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EXEGIT MONUMENTUM AERE PERENNIUS *

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Exegit monumentum aere perennius. This slight misquotation from an earlier author [1] who said "I have constructed a monument more lasting than bronze", seems an apt quotation in a paper honouring Professor Kubaschewski; the monument he has built in metallurgical thermochemistry will endure for, as I hope to show, it is a living entity.

I shall start the account in a war-torn Stuttgart in 1945, when Dr. Kubaschewski, or Kuba as he is mostly called, was on the staff of the (then) Kaiser-Wilhelm Institut. With some astuteness, the British Government decided that Kuba's team there would be a desirable part of what today would be called a "brain drain". Accordingly, in September 1945 Kuba was interviewed by four scientists, one of whom was Colin Smithells, later editor of the massive *Metal Reference Book*, for which Kuba in fact contributed much material. However the British Government was not noted for moving very quickly and nothing happened until February 1947, when a young Army Officer arrived at Kuba's office saying "The British Government invites you to attend some interviews in London". "Is this voluntary?", asked Kuba. "Oh yes, it's quite voluntary", said the officer, "but I have my orders to get you there". Thus Kuba, accompanied by the Commercial Director of a materials firm (who had mistakenly been invited instead of his brother, the Technical Director) had an eventful journey with the officer via Frankfurt, Göttingen and Hoek van Holland in a four-wheel drive Jeep to a "compound" in Hampstead, London.

During the following weeks Kuba was "interrogated" by a number of British scientists, including Phillip Gross, and as a result in November 1947, left Stuttgart with a small team to work at the National Physical Laboratory (NPL) in Teddington, close to London.

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* This paper is based on an encomium presented at Rheinish-Westfälische Technische Hochschule, Aachen on 10 July 1987.
Dedicated to Professor Oswald Kubaschewski in honour of his contribution to thermochemistry.

AT NPL 1947–1973

Conditions in post-war London were somewhat better than those in Germany, although I shall mention later some documents indicating some limitations that were encountered. Once settled in England, Kuba's monument-building started in earnest and I cannot do better than paraphrase the description of the work of Kuba's team than that given by Hopkins [2].

"Thereafter at the NPL, Kuba pursued with characteristic single-mindedness his main objective of remedying the situation that prevailed in his early days whereby the application of thermodynamic principles to metallurgical equilibria was severely hampered by the lack of sufficient data of the necessary accuracy. He pursued this objective on two fronts:

> by improvements and extensions, particularly to higher temperatures, of experimental methods, not only in calorimetry, but in measurements of component activities
>
> secondly, by the systematic collection and critical assessment of published data of inorganic compounds of importance in metallurgy."

The latter activity led in 1951 to the publication of the first edition of one of the main parts of the Kuba monument, his book *Metallurgical Thermochemistry*, which has been translated into French, German, Russian and Japanese, and is now in its fifth English edition [3]. However, other aspects of the physical chemistry of metals were not neglected and following an earlier collection of kinetic data in *Landölt-Bornstein Tabellen*, Kuba and an NPL colleague Hopkins published their book on the oxidation of metals, and Kuba also started/published a collection of diffusion data.

During this period of the NPL, one of Kuba's unenviable tasks was to try to transfer some of the thermochemical thinking from the essentially academic atmosphere of the universities and NPL (at that time) to British Industry. One way Kuba tried to generate industrial interest was to organize two extremely stimulating conferences on metallurgical thermochemistry in 1958 and 1971. The list of participants at the first conference [4] was a veritable roll-call of the leading scientists in the field at that time—65 overseas visitors from 14 different countries including Chapman, Darken, Elliott, Gross, Hillert, Hultgren, Hume-Rothery, Kapustinskii, Laves, Lumsden, Nowotny, Olette, Predel, Rosenqvist, Turkdogan and Wagner. Certainly, I think one of the most impressive attendance list at any thermodynamic conference one has ever seen.

