Appendix I History of the International Thermoelectric Society

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AI.1 Introduction

Thermelectrics is defined as the science and technology associated with thermoelectric generation and refrigeration.[1] The technology of thermoelectricity began during the "Great Patriotic War" (World War II) when the Soviet Union, under Academician Ioffe's inspiration, produced 2–4 watt thermoelectric generators to be included in a "partisan mess kit" and capable of powering a small radio from a small cooking fire.[2] Spurred by major advances in semiconductor technology, discovery of more efficient thermoelectric semiconductor alloys, and advances in thermoelectric theory, the 1950s and 1960s witnessed significant efforts to further develop thermoelectric technology. Most of this effort was concentrated in the former Soviet Union, the United States and, to a lesser extent, Europe and Japan.

This early period was characterized by rapid improvements in all areas of thermoelectrics, along with a high measure of enthusiasm. In 1961, Snyder[3] listed 38 US organizations actively engaged in thermoelectric research, including many major corporations such as Whirlpool, Westinghouse, Bell Telephone, GE, Carrier and others. By the mid-1960s, practical thermoelectric devices emerged for niche specialty cooling applications (mostly aerospace) and for space power applications. Progress in efficiency improvement slowed and research peaked by about 1963 (Figure AI.1), followed by a steep decline in activity that was to continue for nearly three decades. Major US corporations shed their thermoelectric activities, in several cases resulting in start-up companies which are active to the present day (Melcor from RCA, Marlow Industries from Texas Instruments, and Global Thermoelectrics from 3M). The pattern of using thermoelectrics for niche applications requiring reliability more than efficiency has dominated the field ever since. However, this situation is likely to change with the use of this technology in the recovery of waste heat, the advent of high-performance nanostructured materials and advances in thin-film devices leading to wide-scale domestic and industrial thermoelectric applications.

A ballpark measure of activity can be arrived at by counting the number of publications that use the word "thermoelectric," recognizing that not all such publications are relevant nor will such an

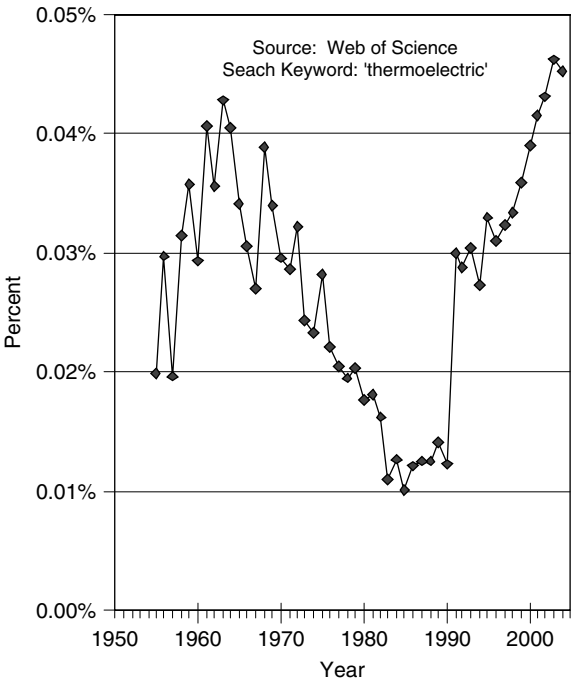

FIGURE AI.1 Open literature publications in the Web of Science database with the keyword "thermoelectric" as a percentage of all publications in the database for each year from 1955 to 2003.

enumeration include all relevant activity. Figure AI.1 displays open literature publications containing the keyword "thermoelectric" as a percentage of all publications in the database from 1955 to 2003. Between 1963 and 1983, publications in thermoelectrics decreased by a factor of four. During this period, thermoelectric technology was in fact successfully transitioning from the laboratory to a variety of applications. The marrying of a nuclear heat source to a thermoelectric generator provided long-life power sources for use in inaccessible and hostile environments. Notable were the radioisotope thermoelectric generators (RTGs) providing critical power for NASA missions on the moon and on Mars and for spectacularly successful outer-planetary exploration missions, such as Voyager I and II. Applications were also found in a number of maritime, terrestrial, and medical applications, the most successful being the nuclear-powered thermoelectric cardiac pacemaker battery.[4]

Despite successful use of RTGs, basic thermoelectric science continued to decline. The nascent thermoelectric cooler industry in the US was too small to support significant R&D. The oil crises of the 1970s were just beginning to modify public R&D policy in Japan, but had little lasting effect elsewhere. And during this period, activities in the Soviet Union remained largely unknown in the West. While important technological advances were being made, scientific progress, publications, and meeting activity declined. In this inauspicious environment, two men in Texas teamed up in 1970 to organize a series of short courses and conferences which eventually spawned the International Thermoelectric Society (ITS).

