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Nuclear Structure Research

Annual Progress Report

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1.0 Introductory Overview

The most significant development this year has been the realization of a method for estimating E0 transition strength in nuclei and the prediction that the de-excitation ("draining") of superdeformed bands must take place, at least in some cases, by strong E0 transitions. An invited talk on E0 transitions and shape coexistence was given at the Nuclear Chemistry Gordon Research Conference in June 1995. Also an invited paper on E0 transitions, in collaboration with Prof. E. F. Zganjar (LSU), was presented in Arles, France in June 1995, at the International Conference on Exotic Nuclei and Atomic Masses.

A considerable effort has been devoted to planning the nuclear structure physics that will be pursued using the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge. (Full details appear in the accompanying Renewal Proposal.)

A significant effort has been devoted to HRIBF target development. This is a critical component of the HRIBF project. Exhaustive literature searches have been made for a variety of target materials with emphasis on thermodynamic properties. Vapor pressure measurements have been carried out. This work has been in collaboration with Dr. R. A. Braga (School of Chemistry, Georgia Tech) and Drs. J. Breitenbach and H. K. Carter (Oak Ridge National Lab.).

Five graduate students are working in the group. Four are working on experimental topics, one on a theoretical topic. Three of these students have been supported on the grant. Two are expected to receive their Ph.D.'s later this year.

Experimental data sets for radioactive decays in the very neutron-deficient Pr-Eu and Ir-Tl regions have been under analysis. These decay schemes constitute parts of student Ph.D. theses. These studies are aimed at elucidating the onset of deformation in the Pr-Sm region and the characteristics of shape coexistence in the Ir-Bi region. Some of these analyses are in collaboration with Prof. E. F. Zganjar (LSU), Prof. K. S. Krane (Oregon State Univ.), Dr. B. E. Gnade (Texas Instr. Corp., Dallas), and Dr. R. A. Braga (School of Chemistry, Georgia Tech). Further experiments on shape coexistence in the neutron-deficient Ir-Bi region are planned using α decay studies at the FMA at ATLAS. The first experiment is scheduled for later this year. This is in collaboration with E. F. Zganjar. A full discussion is given in the accompanying Renewal Proposal.

Theoretical investigations have continued in collaboration with Prof. K. Heyde (Rijksuniversiteit, Gent, Belgium), Prof. D. J. Rowe (Univ. of Toronto), and Prof. P. B. Semmes (Tenn. Tech. Univ.). These studies focus on shape coexistence and particle-core coupling.

This year the grant has supported the principal investigator (two months, full time), three graduate students (twelve months, half time), and two graduate students (three months, half time).

2.0 Experiment

Experimental research has involved data analysis, level scheme construction, and comparison of level schemes with theory. All or part of four students' theses depend on this. There are on-going collaborations with E. F. Zganjar, K. S. Krane, B. E. Gnade, and R. A. Braga. The data sets relate to two areas of nuclear structure: the onset of deformation in the extremely neutron-deficient Pr, Nd, Pm, Sm, and Eu isotopes; and shape coexistence in the neutron-deficient Ir, Pt, Au, Hg, Tl, Pb, and Bi isotopes.

2.1 Onset of Deformation in the Extremely Neutron-Deficient Pr, Nd, Pm, and Sm Isotopes

A paper on the decay scheme for $^{133}Pm \rightarrow {}^{133}Nd$ and detailed particle-core coupling calculations for ^{133}Nd is in press with Nuclear Physics A.

A paper on the decay scheme for $^{133m,g}Nd \rightarrow {}^{133}Pr$ and detailed particle-core coupling calculations for ^{133}Pr has been submitted to Nuclear Physics A.

Analysis of data on $^{135}Sm \rightarrow {}^{135}Pm \rightarrow {}^{135}Nd \rightarrow {}^{135}Pr$ and $^{137}Eu \rightarrow {}^{137}Sm \rightarrow {}^{137}Pm$ is essentially completed. Some results for $^{135,137}Pm$ are shown in figure 2.1. This is in collaboration with R. A. Braga.

The major finding of our work is that systematic identification of Nilsson configurations and associated rotational bands is possible and that the onset of deformation is gradual. A full discussion is given in the accompanying ^{133}Nd and ^{133}Pr manuscripts.

This program will be completed in the next year.

2.2 Shape Coexistence in the Neutron-Deficient Ir, Pt, Au, Hg, Tl, Pb, and Bi Isotopes

The region of very neutron-deficient nuclei near $Z \sim 80$, $N \sim 104$ exhibits

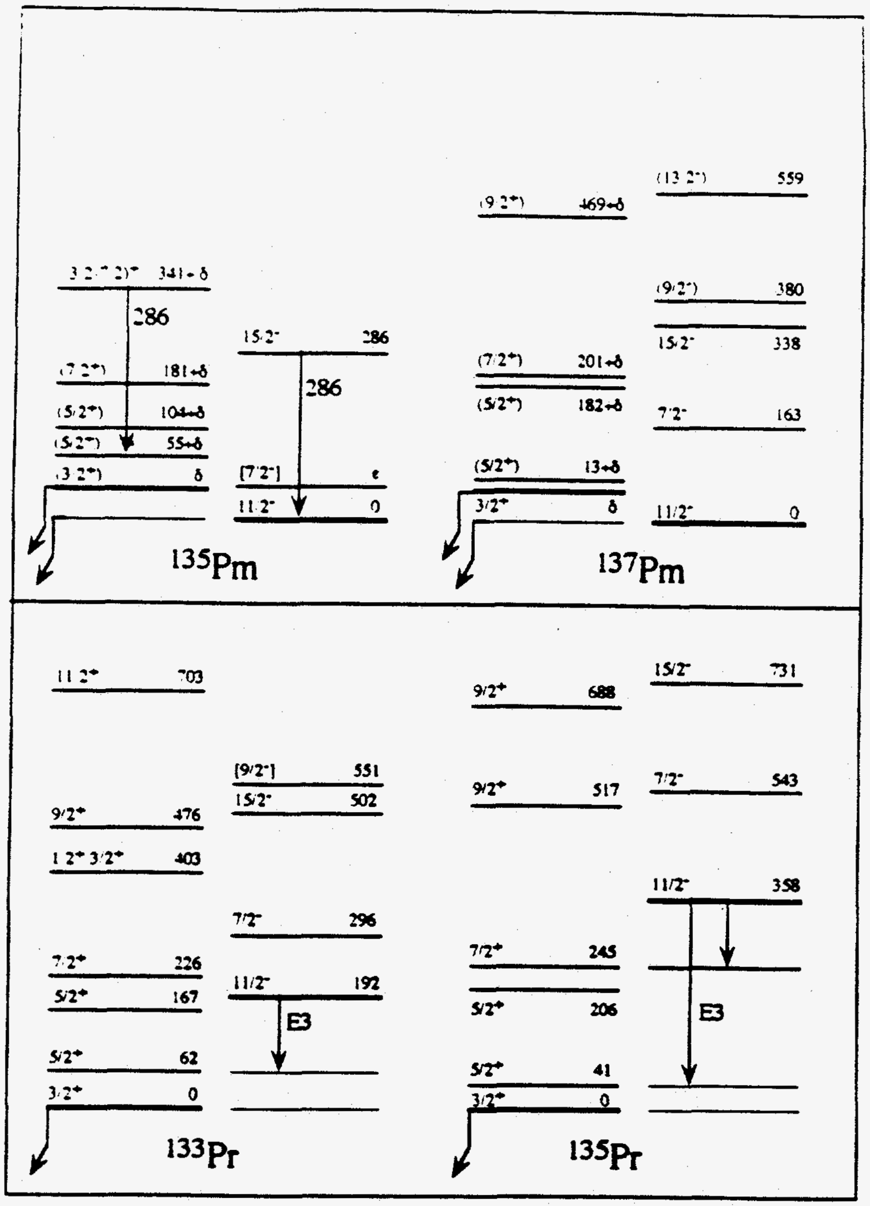


Figure 2.1 Level systematics for the N = 74 and N = 76 Pm and Pr isotopes. Data are taken from: ^{135}Pm -- C. W. Beausang et al., Phys. Rev. C36, 602 (1987); K. S. Vierinen et al., Nucl. Phys. A499, 1 (1989); and the present studies; J. K. Tuli, Nucl. Data Sheets 72, 355 (1994) and the present studies; ^{133}Pr -- Yu. V. Sergeenkov and V. M. Sigalow, Nucl. Data Sheets 49, 639 (1986); C. F. Liang et al., Phys. Rev. C40, 2796 (1989); L. Hildingsson et al., Phys. Rev. C37, 985 (1985); and the present studies; ^{135}Pr -- Yu. V. Sergeenkov, Nucl. Data Sheets 52, 205 (1987); T. M. Semkov et al., Phys. Rev. C34, 523 (1986); and the present studies.

the best example of shape coexistence anywhere on the mass surface. A wide variety of studies are in progress, aimed at various detailed aspects of shape coexistence in this region.