One of the papers at this conference (ref. 4, Vol. 2, Paper 5A) was by Jan Meijering (then at Philips Research Labs.) on the thermodynamical calculation of phase diagrams, which dealt with miscibility gaps in binary and ternary systems, and lattice stabilities (or $\Delta_{trs}G$) of α and γ iron.

That interest in phase diagram calculation increased slowly in the early 1960s in Kuba's team, notably in papers in 1965 [5] with Tim Chart, who

gave several good examples of phase diagram calculation, emphasizing its use in providing information at low temperatures, where equilibrium is slow, (e.g. Sn–Zn system) at high temperatures (Hf–Zr) where experimentation is difficult, and with Franz Müller [6] on the calculated phase diagram for the Cr–Fe system, showing that the σ phase must undergo a eutectoidal decomposition at low temperature, unlike the diagram in Hansen at that time. These calculations were done by hand, but much computer software was being written for the storage and manipulation of thermodynamic data and for the calculation of phase diagrams; of course Philip Spencer and Jack Counsell made important contributions to this. By 1971, the date of the second conference noted above [7], the calculational approach was far enough advanced to have sessions where the prospects of "ab initio" calculations of phase stability were explored by John Inglefield and David Pettifor. Thermochemical calculation of phase boundaries and equilibrium diagrams was now possible. This was essentially the birthplace of the international Calphad group, which has since become a successful and stimulating grouping, with applications in many fields, its own journal and annual conferences already planned through to 1993, with a booking already for the year 2000 in Boston, Mass.

There is a second international co-operation which owes much of its early impetus to Kuba. At the end of the sixties, several European laboratories interested in the storage, manipulation and exploitation of thermodynamic data by computer agreed to collaborate more closely, particularly on databases. Kuba was of course the leader of the UK team, and aided by some far-sighted funding, initially from the French CNRS and subsequently from the European Community (CEC), this grouping has solidified into a non-profit making French Company called Scientific Group Thermodata Europe (SGTE). This now has databases for individual substances and solution phases, and has undertaken a number of successful projects, particularly for the CEC.

Not only was Kuba involved in the beginnings of SGTE, but in their substance database a fair proportion of the assessed data still owe their origin to Kuba.

AACHEN 1973–1980

Kuba retired from the NPL in 1973 and joined Professor Knacke at the Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen, having collected en passant two honorary doctorates from RWTH Aachen (Germany) in 1968 and Brunel University (England) in 1971.

Kuba was of course mindful of the need to build up a strong team to continue his work at the NPL after he retired and I have already mentioned his colleagues Tim Chart and Philip Spencer. The latter soon left to join

Kuba in Aachen, but Tim Chart and his colleagues continued, and continue, Kuba's work in applying thermodynamic principles to the solution of real industrial problems. Of course, they have made much progress in the years since Kuba retired—the computer software is now very sophisticated and the models for solution phases more realistic, so we can do meaningful calculations on for example eight-components steels and multicomponent slags. However, I have no doubt that Philip Spencer and Tim Chart and their colleagues would acknowledge their debt and gratitude, as I do, to the basic principles they learnt at Kuba's desk with a slide rule.

Philip Spencer had another reason to thank Kuba, for the latter was one of his examiners for his PhD thesis. Kuba was on an extended visit to Norway and had the thesis forwarded to him there. The thesis was of course excellent and Kuba and the co-examiner had agreed that the occasion should not be too arduous for the candidate. Nevertheless, Philip was somewhat taken aback by Kuba's opening remark: Mr. Spencer, when I received your thesis, I was in Norway, and it came in a package with a green Customs label stating "Contents of no value"; would you agree or disagree with that assessment?

INTERNATIONAL CONTACTS

I have concentrated so far mainly on Kuba's work in Britain, but of course he had a wide range of interactions with scientists all over the world. In 1964, he spent a sabbatical term at the University of Pittsburg and during his visits round the States cemented friendships with Darken, Hultgren and Chapman amongst others. Kuba also enjoyed the time he spent as a consultant at the Central Institute for Scientific Research in Oslo, and his many visits to France—to Bordeaux, where he was, most aptly, inaugurated as Tastevin de Jurat de St. Emilion, and to Grenoble, where he received his third honorary doctorate from the Institut National Polytechnique de Grenoble in July 1975.