AI.2 Thermoelectric Activities around the World

The technical aspects of the history of thermoelectricity in the Soviet Union[5] and Japan[6,7] have been discussed elsewhere. Goldsmid has described his pioneering work on Bi_2Te_3 in England in 1954[8] and

thermoelectric activities in Europe have been catalogued by Rowe.[9] This section will discuss regional thermoelectric conferences held in the Soviet Union, the United States, Europe, and Japan.

AI.2.1 Soviet Union

Academician A. F. Ioffe pioneered the development of thermoelectricity, including the first practical generators distributed as part of a "partisan mess kit" during World War II.[2] His classic text, *Semiconductor Thermoelements and Thermoelectric Cooling*[10] still serves as an excellent introduction. It is hardly surprising, then, that the first thermoelectric meetings were held in the Soviet Union.

The first meeting having notable thermoelectric content appears to have been the Eighth All-Union Conference on Semiconductors, organized in St. Petersburg by Ioffe in 1955.[11,12] The word "thermoelectricity" was omitted from the title because practically nobody would have recognized the term, but this conference featured the world's first exhibition of working thermoelectric generators and coolers. Ioffe organized a second conference, The All-Union Conference on Thermoelectric Materials, held in 1957, also in St. Petersburg.

A collection of papers titled "Thermoelectric Properties of Semiconductors" published in Russian in 1963 and translated into English in 1964[13] bears the subtitle "Proceedings of the First and Second Conferences on Thermoelectrics." This collection represents two conferences hosted by the Institute of Semiconductors of the Academy of Sciences of the USSR in St. Petersburg, December 13–17, 1960 and February 20–24, 1962.[14] While the collection edited by Kutasov[13] appears to be the first proceedings published in the Soviet Union, the 1955 and 1957 conferences actually predate the meetings in 1960 and 1962, which came to be known as the First and Second Conferences on Thermoelectrics.

Since those first meetings, many regular meetings have been organized by several organizations within the former Soviet Union. The Scientific Council of the Academy of Sciences of the USSR for Methods of Direct Energy Conversion created a Section on Thermoelectric Energy Conversion, originally chaired by Professor A. R. Regel in 1960. The Section held annual sessions on thermoelectrics with both Academy and non-Academy attendees. This council is still in operation, currently chaired by Professor Vedernikov of the Ioffe Physico-Technical Institute. Professor Vedernikov also chairs the Russian Thermoelectric Society, which was formed in 1998.

Another conference was the annual Meetings on Heat-Physics Methods of Direct Energy Conversion held in Kiev, Ukraine from 1963 to about 1991, organized by Academician Geraschenko. More recent is the Interstate Workshop, "Thermoelectrics and its Application," held every two years in Leningrad (now St. Petersburg) by Professor Vedernikov. And the Chernivtsi Thermoelctric Centre in Ukraine organized conferences in 1976, 1978, 1982, 1986, and 1990 with about 200 to 300 attendees.[14] This conference, renamed the International Forum on Thermoelectrics, was organized by Professor Anatychuk in Chernivtsi (except 1996), Ukraine in 1994, 1996 (Kiev), 1998, and 2000. 2004 will mark the eleventh forum, which has been published in the Journal of Thermoelectricity since 1994.

AI.2.2 United States

Outside the Soviet Union, the earliest meeting on thermoelectricity appears to be the Conference on Thermoelectricity held in September of 1958 (probably in Washington, DC), which forms the basis for Egli's well-known book *Thermoelectricity*.[15] Conferences specifically on thermoelectricity, such as the "Thermoelectric Specialists Conference,"[16] were relatively scarce, more commonly being included in meetings on space power or direct energy conversion generally, such as the annual Intersociety Energy Conversion Engineering Conference (IECEC) beginning in 1966. There were also various unpublished Working Group meetings on RTGs and thermoelectrics organized by NASA/CalTech's Jet Propulsion Laboratory from about 1968 to 1984.