In ^{187}Au we have found evidence for nearly identical diabatic intruder structures. A paper describing this has been published in Physical Review C.

An extensive study of ^{189}Au has been completed. Detailed features include intruder states, particle-hole symmetry, and triaxiality. Extensive particle-core coupling calculations have been made (see Sect. 5.1). A paper describing the work has been submitted to Nuclear Physics A.

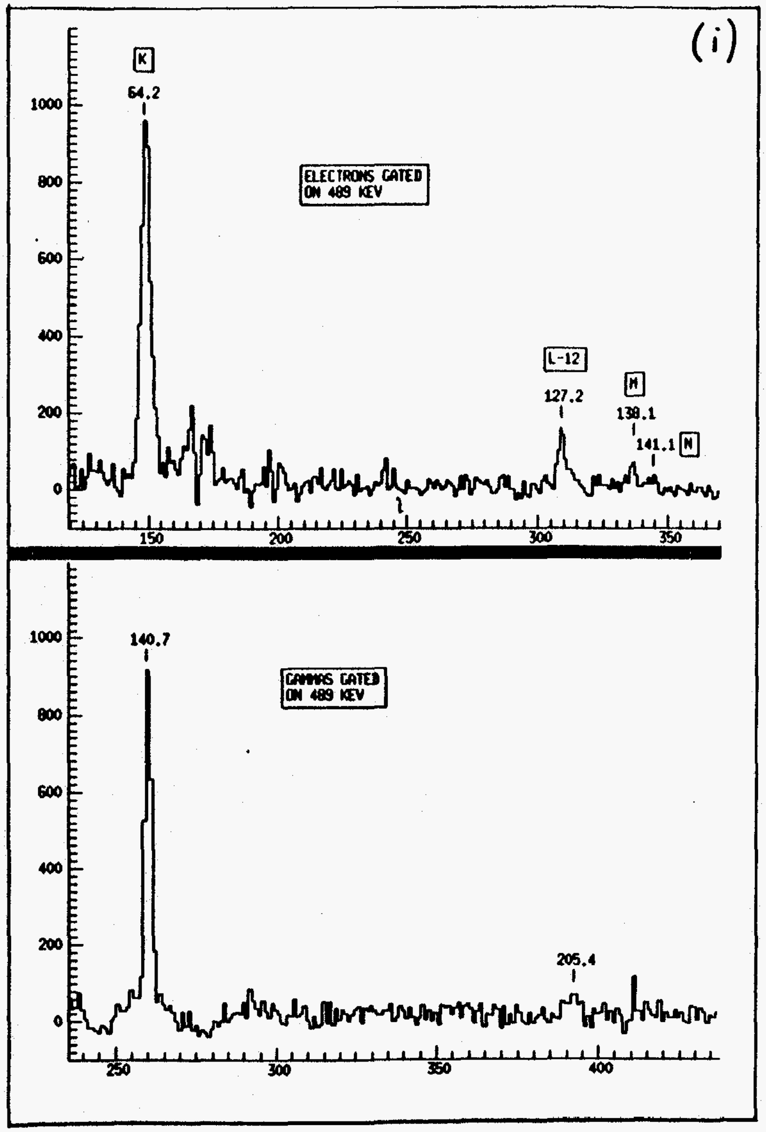
The study of the systematic features of the very neutron-deficient odd-mass Ir isotopes is nearing completion. Some results are shown in figures 2.2a,b,c. This is part of the thesis work of K. Jentoft-Nilsen.

The study of shape coexistence, collectivity, and electric monopole transitions in the very neutron-deficient even-mass Pt isotopes is in progress. Some results for ^{186}Pt are shown in figure 2.3. A short note on the 3+ → 3+ pure E0 transition in ^{186}Pt is in preparation. This is part of the thesis work of J. McEver. A surprising finding of two high-energy E0(+M1+E2) transitions feeding the 6_1^+ state in ^{184}Pt is depicted in figure 2.4. A short note on this is in preparation. Further, the decay of ^{184}Au to ^{184}Pt has finally been deciphered. There are two isomers with J^{π} ($T_{1/2}$) of 2^+ (49s) and 5^+ (19s) with the 2^+ decaying by an M3 transition to the 5^+ (ground state). A short note on this is in preparation. This work is in collaboration with K. S. Krane and E. F. Zganjar.

Analysis of data on ^{190}Hg is in progress. This is part of the thesis work of M. DeShon.

The study of ^{189}Hg is nearing completion with particle-core coupling calculations now being carried out. This work is in collaboration with B. E. Gnade, E. F. Zganjar and P. B. Semmes.

(i)



(ii)

The $\frac{11}{2}^- \frac{1}{2}^-[541]$ level in ^{183}Ir

Conversion coefficient ratios for the 140.8 keV transition

	exp.	E1	E2	M1
L_{12}/K	0.16	0.14	0.93	0.16
L_3/K		0.031	0.62	0.001
M/K	0.07	0.040	0.40	0.038

These measured values indicate a multipolarity of $M1(+E2)$.

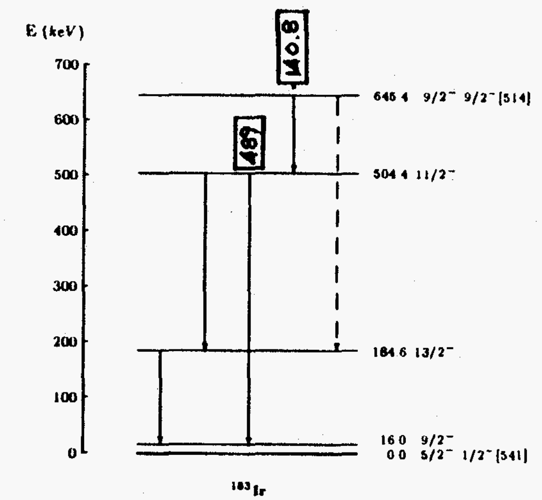


Fig. 2.2a. (i) Conversion electrons and γ rays gated by the 489 keV transition, showing the evidence for the transition between the 645.4 and 504.4 keV levels. (ii) The conversion-electron subshell ratios and location of the 140.8 keV transition in ^{183}Ir.

