Defense Systems Information Analysis Center

DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Open-Source Reflectance and Thermal Property Databases

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The Defense Systems Information Analysis Center received a technical inquiry for any public distribution material property databases near standard temperature and pressure conditions, specifically for thermal and radiative properties of materials. No mention was made if the materials should be metals, nonmetals, ceramics, etc., but the inquirer specifically mentioned material reflectivity and thermal properties. There are nine publicly available databases or repositories described in this report.

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ABOUT DTIC AND DSIAC

The Defense Technical Information Center (DTIC) preserves, curates, and shares knowledge from the U.S. Department of Defense (DoD's) annual multibillion dollar investment in science and technology, multiplying the value and accelerating capability to the Warfighter. DTIC amplifies this investment by collecting information and enhancing the digital search, analysis, and collaboration tools that make information widely available to decision makers, researchers, engineers, and scientists across the Department.

DTIC sponsors the DoD Information Analysis Center's (IAC's) program, which provides critical, flexible, and cutting-edge research and analysis to produce relevant and reusable scientific and technical information for acquisition program managers, DoD laboratories, Program Executive Offices, and Combatant Commands. The IACs are staffed by, or have access to, hundreds of scientists, engineers, and information specialists who provide research and analysis to customers with diverse, complex, and challenging requirements.

The Defense Systems Information Analysis Center (DSIAC) is a DoD IAC sponsored by DTIC to provide expertise in 10 technical focus areas: weapons systems; survivability and vulnerability; reliability, maintainability, quality, supportability, and interoperability (RMQSI); advanced materials; military sensing; autonomous systems; energetics; directed energy; non-lethal weapons; and command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR). DSIAC is operated by SURVICE Engineering Company under contract FA8075-21-D-0001.

A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

ABSTRACT

The Defense Systems Information Analysis Center received a technical inquiry for any public distribution material property databases near standard temperature and pressure conditions, specifically for thermal and radiative properties of materials. No mention was made if the materials should be metals, nonmetals, ceramics, etc., but the inquirer specifically mentioned material reflectivity and thermal properties. There are nine publicly available databases or repositories described in this report.

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1.0 TI Request

1.1 INQUIRY

What thermal and radiative material property databases are publicly available near standard temperature and pressure (STP) conditions?

1.2 DESCRIPTION

As a clarification, the inquirer provided context from material taken from the National Materials Information System (NAMIS) database hosted by the Defense Systems Information Analysis Center (DSIAC). The NAMIS database includes material properties for high-temperature applications. The inquirer was looking more in the neighborhood of –20-°C to 250-°C types of conditions (nearer to STP than plasma).

2.0 TI Response

One example of an existing database is the Ecosystems Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS). However, ECOSTRESS lacks many man-made materials and has a relatively scattered schema of mostly diffuse reflectance, mostly natural, and mostly pure materials. The inquirer is looking for resources that cover man-made/mixed/coated materials (potentially non-Lambertian), as well as a database with thermal properties, such as heat capacity, conductivity, and emissivity/transmissivity. Anything along these lines and in the public domain is considered responsive.

As part of the search, DSIAC identified several online repositories of measured optical data about various materials. Nine publicly available databases are presented that provide information on thermal and radiative material properties near STP conditions. This report gives a summary of each, while it is up to the user to dive deeper into each database.

2.1 MITSUBISHI ELECTRIC RESEARCH LABORATORIES (MERL) BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION (BRDF)

The MERL BRDF database contains reflectance functions of 100 different materials [1]. Each reflectance function is stored as a densely measured BRDF. MERL provides this data only for research or academic use. Sample code to read the data is included with the database. The database appears to have been last updated in 2007.

2.2 COLUMBIA-UTRECHT REFLECTANCE AND TEXTURE DATABASE (CURET)

Researchers at Columbia University and Utrecht University have collaborated in an extensive investigation of the visual appearance of real-world surfaces, resulting in CUReT [2]. This joint effort, sponsored in part by REALISE of the European Commission, the National Science Foundation, and by the Defense Advanced Research Projects Agency/Office of Naval Research under the Multidisciplinary University Research Initiatives Grant No. N00014-95-1-0601 has resulted in three databases:

1. **BRDF database** with reflectance measurements for over 60 different samples, each observed with over 200 different combinations of viewing and illumination directions.
2. **BRDF parameter database** with fitting parameters from two recent BRDF models: the Oren-Nayar model and the Koenderink et al. representation [3]. These BRDF parameters can be directly used for both image analysis and image synthesis.
3. **Bidirectional texture function database** with image textures from over 60 different samples, each observed with over 200 different combinations of viewing and illumination directions.

Each of these databases is made publicly available for research purposes.

2.3 ENGINEERING TOOLBOX

The Engineering Toolbox website [4] has data on several different materials. The material provided is basic, but it is a good starting point.

2.4 USGS DATABASE

The U.S. Geological Service (USGS) has ample data on natural materials. Researchers at the USGS Spectroscopy Laboratory have measured the spectral reflectance of thousands of materials in the lab and compiled them in the USGS Spectral Library [5].