The Materials Research Society has supported Symposia on Thermoelectricity in 1987 (v. 97), 1991 (v. 234), 1996 (v. 410), 1997 (v. 478), 1998 (v. 545), 2000 (v. 626), 2002 (v. 691), and 2003 (v. 793) as part of its large multidisciplinary conferences. In recent years, thermoelectric sessions have sometimes

appeared at American Physical Society meetings. We should also mention the unpublished "First National Thermogenic Cooler Conference"[17] and the "First International Conference on Thermoelectric Properties of Metallic Conductors,"[18] neither of which managed to spawn sequel conferences.

AI.2.3 Europe

Serious research into thermoelectrics mainly for cooling applications was carried out in Europe in the early 1950s, notably at the Hirst Research Centre of the General Electric Co. Ltd. UK, culminating in the first demonstration of practical thermoelectric refrigeration. In 1961, a Conference on Thermoelectricity was held at the University of Durham. This was originally planned as a small specialist conference of some eighty participants, but there were so many applications that this number had to be doubled.[19] Major sessions on radioisotopic-powered generators were held in the Harwell (1966)[20] and Madrid (1972)[21] International Symposia on Power from Radioisotopes. During this early period and into the 1970s, progress in European RTG development was regularly reported in OECD Nuclear Energy newsletters.[22]

In 1987, Professor Rowe organized and chaired the first European Conference on Thermelectrics, hosted at the University of Wales Cardiff,[23] which attracted participants worldwide. Subsequent European meetings have been held biannually in different European cities and their proceedings published.

AI.2.4 Japan

While research on thermoelectricity began in Japan as early as 1955, no specialist conferences were held there before 1980.[24,25] Thermoelectric topics have been discussed at various nonspecialist meetings, particularly those sponsored by the Japan Society of Direct Energy Conversion (DEC), established in 1962 and supported by Japan Science Foundation, located in Tokyo. DEC's activities include organizing academic meetings and publishing annual, up-to-date technical reports on energy conversion technologies such as thermoelectrics, thermionics, MHD, and fuel cells. DEC is somewhat less active than 20 years ago, because today individual technologies such as thermoelectrics and fuel cells have their own academic specialist societies in Japan.

Spurred by oil crises in 1973 and 1979, the first workshop known to focus on thermoelectricity in Japan was sponsored by the Society of Thermoelectric Energy Conversion of the Japan Society of Applied Physics in 1983 and was organized by Professor Shoji Aoki, then of the Tokyo University of Science.[24] Further meetings have been held over the following years.

AI.3 Professor Rao's Short Course and Founding the ITS

Undeterred by the inauspicious environment in 1970, two men in Texas began a collaboration. At the suggestion of Raymond Marlow of Marlow Industries, Dr. K.R. Rao, a Professor of Electrical Engineering with the University of Texas at Arlington, organized a short course on thermoelectrics in 1970, in part to educate his students. Prospective participants were solicited from Marlow's customer list, from journal authors, and from other likely arenas. Speakers came from industry (including Marlow Industries), federal agencies, and other avenues.

Initially, attendance was quite modest, as shown in Figure AI.2. By 1975, there were more speakers than attendees. Seemingly, everyone who needed the short course had already taken it. Marlow suggested that Professor Rao reorganize as the International Conference on Thermoelectric Energy Conversion (ICOTEC), to be held biannually. Marlow Industries supported all aspects of ICOTEC I to VII held biannually from 1976 through 1988 at the University of Texas at Arlington, contributing financing, papers, session chairs, prospective attendees, and encouragement. Several others, notably D. Allred, D. Buist, E. Burke, R. Duenn, L. Danielson, J. Goldsmid, G. Guazzoni, B. Mathiprakasam, V. Raag,

FIGURE AI.2 Attendees of a Short Course on Thermoelectrics, circa 1970–1975. Prof. K.R. Rao, the Short Course organizer, is shown seated second from right.

D.M. Rowe, J. Stockholm, V. Vedernikov, C. Vining, K. Uemura, and Yamamura helped significantly in both the workshops and ICOTEC.