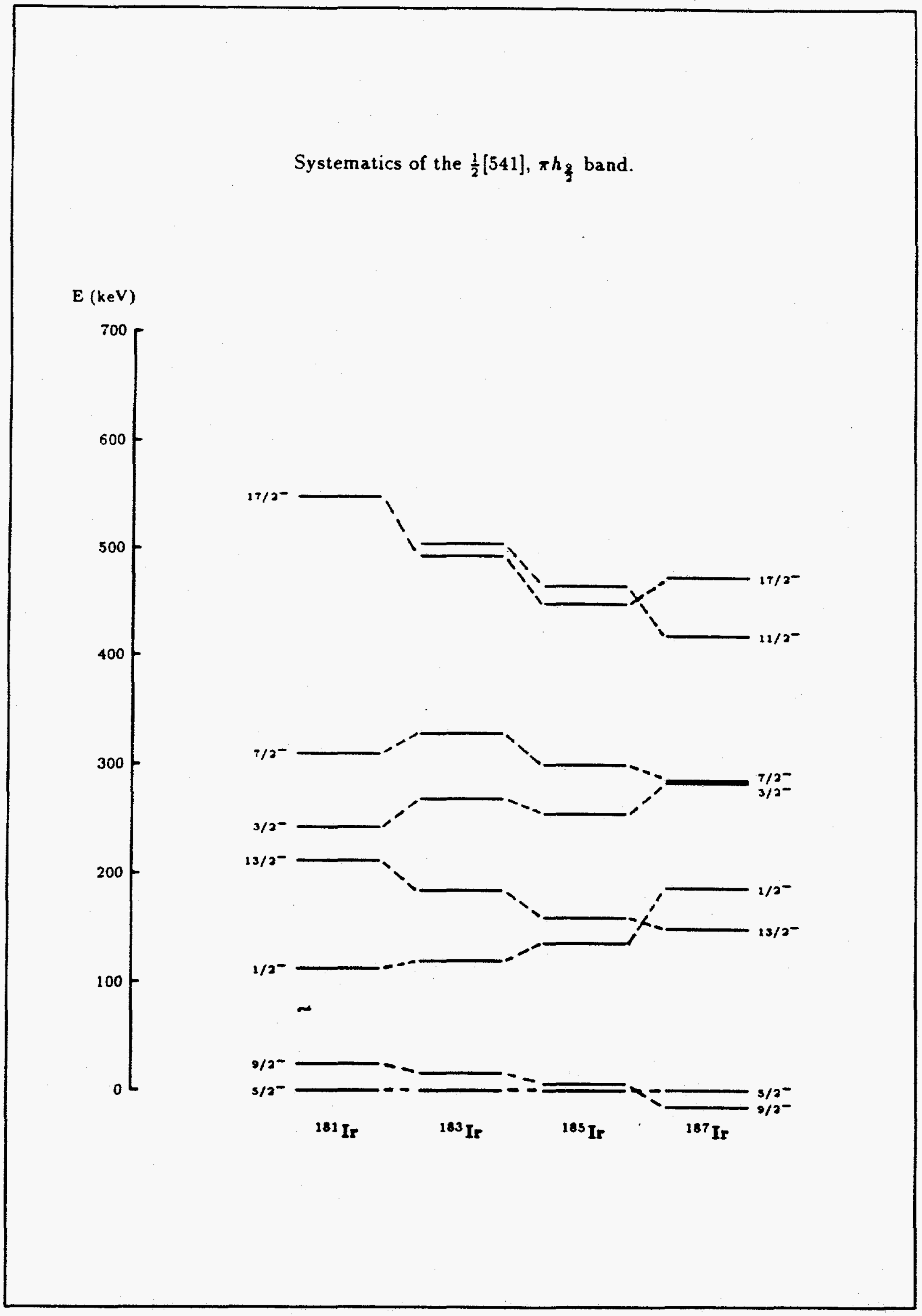


Fig. 2.2b. The systematics of the negative-parity states built on the 541↓ configuration in $^{181-187}Ir$. The data are taken from the relevant Nuclear Data Sheets together with the present work.

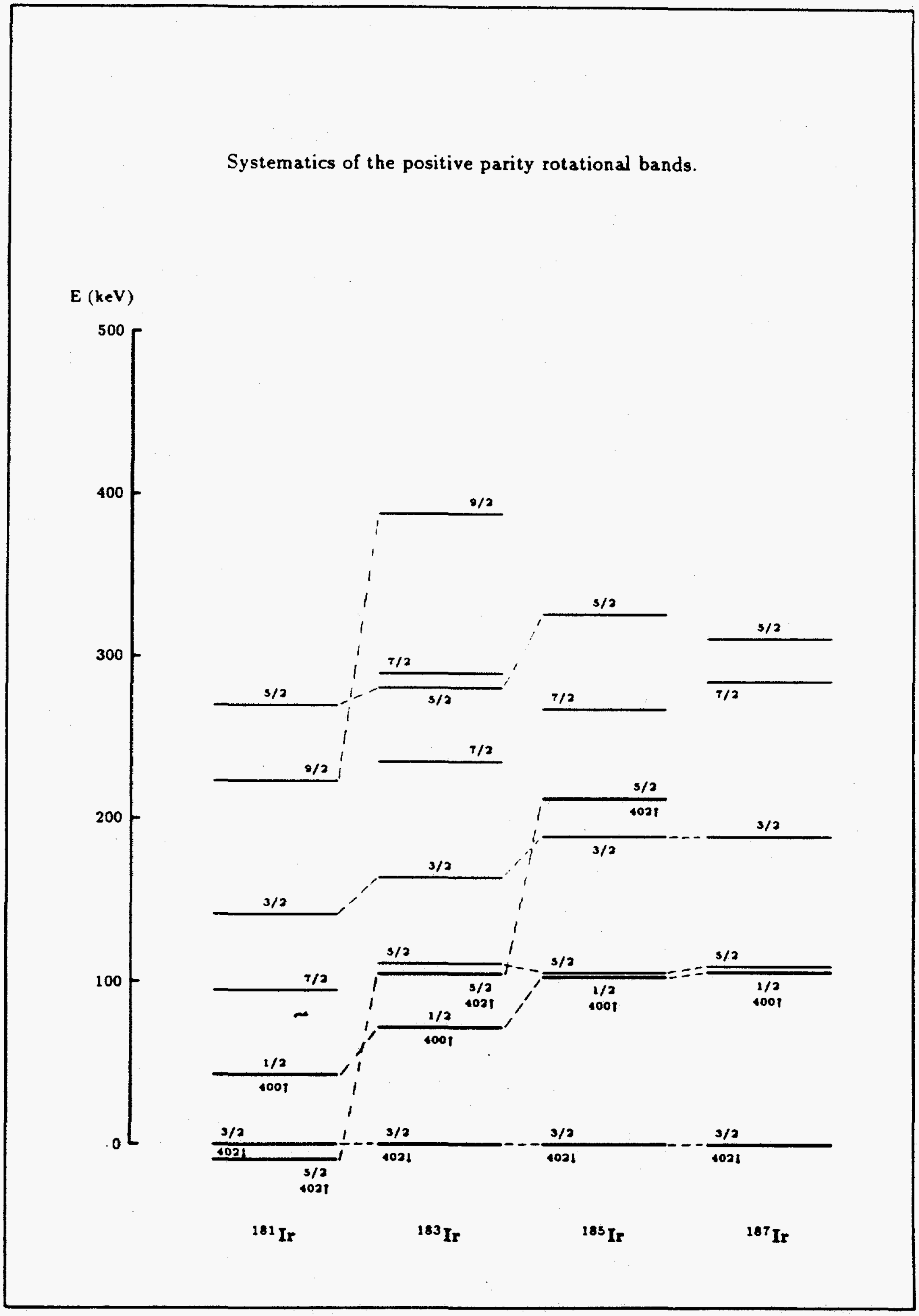


Fig. 2.2c. The systematics of the positive-parity states in $^{181-187}$Ir. The data are taken from the relevant Nuclear Data Sheets together with the present work.