But I know rather more about his visits to Vienna, particularly his interactions with the International Atomic Energy Agency, who during the period 1962–1980 were responsible for a series of conferences and monographs on the thermodynamics of materials of interest in atomic energy. The first such conference was held in May 1962. At that meeting it was clear that the thermochemistry of the carbides of uranium and plutonium—possible nuclear fuels—needed reviewing and a panel of about 15 people was convened in October of that year, again in Vienna.

As usual in Vienna, there was a fair amount of extra-curricular activity, and one evening the whole panel visited a Heurigen at Grinzing. Again as usual, this went on rather late and unhappily on his way to his hotel from the Grinzing tram, Kuba stumbled in a dark alley, heavily enough to not

only cut rather badly, but break, one of his fingers. After passing what must have been a very painful night, Kuba stoically appeared sharp at 9 o'clock at the meeting the next morning, the finger by now very swollen, and was promptly taken to hospital for treatment. Returning later in the day, Kuba continued to chair the meeting, and except for a certain amount of confusion with headlines in the Vienna newspapers about a "Kubacrise"—which referred to the Cuban missile crisis and not to Kuba's accident—the panel completed their deliberations successfully [8].

But the story was not over for Kuba. When he returned home at the weekend his wife sent his suit to the cleaners. Now it so happened that while Kuba was in Vienna, a girl had been attacked and murdered on the towpath by the River Thames in Teddington and the police were on the lookout for

TABLE 1

Panel members, IAEA, Vienna, 1962

Dr. V.V. Achachinskii	Lomonosov State University, Moscow, U.S.S.R.
Dr. C.B. Alcock	Imperial College of Science and Technology, University of London, Royal School of Mines, Prince Consort Road, London S.W. 7, Gt. Britain
Dr. Charles E. Holley	University of California, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, New Mexico, U.S.A.
Dr. O. Kubaschewski (Chairman)	Metallurgy Division, National Physical Laboratory, Teddington, Middlesex, Gt. Britain
Dr. D.T. Livey	Atomic Energy Research Establishment, Metallurgy Division, Building 47.2, Harwell, Didcot, Berks., Gt. Britain
Professor T. Mukaibo	Department of Nuclear Engineering, University of Tokyo, Hongo, Bunkyo-ku, Tokyo, Japan
Dr. A. Neckel	Institut für Physikalische Chemie der Universität Wien, Währingerstrasse 42, Wien IX, Austria
Professor Dr. H. Nowotny	Institut für Physikalische Chemie der Universität Wien, Währingerstrasse 42 Wien IX, Austria
Dr. M.H. Rand	Chemistry Divison, Atomic Energy Research Establishment, Harwell, Didcot, Berks. Gt. Britain
Dr. F. Reshetnikov	Metallurgy Institute, Academy of Sciences, Moscow, U.S.S.R.
Dr. Robert J. Thorn	Chemistry Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois, U.S.A.
Professor Edgar F. Westrum	Department of Chemistry, University of Michigan, Ann Arbor, Michigan, USA
Dr. R. Hara (Scientific Secretary)	Division of Research and Laboratories, International Atomic Energy Agency, Vienna I, Kärntnerring 11

blood-stained clothing. So, much to Kuba's surprise, he received a telephone call at the NPL the following Wednesday from a courteous police inspector, and the following conversation took place: "Could you please tell me, sir, where you were last Wednesday evening." "In Vienna." "Do you have any witnesses?" "Oh yes, I was chairing a scientific meeting and have a list of the delegates here." "Well just give me one name." "O.K., I'll start at the top" (see Table 1). "Dr. V.V. Akhachinskii, Moscow State University"—Short pause—"Is there no one closer sir?" "Well yes, the next name is Dr. C.B. Alcock, Imperial College, London." Fortunately, Ben Alcock was able to confirm that he had seen Kuba in Vienna at both 1 a.m. and 9 a.m. on the morning in question, and Kuba was eliminated from the suspect list.