Q2 It was at the 1988 meeting (VIIth ICOTEC) that Dr. Charles Wood (Figure AI.3) of NASA/CalTech's Jet Propulsion Laboratory (JPL) and Professor Mike Rowe, Cardiff University, UK, discussed the sensibility of merging the European Conferences on Thermoelectrics with the International Conference on Thermoelectric Energy Conversion. Clearly, interest in thermoelectric conferences was increasing and agreement was reached that future conferences would be combined and called the International Conference on Thermoelectrics. An annual conference would be held alternate years in Europe and the US. This would encourage more researchers to participate, allow additional organizations to host

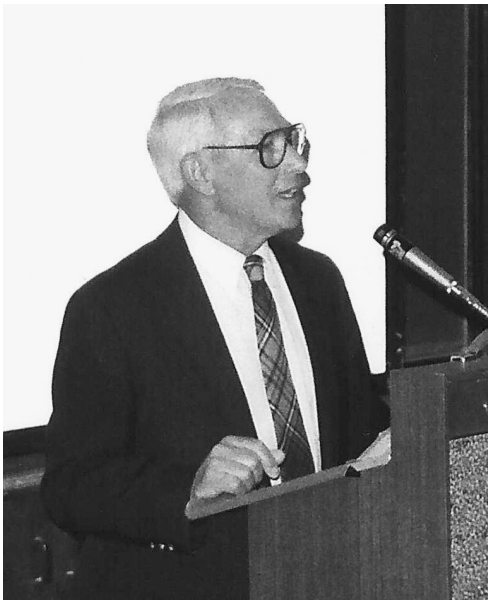

FIGURE AI.3 Charles Wood, the first ITS President, at ICT1990 in Pasadena, CA.

the conference, and provide greater interaction within the now growing international community. However, it was evident that some framework would be required to coordinate the organizational activities.

An *ad-hoc* committee was promptly formed to discuss the matter. The benefits of a Society being apparent to all present, a constitution was drafted by Allred and Burke, and Dr. Wood was asked to serve as the Society's first president. Dr. Wood suggested the name "International Thermoelectric Society" based on the easily-remembered acronym "ITS." Allred was elected secretary/treasurer and an advisory committee was selected consisting of Burke (chairman of the advisory committee), Buist, Mathiprakasam, Rowe, Chatterjee, Rao, and Guazzoni.

The opening portion of the ITS original constitution remains in effect to this day:

> WHEREAS a united body which can effectively call on society for resources, for example to assist in setting up centers of excellence, in editing and publishing previously unpublished work, and such a body can establish uniform methods of measurement and evaluation, promote education, and coordinate international exchange of information including conferences. We organize the International Thermoelectric Society.
>
> GOALS:
>
> TO PROMOTE the advancement of the thermoelectric industry, science and engineering;
> TO PROMOTE collection and exchange of information and education which will benefit the thermoelectric community;
> TO PROMOTE systemization of measurements to and in comparison of materials and devices;
> TO PROMOTE awareness of the larger community to thermoelectric issues and solicit wider involvement;
> TO PROMOTE a forum of exchange of information and achievements by newsletters;
> TO PROMOTE a mechanism for coordinating and promoting conferences.

The first order of business was to coordinate with the organizers of the 2nd European Conference on Thermoelectrics to be hosted by Ecole des Mines de Nancy and already planned for July 1989. Professor Hubert Scherrer and the local organizing committee agreed to rename their conference the VIII International Conference on Thermoelectrics (ICT) as well as to contribute $30 per registrant to the fledgling ITS. Thus, the meeting in Nancy in 1989 functioned both as the 2nd European Conference on Thermoelectrics and the 8th ICT. This successful first effort for the ITS established several precedents: standardizing the conference name to the International Conference on Thermoelectrics (ICT), ITS membership fees to be paid as part of the conference registration fee, and independence of action of the local conference organizing committee. The precedents remain in effect today. An ICT is organized by a local organizing committee with wide latitude in deciding details. The ITS may or may not loan the local committee operating funds before a conference to be repaid to ITS along with a per-registrant fee.

In 1993, the ICT was held for the first time in Japan and a three-year rotation of locations between the US, Europe (including the former Soviet Union), and Asia became established. To date, the ICT has been held in the US (3), France (2), Wales (2), Japan (2), Russia (1), Germany (1) China (1), and Australia (1). In 2005, the ICT will be held in the US (at Clemson University), and at Vienna, Austria in 1996. Q3

Succeeding Wood (1988) as President have been J. Stockholm (1991), C. Vining (1994), D. M. Rowe (1996), J.P. Fleurial (2000), and K. Koumoto (2003). Through 2003, some 38 individuals have served as volunteer officers of the Society, each in their own way. Noteworthy are Mathiprakasam, Rowe, Buist, Stockholm, and H. Scherrer, each of whom has served 10 or more years.

Dr. Mathiprakasam (aka "Mathi") must particularly be singled out for the distinction of being the only officer to serve continuously since the formation of the Society, and as treasurer the entire time since 1989. Throughout this period, Dr. Mathiprakasam has handled all financial matters, culminating in the incorporation of ITS as a not-for-profit corporation headquartered in Missouri in 1996.