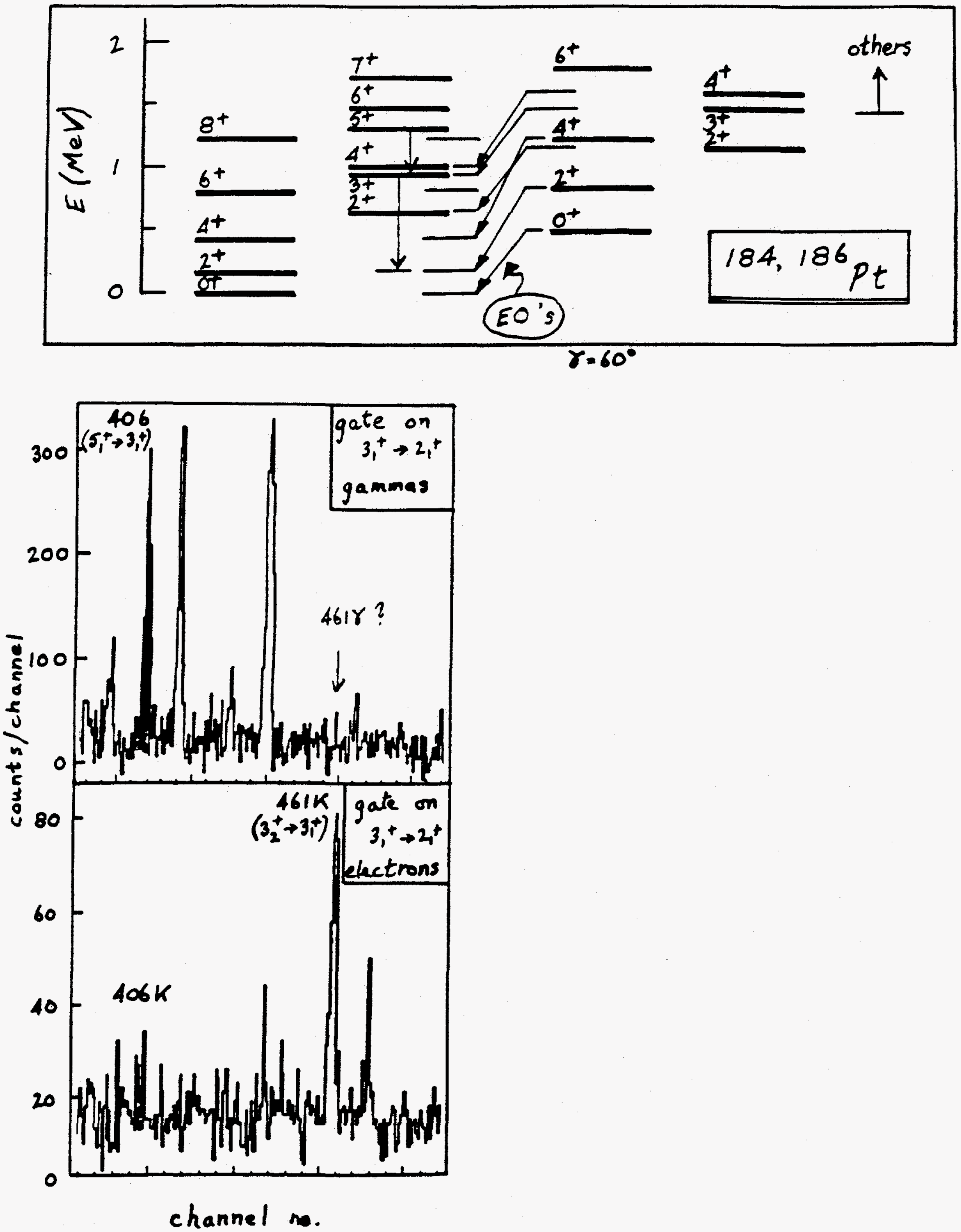


Fig. 2.3. The $K^{\pi} = 0^{+}$ and $K^{\pi} = 2^{+}$ bands established in the present studies and the evidence for the pure E0 transition, $3_2^{+} \rightarrow 3_1^{+}$ in ^{186}Pt. Evidence for a similar transition in ^{184}Pt is presented in Y.-S. Xu et al., Phys. Rev. Lett. 68, 3853 (1992).

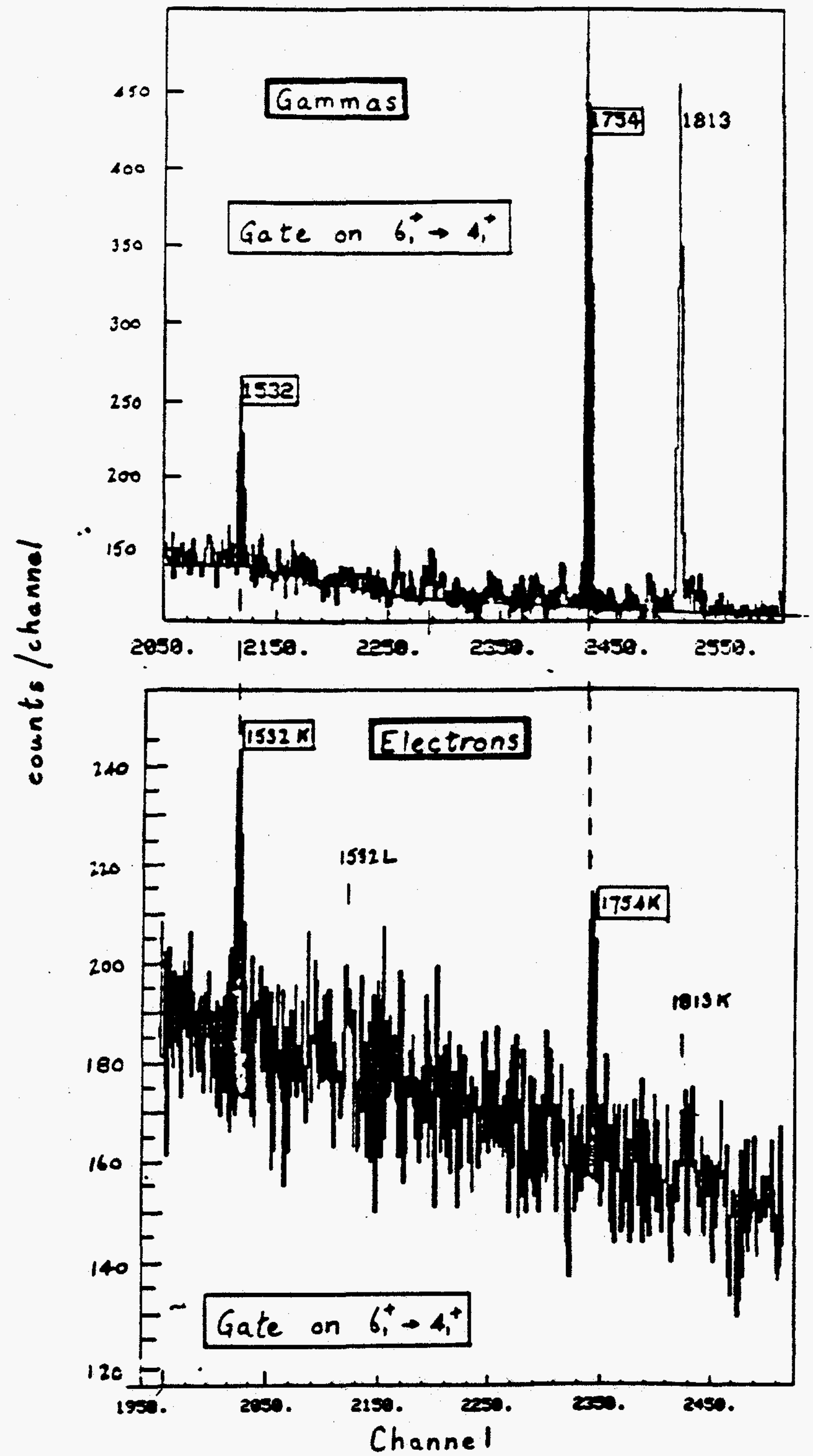


Fig. 2.4. The evidence for E0 components in two high-energy transitions (1532 and 1754 keV) feeding the 6_1^+ state in ^{184}Pt (from the present studies).

A study of intruder states in the very neutron-deficient Bi and Tl isotopes using α decay is planned for later this year. Details are presented in the accompanying Renewal Proposal.

A paper on α decay rates in $^{181-186}$Au and $^{181-185}$Pt has been published in Physical Review C.

3.0 <u>Planning of Experiments for HRIBF</u>

A considerable effort has been applied to planning the nuclear structure physics that will be pursued at HRIBF. A number of the ideas emerging from this process were included in the White Paper entitled "The UNIRIB Consortium", a document outlining the physics that might be done using the HRIBF Facility, put together by a consortium of universities many of which are former UNISOR members.

Full details of these Georgia Tech plans appear in the accompanying Renewal Proposal.

4.0 HRIBF Development Work

The program of target development for HRIBF has been continued and expanded. In order to be a good target, a material must be stable within the ion source environment, it must maximize production of the desired radionuclide while minimizing production of undesirable species, and it must optimize extraction of the radionuclide species from the target material. A data base has been created to organize the properties of all target material candidates in such a way as to ultimately allow the selection of the target that will contribute the highest efficiency to the production of a specific radioactive ion beam. An extensive and ongoing literature search is providing the groundwork for this data base. In addition, since the properties of many materials of interest have not been throughly studied, a materials testing program is also being developed.

One focus of the search for target candidates has been the thermophysical properties that will allow the material to remain stable within the ion source, which is of primary importance. Since liquid targets will probably not be supported at least in the first ion sources, the material must have a melting point above about 1600^{o} degrees Celsius. The material must also have a low vapor pressure for the successful operation of the ion source. The maximum vapor pressure that will allow this is around 0.1 mTorr. This value, however, is dependent on the type of ion source and will be as low as 1 μTorr in some cases. Melting points of 50 candidate materials have been gathered into the data base. Vapor pressure information is known for only 29 of these materials, and often this information consists of a single data point. Vapor pressure over a range of temperatures is more useful.

Particular effort has been made to find an appropriate sulfur target for the production of a radioactive chlorine beam. A systematic review of the melting points of all known binary sulfur compounds has been completed (see

Table 1 in the Appendix). Once again, very little vapor pressure information exists. A less extensive, preliminary review, has also been made of binary nickel compounds (for the production of a copper beam). Also, possible zinc target materials (for a Ga beam) have been reviewed. Some materials that show promise in terms of diffusion characteristics include zeolites and stabilized zirconias. The stability of these materials at high temperatures still needs to be investigated.

For many materials, adequate data to determine target suitability is not available. An existing vacuum bell jar system is being used to test the stability of some of these materials in an environment similar to that of an ion source. Melting points are being measured with an optical pyrometer. A quartz crystal microbalance is being used with the Langmuir free evaporation technique in order to determine information about vapor pressures and evaporation rates. Concurrently, estimates of the reactivity of the material with the possible target holders are being made. A new materials test stand has been designed specifically for these tests. This stand will also be used for outgassing of ion sources and targets before use online.