The spectral library was assembled to facilitate laboratory and field spectroscopy and remote sensing for identifying and mapping minerals, vegetation, and man-made materials. For many of the samples, wavelength coverage spans the ultraviolet, visible, near-infrared, mid-infrared, and far-infrared regions (0.2–200 μm). A wide range of materials is included in the library: minerals and soils (including rocks and mineral mixtures), coatings on rock surfaces, liquids (including mixtures of liquids, water, other volatiles and frozen volatiles), organic compounds (including biochemical constituents of plants and chemical compounds), man-made materials (including materials introduced into the environment by human activity), vegetation, and other

biologic materials. Detailed sample descriptions are provided with the spectra, including the results of x-ray diffraction, electron probe micro-analysis, and other analytical methods.

2.5 THERMOLIT

The ThermoLit web application provides free and open access to literature information contained in the National Institute of Standards and Technology (NIST) SOURCE Data Archive and provides an easy-to-use tool for generating a NIST literature report in portable document format [6]. The tool is intended to aid researchers and reviewers in determining relevant literature sources for a given experimental measurement; however, it is not intended to replace the comprehensive literature review required by all journals and no guarantee is made regarding completeness of the information provided. For an analysis of the comparative impact a particular measurement may have, the ThermoPlan web application is recommended [7].

2.6 NIST-JOINT ARMY-NAVY-AIR FORCE (JANAF) THERMOCHEMICAL TABLES

The NIST-JANAF Thermochemical Tables [8] provides tables of enthalpies (H) and Gibbs energies of formation (G) for more than 1,000 chemical species in solid, liquid, and gas phases. They were last updated in 1998.

2.7 THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) OPEN-SOURCE BLACKBODY VISUAL BASIC APPLICATIONS (VBA) EXCEL FUNCTIONS

The NASA Armstrong Flight Research Center developed a set of computer functions that can be used in predicting the behavior of heated surfaces named the Open-Source Blackbody VBA [9]. These routines include functions for calculating important engineering quantities of primary importance to engineers and scientists, such as radiative flux and spectral distributions. In addition, the routines also provide the capability to use such information to determine surface temperatures from spectral intensities and to calculate the sensitivity of these temperature measurements to unknowns in the input parameters.

2.8 AUTOMATED DATABASE GENERATION

The number of materials and coatings being developed is increasing at a very rapid pace, meaning that any static database will quickly be made obsolete. There is an effort to build an automated database on materials hosted on the web. A recent, open-access paper by Talley et al. details the effort [10]. The database being developed is available online [11].

2.9 THERMOPHYSICAL PROPERTIES OF MATTER: THE THERMOPHYSICAL PROPERTIES RESEARCH CENTER (TPRC) DATA SERIES

The Thermophysical Properties of Matter Database (TPMD) is curated by Cindas LLC and contains data and information on thermophysical properties [12]. This is the searchable, electronic version of *Thermophysical Properties of Matter: the TPRC Data Series* shown in Table 1 [13]. TPMD is available in a web-based format. The database is continually updated and expanded. It contains over 5,200 materials categorized into 94 material groups, 148 properties, and 53,241 data curves.

Table 2: Summary of Statistical Data on Thermophysical Properties of Matter: The TPRC Data Series [13]

SUMMARY OF STATISTICAL DATA ON THERMOPHYSICAL PROPERTIES OF MATTER – THE TPRC DATA SERIES

	Number of pages	Number of data sets	Number of references	Number of materials
Volume 1: Thermal Conductivity – Metallic Elements and Alloys	1595	5539	1446	892
Volume 2: Thermal Conductivity – Nonmetallic Solids	1302	4627	1037	812
Volume 3: Thermal Conductivity – Nonmetallic Liquids and Gases	707	1505	1406	170
Volume 4: Specific Heat – Metallic Elements and Alloys	830	1186	789	322
Volume 5: Specific Heat – Nonmetallic Solids	1737	1009	518	550
Volume 6: Specific Heat – Nonmetallic Liquids and Gases	383	863	665	56
Volume 6 Supplement	169	726	878	307
Volume 7: Thermal Radiative Properties – Metallic Elements and Alloys	1644	5130	520	242
Volume 8: Thermal Radiative Properties – Nonmetallic Solids	1890	4971	576	782
Volume 9: Thermal Radiative Properties – Coatings	1569	5269	475	1161
Volume 10: Thermal Diffusivity	760	1733	568	445
Volume 11: Viscosity	801	1803	1595	188
Volume 12: Thermal Expansion – Metallic Elements and Alloys	1440	4253	872	672
Volume 13: Thermal Expansion – Nonmetallic Solids	1786	4990	1213	815
Totals	16,613	43,604	12,258	

The original data series was published during the 1970s–80s and is also available in the Defense Technical Information Center (DTIC) Research and Engineering (R&E) Gateway as a total of 14 volumes. This is a comprehensive compilation of data by TPRC at Purdue University. The Master Index is available through the DTIC R&D Gateway by searching the accession number ADA129117 [13].

Specifically, in terms of thermal radiative properties, the DTIC accession numbers are as follows:

- Volume 1: ADA129294 [14]
- Volume 2: ADA951936 [15]
- Volume 3: ADA951937 [16]
- Volume 7: ADA951941 [17]
- Volume 8: ADA951942 [18]
- Volume 9: ADA951943 [19]

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BIOGRAPHY

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