fabricated sensor arrays would eliminate the need for an expensive (approximately \$500,000) magnetically shielded room, thereby lowering the overall cost of a BHIS system. This tremendous cost reduction would improve the commercial attractiveness of the resulting system, allowing installation of more units at several locations as well as an overall reduction in the cost per evaluation.

Finally, we completed an assessment of the computer-processing applications required for a clinical biomagnetic imaging system. Although several groups at LLNL are developing computer-aided tomographic analysis techniques, a BHIS will require development of near real-time inverse problem solutions for analysis and display of the data by a physician. Network-distributed computing technology relevant to requirements for a BHIS is being applied to computationally similar problems at LLNL. These distributed computation concepts could be applied directly on existing computer systems present in clinical institutions such as those involved with advanced radiological evaluations.

In summary, we have characterized the medical need, fabrication issues, and computational problems associated with development of a BHIS for clinical applications. Future efforts in this area could include data handling and analysis using an imaging array that BTi is installing at UCSF. We could also develop new signal processing algorithms and displays using data from existing human brain measurements available to LLNL. Our long range goal of developing a clinical BHIS system still remains.