From 1988 through 1998, ITS published a newsletter edited by Burke, Vining, and Buist and, from 1994 to 1996, a directory of people interested in thermoelectrics was published. Since then, both of these information functions, as well as other news and announcements, have been entirely supplanted by the ITS website (http://www.its.org) and a non-periodic email newsletter called "Ztspam," which may be subscribed to via the website.

Since the first ITS sponsored a conference in 1989, Best Paper Awards have been a fixture at ICTs and in more recent years, as financial conditions permit, the award included a monetary reward. In 1999, with financial backing from Marlow Industries, ITS began sponsoring the Goldsmid Award for Excellence in Research in Thermoelectrics by a Graduate Student. The Goldsmid Award has demanding criteria and carries a cash prize of $1000 as well as an additional $1000 support towards attending an ICT. Two awards have been made to date to R. Littleton (1999), then of Clemson University, and Mr. X. Fan (2001), then of University of California, Santa Barbara.

Twice, in 1993 (Yokohama) and 1996 (Pasadena), ICT organizers held a Short Course on Thermoelectrics. These short courses, which represent a considerable investment of time and effort by the volunteer lecturers, have been popular and well received. With the rapid changes in subject matter in the past few years, an updated Short Course is an identified priority of the ITS.

AI.4 Present Status of the ITS

The International Thermoelectric Society today is healthy and growing, as indicated by the substantial increase in both attendance and papers presented at the now annual International Conference on Thermoelectrics (Figure AI.4). Annual conferences are organized at locations rotating between the US, Europe, and Asia. In years when the ICT is not held in Europe, the European Thermoelectric Society, an affiliate of the ITS, organizes a workshop somewhere in Europe.

Moreover, the field itself appears to be growing rapidly, judging by the number of open literature publications on thermoelectrics (Figure AI.1). The most important goals of the Society dealing with communication, conferences, and overall growth appear to be progressing satisfactorily. Some of the other stated goals of the Society, such as the areas of standards, measurements and, in particular, serving

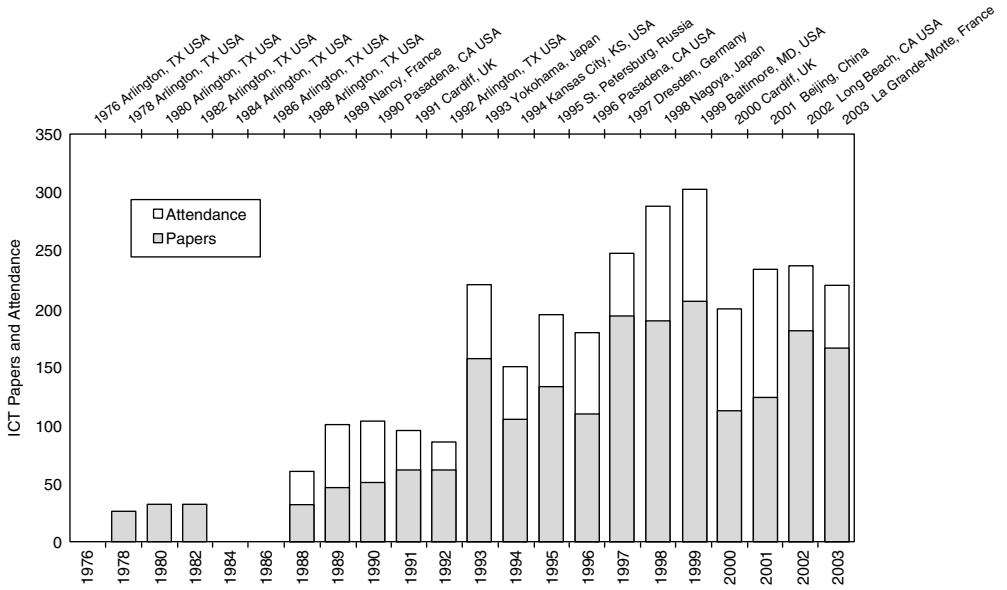

FIGURE AI.4 International Thermoelectric Conference attendance and papers presented (attendance records not available before 1988; number of papers presented not available for 1976, 1984, and 1986).

the interests of the thermoelectric industry, are currently receiving attention. In the 15 years since the ITS was founded, the number of publications in thermoelectrics has increased more than fourfold and the authors are confident that healthy growth will continue.

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