This work has been carried out by K. Jentoft-Nilsen and J. McEver and will shortly be taken over by M. DeShon and B. MacDonald. (Last year Kristi Jentoft-Nilsen spent ten weeks at the Holifield Lab making measurements and gave an invited talk entitled "Vapor Pressure Measurements Using a Quartz Crystal Microbalance" at the North American Conference on Radioactivity, Ion Sources, and Targets held in Vancouver, Canada, August 10-12, 1994. Two conference papers are in press.)

Further, to provide a basis for selection of appropriate targets, thermodynamic calculations of the reactivity of target and crucible materials were undertaken. These calculations of the Gibbs free energy (ΔG, a measure of reaction spontaneity) were performed for combinations of various metal oxide (NiO,ZnO) and sulfide (BaS, BeS, CaS, CeS, MgS, ZnS) targets with Ta, W, Mo, C (graphite), Re, BN, Al_2O_3 and BeO crucibles as a function of temperature. Values of enthalpy (ΔH) and entropy (ΔS) changes were taken from various compilations.

For example, the calculated changes in free energy for NiO and ZnS targets with selected crucibles are given in figures 4.1a,b. These figures indicate that while some combinations are not reactive ($\Delta G > 0$) at all temperatures, others are reactive ($\Delta G < 0$) at all temperatures, and the reactivity of others is dependent on temperature. While the magnitude of the free energy change is indicative of the reactivity, it is not an indication of the rate at which a reaction will occur. Therefore, although a particular reaction may be spontaneous, it may proceed very slowly.

Of particular note are reactions such as ZnS + Mo ---> Zn(g) + Mo_2S_3(c), in which a solid ZnS target reacts with the Mo crucible to yield Mo_2S_3 solid and Zn vapor. This reaction is predicted to be spontaneous at elevated temperatures and would result in loss of the target material.

This work has been carried out in collaboration with R. A. Braga (Georgia Tech, School of Chemistry).

(An appendix summarizing some of the target development literature that has been assembled is attached at the end of this report.)

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1. "Handbook of Chemistry and Physics", CRC Press, Inc., Boca Raton, Fl. (1984).
2. "Handbook of Thermodynamic Constants of Inorganic and Organic Compounds", M. Kh. Karapet'yants and M. K. Karapet'yants, Ann Arbor-Humphrey Science Publishers, Ltd., Ann Arbor (1970)(translated by J. Schmorak).
3. "CODATA Key Values for Thermodynamics", J. D. Cox, D. D. Wagman, V. A. Medvedev, editors, Hemisphere Publishing, New York (1989).

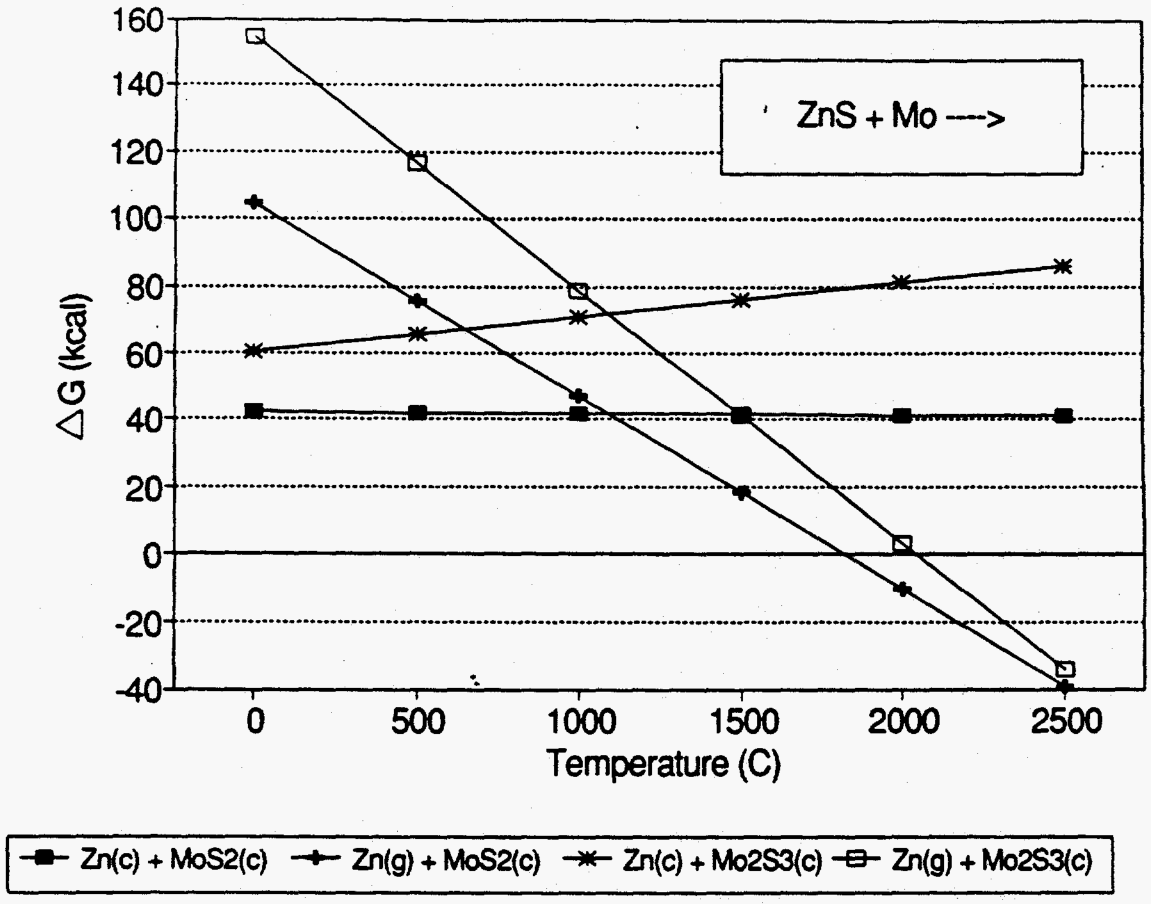
ZnS + Mo --->
160
140
120
100
80
60
40
20
0
-20
-40
ΔG (kcal)
0
500
1000
1500
2000
2500
Temperature (C)
Zn(c) + MoS2(c)
Zn(g) + MoS2(c)
Zn(c) + Mo2S3(c)
Zn(g) + Mo2S3(c)

Fig. 4.1a.

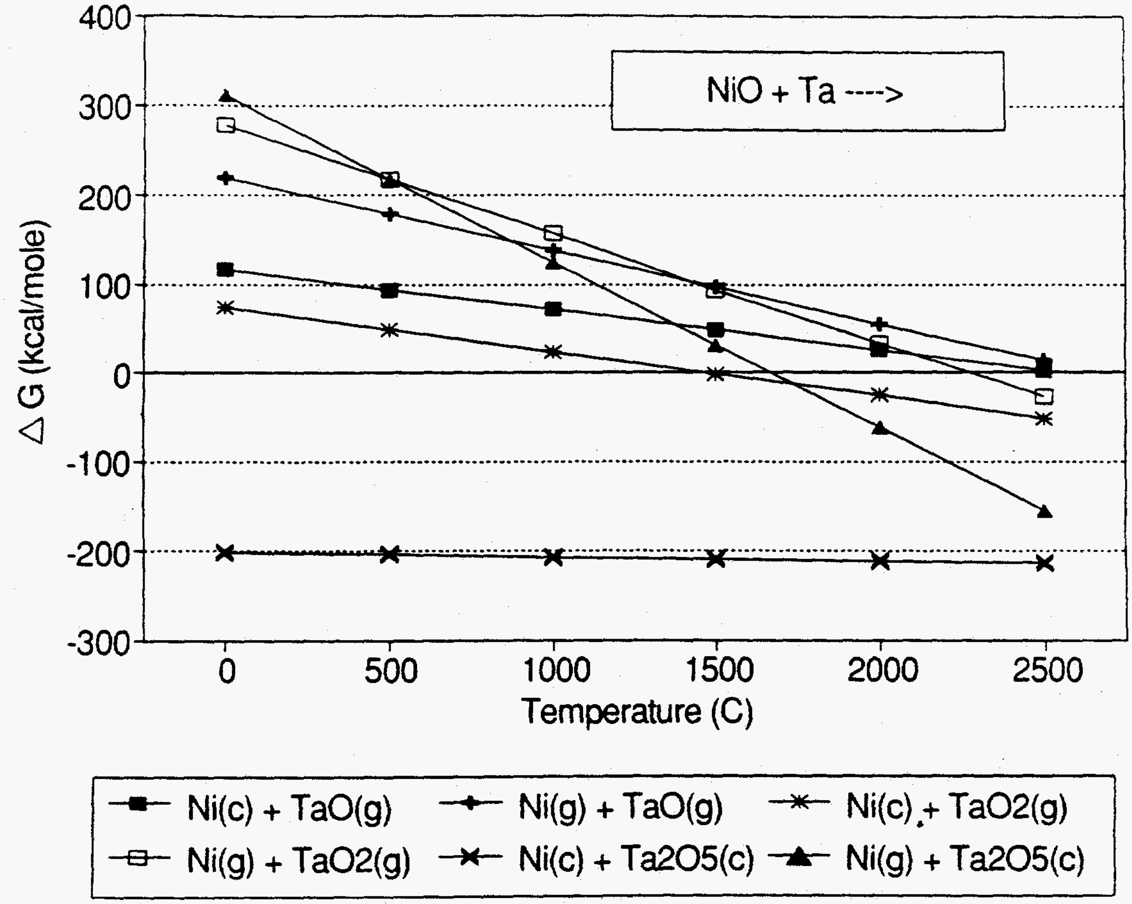
NiO + Ta ---->
400
300
200
100
0
-100
-200
-300
Δ G (kcal/mole)
0
500
1000
1500
2000
2500
Temperature (C)
Ni(c) + TaO(g)
Ni(g) + TaO(g)
Ni(c) + TaO2(g)
Ni(g) + TaO2(g)
Ni(c) + Ta2O5(c)
Ni(g) + Ta2O5(c)

