Executive Summary (U)
Superconductivity

The remarkable phenomenon of superconductivity has been the subject of intense scientific and technological interest since the initial discovery in mercury below its critical temperature (high-T_c) of 4.2K. The discovery (around 1960) of superconducting materials capable of supporting high electrical current densities in strong external magnetic fields, and the discovery of the Josephson tunneling effect, accelerated the rate at which potential applications were identified. Many of these applications have since been reduced to practice. The Navy has long recognized the significance of superconductivity and, for this reason, has supported a substantial effort in superconductivity research and development. Nonetheless, progress has been inhibited, in many cases, by the low critical temperatures and the attendant cost and complexity of liquid helium refrigeration.

The dramatic discovery of a class of ceramic oxides exhibiting critical temperatures above 100K has created an extraordinary increase in interest in both scientific and technological aspects of superconductivity. Among the important potential benefits of high-T_c Superconductors (SCs) are operating temperatures at or above the boiling point of liquid nitrogen (77K), and the potential for sustaining higher magnetic field strengths and higher frequencies. The existence of high-high-T_c superconductors has also renewed speculation on the possibility of achieving "room-temperature" superconductivity.

Based on a review of the Navy superconductivity program, including the current technical status, management, funding levels, and future plans, the panel reached eight broad conclusions.

- The Navy has correctly identified a number of opportunities for <u>revolutionary</u> system advances. Examples are superconductive electric-drive propulsion and its application to radical hull designs, and high sensitivity superconductive Magnetic Anomaly Detection (MAD) of mines, torpedos, and submarines.
- Many opportunities also exist for <u>evolutionary</u> system improvements based on superconductive technologies such as very high-speed integrated electronics, energy storage, launchers, high-Q cavities and electromagnetic shields.
- Most Navy superconductivity applications in systems compatible with liquid helium operating temperatures can be accomplished with relatively mature low-high-T_c technology.
- The introduction of high-high-T_c technology could, in principle, offer significant operational advantages, including improved performance in comparison with low-high-T_c materials, greater refrigeration efficiency, and the potential for achieving semiconductor/ superconductor device integration at 77K.
- Although achievements to date are encouraging, high-high-T_c materials technology is still immature. Significant progress in high-high-T_c materials science and engineering will be required to realize the full potential of high-high-T_c superconductors. In particular, the electrical transport properties of bulk

specimens (especially in external magnetic fields) fall far short of requirements. The mechanical properties (e.g., toughness and ductility) and chemical stability also require improvement. The best performance has been achieved in thin films, although for many applications surface resistance must be reduced further and acceptable low dielectric-constant substrates must be demonstrated.

- Given the current state of high-high-T_c materials technology, it is premature to invest significant development effort in enabling technologies (e.g., refrigeration systems and multifilamentary conductor cables) at this time.
- The Navy has played a significant role in superconductivity science and engineering for four decades. The present investment level is fully justified and addresses Navy needs with appropriate technical balance. However, while several focal points are evolving, the materials research and development activities have become fragmented and central authority is still lacking.
- Continued Navy investments in high-high-T_c technology can have a significant impact on the field. It is reasonable to anticipate that Navy Research and Development (R&D) can produce useful thin-film electronic devices for specialized applications involving sensors, shields, and high-Q cavities. However, even after the requisite materials performance levels have been achieved, many applications, especially those requiring high current density conductor cables, will require sustained investments on a national scale which are beyond Navy means. In those instances, Navy R&D will still play an important role by contributing to the national effort, thereby accelerating the introduction into Navy systems.

The conclusions summarized above have led the panel to make the following recommendations.

(1) Within available resources, the Navy should concentrate the near-term tech-base effort in five areas.

- Continue support of low-high-T_c superconductivity research.
- Resolve materials science and engineering issues (e.g., critical current density (Jc) and surface resistance (R_s)) limiting performance of known high-high-T_c materials.
- Initiate advanced technology demonstrations for useful small-scale applications of high-high-T_c superconductivity.
- Stimulate invention of new device concepts, not only by extension of low-high-T_c concepts but also by exploitation of novel high-high-T_c material properties such as their extreme anisotropy.
- Encourage research for new classes of superconductive materials with improved characteristics.

(2) While the Navy has been well served by the enthusiasm of its superconductivity community, it is important that a more structured approach guide the evolution of the tech-base effort. Specifically, it is recommend that the Navy:

- Establish a coordination authority.

- Establish lead laboratories for promising areas.
- Discourage unproductive duplicative efforts among Navy laboratories and centers.
- Review the performer balance among universities, laboratories, centers, and industry to ensure optimal access to a broad community of ideas.
- Generate and execute an integrated R&D plan.

(3) While it is not too early to plan for the future, it is essential that near-term efforts not be compromised by premature commitments to large-scale applications. It is recommended that the Navy:

- Continue system-level studies of superconductivity applications aimed at identifying operational advantages and disadvantages, as well as necessary enabling technologies.
- Define a long-range research strategy which incorporates an appropriate balance between sequential and parallel effort, and which relies on cooperation with other government and commercial efforts in areas requiring major investments.