More seriously, Kuba edited a whole series of extremely useful monographs on the phase diagrams and thermochemical properties of the compounds of a wide range of elements—Nb, Ta, Be, Th, Hf, etc., to which Mrs. Kuba of course made substantial contributions.

FRAU KUBASCHEWSKI

This brings me to Mrs. Kuba. It is said that behind every great man there stands a lady. If we go back to November 1947, the small scientific team that came from Stuttgart to London included Fräulein von Goldbeck. She worked with Kuba initially on experimental work on the Ti–N, Fe–Ni and V–O systems. Kuba and his team were always trying to increase the temperatures at which accurate thermodynamic measurements could be made. The NPL is, of course, extremely good at keeping records and with Tim Chart's help I have managed to locate some of Mrs. Kubaschewski's notebooks. She was trying to build a molybdenum-wound furnace, and some of the exasperation that she found with life in post-war England (1948) can be seen from the extract from her notebook reproduced here.

Starting (another time) once more
1 September: Telephoned to Morgan.
24 September: After three weeks got a telegram.
Result: may be in 2/3 days some ordered tubes will come.
24 September: The ordered Mo-wire comes (31 metre, 0.6 mm).
1 October : 2 tubes Al_2O_3, 85 cm length arrive. Something is to be changed. Bigger furnace tube, cooling parts don't fit, glassblower.
20 October : First experiment.

Extract from Mrs. Kubaschewski's notebook, 1948.

I doubt if this was a contributing factor, but shortly after that, as an NPL newsletter put it, Kuba's little team became smaller when he and Ortrud were married—the only time Kuba's friends can recall that he put the interests of physical chemistry second, but of course his decision in this instance was as wise as any of his scientific ones. Since then Ortrud has been

Fig. 1.

a "supportive" wife and mother and a charming hostess in entertaining their multitude of friends from many countries, all at the same time as continuing her scientific work, for example in the IAEA monographs I have already mentioned and culminating in her superb book on binary iron systems [9].

THE FUTURE

So much for the past, what now of the future?

Kuba has had numerous interactions with the European Communities, particularly the European Coal and Steel Community (ECSC). It was at a meeting of the Theoretical Steelmaking Committee of the ECSC that Kuba and I were introduced by Professor Alfonsi to an interesting slim volume published by the Vatican [10], making the case that Latin should be the language of the European Communities. Kuba was obviously impressed by the arguments put forward in the book, because it may well be that the sixth edition of his *Metallurgical Thermochemistry* is to be published in Latin. In fact I recently received a publisher's pre-announcement for the volume. This was very informative, giving not only the title page (Fig. 1) (which suggests that the library at Pergamon had some far-flung satellites before its destruction), but pointed out that to be consistent with the new language in which it was being published, data for four further elements had been included.

TABLE 2

Properties of the classical elements

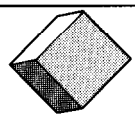
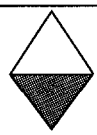
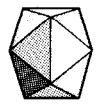
Elementum	Structura	Caloris $_{CCXCVIII}$ Unitas Caloris	Confusio $_{CCXCVIII}$
Ignis		minus XVIII	XLIV
Terra		minus CCXVIII	X
Aer		nullus	XLVI
Aqua		minus LXVIII	XVII

Table 2 shows the properties of these four classical elements, with their enthalpies of formation and standard entropies at 298.15 K, referred to conventional elements for traditionalists. The Romans and the Greeks before them knew all about the structures of their four elements—the sharpness of fire was associated with the tetrahedron, the solidity of the earth with the cube and the fluidity of water with the icosahedron. These structures are included in Table 2.

We all look forward with eagerness to the sixth edition of Kuba's monument, in whatever language it finally appears!

With that glimpse of the Latinate future, we have come full circle, so I proclaim again of Kuba: Exegit monumentum aere perennius.

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