Fig. 4.1b.

5.0 Theory and Systematics

Theory has pursued three themes. The first is detailed particle-core coupling calculations to complement the experimental studies in the very neutron-deficient Pr-Eu and Ir-Tl isotopes. The second is the modelling of shape coexistence and intruder state structures. The third is the modelling of particle-core coupling in heavy nuclei using an SU(3) core description. Systematics has involved a thorough review of E0 transitions and their association with shape coexistence.

5.1 Particle-Core Coupling Calculations in the Very Neutron-Deficient Pr-Eu and Ir-Tl Isotopes

Detailed particle-core coupling calculations have been carried out in the very neutron-deficient Pr-Eu isotopes and Ir-Tl isotopes. These calculations employ the particle-plus-triaxial-rotor model (PTRM) with a Woods-Saxon potential (S. E. Larsson et al., Nucl. Phys. A307, 189 (1978)). The PTRM can be applied over nearly the whole mass surface with a minimum of free parameters.

Details of calculations for ^{133}Nd appear in the paper entitled "The Decay of ^{133}Pm and the Structure of ^{133}Nd", which is in press with Nuclear Physics A. Details of calculations for ^{133}Pr appear in the paper entitled "The Decays of Mass-Separated ^{133m,g}Nd to ^{133}Pr", which has been submitted to Nuclear Physics A. Details of calculations for ^{187}Au appear in the paper entitled "Coexistence Effects in ^{187}Au: Evidence for Nearly Identical Diabatic Intruder Structures", which has been published in Physical Review C. Details of calculations for ^{189}Au appear in the paper entitled "Decay of Mass-Separated ^{189}Hg (8.7 min) and ^{189}Hg (7.7 min) to ^{189}Au", which has been submitted to Nuclear Physics A.

This work is in collaboration with P. B. Semmes.

5.2 Intruder States and Coexisting Collective Structures

Work has continued on the concept of intruder analog states with applications in the Z = 50 and 82 closed shell regions and in light nuclei. This program is aimed at classifying shape coexistence in terms of multi-particle-multi-hole excitations using simple boson algebraic concepts. A "mini-review" has been published in Physica Scripta, entitled "Multi-Particle Multi-Hole Excitations and New Symmetries Near Closed Shells". These ideas were also applied to a detailed description of E2 properties in the Cd isotopes where shape coexistence produced a very complex excitation pattern between 1 and 2 MeV excitation. This has been published in Nuclear Physics A in a paper entitled "Coexistence in Even-Even Cd Nuclei: Global Structure and Local Perturbations".

The program is continuing with applications to light N = Z region nuclei. In light N = Z region nuclei an exploration of intruder spin (K. Heyde et al., Phys. Rev. C 46, 541 (1992)) combined with isospin is being explored as the basis of an algebraic description of coexisting collective structures in, e.g., ^{56}Ni. (This program is, in part, targeted at potential experiments at HRIBF.)

This work is in collaboration with K. Heyde (with whom the P.I. holds a NATO Travel Grant) and Dr. P. Van Isacker (GANIL, Caen, France).

5.3 Modelling of Particle-Core Coupling in Heavy Nuclei Using An SU(3) Core Description

It has long been known that light nuclei can be described quite well by an SU(3) coupling scheme. In heavier nuclei, however, it is expected that strong mixing of irreps will occur due to interactions such as spin-orbit coupling. Nevertheless, we believe that SU(3) models can still provide a context for understanding rotational behavior in heavy deformed nuclei.

Calculations for even-even nuclei are rather straightforward. Using the Coupled Rotor-Vibrator Model, we have found (M. Jarrio, J. L. Wood, and D. J. Rowe, Nucl. Phys. A528, 409 (1991)) that there is, indeed, considerable mixing of SU(3) irreps. However, we find that these mixtures remain rather constant within each particular rotational band. It is thus possible to picture an intrinsic state experiencing adiabatic rotations, and we can describe these nuclei in terms of a "soft" SU(3) structure.

In order to obtain an SU(3) description of odd-mass nuclei, there are a number of issues which must be addressed. First, it is necessary to develop an appropriate basis for the core-plus-particle system. In standard rotor models, the two limits are the strong- and weak-coupled bases. The weak basis is obtained simply by coupling core and particle angular momenta to obtain well-defined values of the total angular momentum; such a basis has a clear SU(3) analog. The necessary coupling can be trivially accomplished in both models via Clebsch-Gordan coefficients.

The strongly-coupled basis includes an additional, key constraint for the core-plus-particle system. In addition to weak coupling, this basis requires that the symmetry axes of core and particle coincide. In the rotor model, this constraint is established by quantizing the odd particle's angular momentum along the core's body-fixed symmetry axis, rather than a space-fixed axis. For an SU(3) model, however, such a procedure does not have a direct analog. A more appropriate method for combining the core and particle symmetry axes is to couple the two systems to form irreducible representations of the combined system. Mathematically, this is accomplished by diagonalizing the second-order Casimir invariant of the core-plus-particle system. This procedure will implicitly satisfy our original strong-coupling constraint; we have thus gained the utility of a precise, algebraic definition of strong coupling, at the expense of more complex expressions for the coupling coefficients.

In the region of heavy deformed nuclei, the strongly-coupled basis is expected to dominate, and indeed, strong-coupled rotor models have proven fairly useful. We have found that a strong SU(3) basis is similarly appropriate for describing such nuclei. Such a result is not surprising when one recalls the well-known result that SU(3) irreps should contract to rotor irreps in the limit of large values of $(\lambda\mu)$, which are appropriate for heavy deformed nuclei. Indeed, there is considerable simplification of SU(3) coupling coefficients in the asymptotic limit, making practical calculations possible.

Another difficulty arises when we begin to consider the effects of deformation on SU(3) representations. The residual core-particle interaction, arising out of deformation, is a quadrupole-quadrupole interaction. This has unfortunate consequences in an SU(3) model, since the mass quadrupole operator has two components - an SU(3) quadrupole, and a $2\hbar\omega$ shell-mixing component. This second component will mix SU(3) irreps, and undermine the utility of an SU(3) model. However, we can embed SU(3) in a larger group - namely, Sp(3,R) - which includes the $2\hbar\omega$ raising and lowering operators. Irreps of this larger group will <u>not</u> be mixed by the quadrupole-quadrupole force, and it is thus possible to construct deformed representations of Sp(3,R). These deformed representations can be expressed in a rather simple form; basis states are constructed by a symplectic stretching of a spherical SU(3) basis state. Thus, even though we are working in the larger symmetry group Sp(3,R), the essential dynamics of heavy deformed nuclei can still be described by an SU(3) structure, albeit a deformed one which involves renormalized parameters.

We are currently in the process of expanding and formalizing our knowledge of asymptotic limits of SU(3) and Sp(3,R) coupling coefficients. With this formalism in place, it will be possible to begin comparing our model with experimental data for odd-mass nuclei. In particular, we will be able to test the validity of our assumptions regarding the asymptotic limit of coupling coefficients, and to discover just how close actual deformed nuclei come to this limit. We also hope to make inferences about the mixtures of SU(3) irreps which make up the intrinsic states of rotational bands. This will lead to a more comprehensive understanding of the SU(3) structure of heavy deformed nuclei.

This investigation constitutes the major part of the Ph.D. thesis work of M. Jarrio and is in collaboration with D. J. Rowe. It will be completed in the next year.

5.4 Electric Monopole Transitions

A broad and thorough survey of E0 transitions in nuclei has been initiated. Following an invited paper entitled "Shape Coexistence and Electric Monopole Transitions", given at the International Conference on Nuclear Shapes and Nuclear Structure at Low Excitation Energies in Antibes, France last year, an invited talk entitled, "Electric Monopole Transitions and Shape Coexistence", was given at this year's Nuclear Chemistry Gordon Research Conference. Also, an invited paper entitled "Electric Monopole Transitions: What They Can Tell Us About Nuclear Structure" was given at the International Conference on Exotic Nuclei and Atomic Masses in Arles, France this year by E. F. Zganjar.

The survey continues with data compilation and evaluation and comparison with theory. A clearly emerging picture is the association of all known strong E0 transitions in heavy nuclei with shape coexisting configurations which are mixed. A strong case can be made for the association of strong E0 transitions with the decay of superdeformed bands. An abstract entitled "Electric Monopole Transition Strength and the Draining of Superdeformed Bands" has been submitted for the Bloomington meeting of the APS Division of Nuclear Physics. A short communication entitled "The Strength of Electric Monopole Transitions and the Decay Out of Superdeformed Bands" has been submitted to Zeitschrift fur Physik A.

This work is in collaboration with E. F. Zganjar and K. Heyde.

6.0 Overseas Trips

No overseas trips were made at DOE expense this year.

7. Personnel

Senior Staff

Dr. J. L. Wood, Professor of Physics, Principal Investigator, Full time, 2 months.

Graduate Students

Mr. Martin Jarrio, Ph.D. thesis work. Half-time, 9 months.

Ms. Kristi Jentoft-Nilsen, Ph.D. thesis work. Half-time, 9 months.

Mr. Jimmie McEver, Ph.D. thesis work. Half-time, 12 months.

Mr. Markus DeShon, Ph.D. thesis work. Half-time, 3 months.

Mr. Brian MacDonald, Ph.D. thesis work. Half-time, 3 months.

8.0 Summary of Publications, Preprints, Abstracts, and Invited Talks, 1995

1. "Shape Coexistence and Electric Monopole Transitions", J. L. Wood in Proceedings of the International Conference on Nuclear Shapes and Nuclear Structure at Low Excitation Energies, Antibes, France, June 20-25, 1994, ed. M. Vergnes et al. (Editions Frontieres, Gif-sur-Yvette, France, 1994), p. 295.

2. "Coexistence in Even-Even Cd Nuclei: Global Structure and Local Perturbations", K. Heyde, J. Jolie, H. Lehmann, C. De Coster, and J. L. Wood, Nucl. Phys. A586, 1 (1995).

3. "Multi-Particle Multi-Hole Excitations and New Symmetries Near Closed Shells", K. Heyde, C. De Coster, P. Van Isacker, J. Jolie, and J. L. Wood, Phys. Scripta T56, 133 (1995).

4. "α-Decay Rates for $^{181-186}$Au and $^{181-185}$Pt Isotopes", C. R. Bingham, M. B. Kassim, M. Zhang, Y. A. Akovali, K. S. Toth, W. D. Hamilton, J. Kormicki, J. von Schwarzenberg, and M. M. Jarrio, Phys. Rev. C51, 125 (1995).

5. "Coexistence Effects in ^{187}Au: Evidence for Nearly Identical Diabatic Intruder Structures", D. Rupnik, E. F. Zganjar, J. L. Wood, P. B. Semmes, and W. Nazarewicz, Phys. Rev. C51, R2867 (1995).

6. "Search for Low-Spin Superdeformed States in Nuclei", C. R. Bingham, M. Zhang, J. A. Becker, E. A. Henry, R. W. Hoff, A. Kuhnert, M. A. Stoyer T. F. Wang, Y. A. Akovali, P. Joshi, T. S. Lam, D. Rupnik, E. F. Zganjar, J. Breitenbach, M. Jarrio, J. L. Wood, H. K. Carter, P. F. Mantica, Jr., and J. Kormicki, Nucl. Instr. and Meth. B79, 309 (1993).

7. "Comment on Shape and Superdeformed Structure in Hg Isotopes in Relativistic Mean Field Models and Structure of Neutron-Deficient Pt, Hg, and Pb Isotopes", K. Heyde, C. De Coster, P. Van Duppen, M. Huyse, J. L. Wood, and W. Nazarewicz, Phys. Rev. C, in press.

8. "The Decay of ^{133}Pm and the Structure of ^{133}Nd", J. B. Breitenbach, J. L. Wood, M. Jarrio, R. A. Braga, J. Kormicki, and P. B. Semmes, Nucl. Phys. A, in press.

9. "Electric Monopole Transitions: What They Can Tell Us About Nuclear Structure", E. F. Zganjar and J. L. Wood, Proceedings of the International Conference on Exotic Nuclei and Atomic Masses, Arles, France, June 19-23, 1995, in press.

10. "The Diffusion Properties of Ion Implanted Species in Selected Target Materials", G. D. Alton, J. Dellwo, H. K. Carter, J. Kormicki, G. di Bartolo, J. C. Batchelder, J. Breitenbach, J. A. Chediak, K. Jentoff-Nilsen, and S. Ichikawa, (in press, Proc. of Conf. on Applications in Nuclear Technology, Heraklion, Crete, Greece).

11. "Target Selection for the HRIBF Project", J. Dellwo, G. D. Alton, J. C. Batchelder, J. Breitenbach, H. K. Carter, J. A. Chediak, G. di Bartolo, S. Ichikawa, K. Jentoff-Nilsen, and J. Kormicki, (in press, Nucl. Instr. and Meth. B).

12. "The Decays of Mass-Separated ^{133m,g}Nd to ^{133}Pr", J. B. Breitenbach, J. L. Wood, M. Jarrio, R. A. Braga, H. K. Carter, J. Kormicki, and P. B. Semmes, submitted to Nucl. Phys. A.

13. "Decay of Mass-Separated ^{189m}Hg (8.7 min) and ^{189g}Hg (7.7 min) to ^{189}Au", J. L. Wood, M. O. Kortelahti, E. F. Zganjar, and P. B. Semmes, submitted to Nucl. Phys. A.

14. "The Strength of Electric Monopole Transitions and the Decay Out of Superdeformed Bands", J. L. Wood, E. F. Zganjar, and K. Heyde, submitted to Z. Phys. A.

15. "Nuclear Orientation and Spectroscopic Studies of the Decay of ^{187}Pt to ^{187}Ir", M. A. Gummin, K. S. Krane, Y. Xu, T. Lam, E. F. Zganjar, J. B. Breitenbach, B. E. Zimmermann, H. K. Carter, and P. F. Mantica, Jr.,

submitted to Nucl. Phys. A.

16. "Electric Monopole Transition Strength and the Draining of Superdeformed Bands", J. L. Wood, abstract submitted for the American Physical Society Division of Nuclear Physics Meeting, Oct. 25-28, 1995, in Bloomington, Indiana.

17. "Electric Monopole Transitions and Shape Coexistence", J. L. Wood, invited talk, Nuclear Chemistry Gordon Research Conference, New London, New Hampshire, June 18-23, 1995.

18. "Electric Monopole Transitions: What They Can Tell Us About Nuclear Structure", E. F. Zganjar and J. L. Wood, invited talk [see 8].

9.0 Related Pedagogical Activities

Nuclear Physics is an essential ingredient of any basic physics curriculum. An introduction to nuclear physics was included in a sequence of 32 lectures on Waves and Modern Physics given to over 400 students (mainly engineers), in three course sections, by the P.I. in the first half of this calendar year. In addition, each year the P.I. gives a course entitled "Nuclear Physics" at the senior undergraduate/graduate level. Typical student enrollment is 25 students (this year the enrollment was 32). Further, J. McEver served as an instructor this year in the Georgia "Governor's Honors Program" for outstanding high school juniors, (for the third year running) and included extensive material on nuclear physics/energy/security issues in discussions. The support of the research group at Georgia Tech unquestionably leads to a considerable enrichment of these pedagogical activities.

The P.I. is currently collaborating on a monograph on collective motion in nuclei. This is in collaboration with D. J. Rowe. Again, the research activities of the Georgia Tech group have influenced this project in a major way.

Although these activities are supported not by DOE but by Georgia Tech, there is a strong cross-fertilization to these processes which bring forefront nuclear science to a wider and more general audience.

10.0 Appendix

This appendix presents selections from the activities relating to target development. It includes:

Material Properties: Handbooks and Compilations (5 pp.)

Top Target Candidates Containing S, Ni, or Zn (1 p.)

Binary Sulfur Compounds by MP (6 pp.)

UNISOR Measurements (6 pp.)

Figure ZnO on Ta (1 p.)

Material Properties: Handbooks and Compilations

HIGH TEMPERATURE MATERIALS

Chemical Rubber Company. *CRC Handbook of Chemistry and Physics. 1994/1995.* Boca Raton, Florida: CRC Press, 1994.

Kosolapova, T. Ya., ed. *Handbook of High Temperature Compounds: Properties, Production, Applications.* New York: Hemisphere Publishing Corporation, 1990. Excludes oxides. Does include borides, carbides, nitrides, silicides, sulfides, selenides, and tellurides. Includes information on temperatures of melting or decomposition; vapor compositions and pressures, reactions, and evaporation rates; diffusion parameters.

R.D. Mathis Company. *Thin Film Evaporation Source Reference.* Includes disclaimer on accuracy of information, and no references are given. Information, in table form, includes melting point and some vapor pressure info.

Samsonov, G.V. *Plenum Press Handboods of High-Temperature Materials No. 2, Properties Index.* New York: Plenum Press, 1964. Most of this material is probably included and updated in the above work by Kosolapova.

Touloukian, Y.S., ed. *Thermophysical Properties of High Temperature Solid Materials.* New York: Macmillan, 1967. This is a six-volume set. Has vapor pressure curves for some materials.

OXIDES

Freer, R. "Bibliography; Self-Diffusion and Impurity Diffusion in Oxides." *Journal of Materials Science* 15 (1980) 803–824. Updates the earlier bibliography by P.J. Harrop. From abstract, includes "data for the diffusion of the host and impurity species in both binary and multiple oxides. Brief descriptions of terminology, diffusional behaviour and new measurement techniques are followed by tables of selected results and associated experimental details."

Harrop, P.J "Self-Diffusion in Simple Oxides (A Bibliography)." *Journal of Materials Science* 3 (1968) 206–222. Abstract: "The paper is directed towards the materials scientist who wishes to employ published values of diffusion coefficients in his investigations. A brief review of self-diffusion behaviour and the likely inaccuracies of the various techniques used in the measurement of diffusion is followed by a selected bibiliography and tabulation of coefficients for oxides." This bibliography is updated and expanded by R. Freer.

Kofstad, Per. *Nonstoichiometry, Diffusion, and Electrical Conductivity in Binary Metal Oxides.* New York: Wiley-Interscience, 1972. A survey of transport properties in binary oxides, correlated where possible with defect-dependent properties of oxides at high temperatures. Includes data on nonstoichiometry, diffusion and electrical conductivity. First six chapters contain a good introduction to defect structures, transport properties, and diffusion theory.

Lamoreaux, R.H. and D.L. Hildenbrand. "High Temperature Vaporization Behavior of Oxides. I. Alkali Metal Binary Oxides." *J. Phys. Chem. Ref. Data* 13 (1984) 151–173. Includes data on enthalpy of formation, Gibbs energy function, partial pressure, vaporization, and vaporization rates. May be of limited use since these are not the most refractory oxides.

Samsonov, G.V., ed. *The Oxide Handbook.* Translated from Russian by C. Nigel Turton and Tatiana I. Turton. New York: IFI/Plenum, 1973. G.V. Samsonov, while at the Institute of Problems in Materials Science at the Academy of Sciences of the Ukrainian SSR, seems to have done much of the original extensive compilation of research results on the refractory compounds. His initial compilations provide the basis of several handbooks on refractory compounds.

SULFIDES

Fries, James A. and E. David Cater. "Vaporization, thermodynamics, and dissociation energy of gadolinium monosulfide: Systematics of vaporization of the rare earth monosulfides." *J. Chem. Phys.* 68 (May 1978): 3978–3989. Data on the vaporization behavior and thermodynamics of the rare-earth monosulfides from LaS to GdS are assembled and/or estimated and discussed.

Jentoft-Nilsen, K, ed. *Melting points and vapor pressures of the binary sulfur compounds.* Excel table. This table is a compilation of all the existing data that I have found so far in the literature.

Senning, Alexander, ed. *Sulfur in Organic and Inorganic Chemistry.* New York: Marcel Dekker, Inc., 1972. Three volume set. Could be useful for detailed approach to finding/ creating the best sulfur target.

Adsorption, Heats of

Following are three documents, in German, from the Akademie Der Wissenschaften Der DDR, with "GANIL Documentation" stamped on the front. They all contain tables of enthalpies of adsorption of the indicated metals.

Eichler, Bernd, Siegfried Hübener and Heinz Roßbach. "Calculation of Heats of Adsorption of the Actinoids." In *Adsorption of Volatile Metals on Metal Surfaces and the Possibilities of its Application in Nuclear Chemistry.* July 1985.

Eichler, Bernd, Siegfried Hübener and Heinz Roßbach. "Calculation of Heats of Adsorption of the Rare Earth Metals." In *Adsorption of Volatile Metals on Metal Surfaces and the Possibilities of its Application in Nuclear Chemistry.* August 1985.

Roßbach, Heinz and Bernd Eichler. "Calculation of Adsorption Enthalpies with the Program AMO." In *Adsorption of Volatile Metals on Metal Surfaces and the Possibilities of its Application in Nuclear Chemistry.* August 1985.

Material Testing

Vapor Pressure Measurement

Benjaminson, A. and F. Rowland. "The Development of the Quartz Resonator as a Digital Temperature Sensor with a Precision of 1×10^{-4}." In *Temperature; Its Measurement and Control in Science and Industry,* Vol. 4, Part 1. New York: American Institute of Physics, etc. The interest in this is not temperature measurement, since it is only applicable over a range of about −80 to 250° C, but in understanding the temperature effects on the quartz crystal microbalance that is being used in the vapor pressure measurement.

Cater, E. David. "The Effusion Method at Age 69: Current State of the Art." In *Characterization of High Temperature Vapors and Gases,* Vol. 1. Edited by John W. Hastle. National Bureau of Standards Special Publication 561, Proceedings of the 10th Materials Research Symposium held at NBS, Gaithersburg, Maryland, September 18–22, 1978. Issued October 1979. Probably should read this when return to vapor pressure measurement.

Gregory, J.W. and L.L. Levenson. "Vapor Pressure Measurements with the Quartz Crystal Microbalance." *High Temperature Science* 22 (1986) 211–216. The paper on which I largely based the design for vapor pressure measurement for the UNIRIB Materials Test Stand.

Lozgachev, V.I. "Distribution of Molecular Flow on a Surface During Evaporation in Vacuum." *Soviet Physics Technical Physics* 7 (Feb. 1963) 736–744. Contains the derivation of the geometrical factor used when calculating vapor pressure with the use of a quartz crystal microbalance.

Nesmeyanov, An. N. *Vapour Pressure of the Elements.* Translated and edited by J.I. Carasso. New York: Academic Press, 1963. A classic for the elements. The first chapter contains a review of methods of measuring vapor pressure at that time.

Wahlbeck, P.G. "Comparison and Interrelations for Four Methods of Measurement of Equilibrium Vapor Pressures at High Temperatures." *High Temperature Science* 21 (1986) 189–232. Reviews Knudsen effusion, transition-flow effusion, Ruff-MKW boiling point, and transpiration. Only the Knudsen effusion method is applicable at pressures below 1 Pa (about 7.5 mTorr).

Temperature Measurement

Optical Pyrometry

Bedford, R.E. "Effective Emissivities of Blackbody Cavities — A Review." In *Temperature; Its Measurement and Control in Science and Industry*, Vol. 4, Part 1. New York: American Institute of Physics, etc. Outlines and compares several methods of calculating the effective emissivities of blackbody cavities, which play a fundamental role in radiation thermometry. If an optical pyrometer is being used to measure temperature, this information is indispensible.

Benedict, Robert P. *Fundamentals of Temperature, Pressure, and Flow Measurements*, Third edition. New York: John Wiley & Sons, 1984. Chapter 8, Optical Pyrometry is good, and contains the following dubious quote: *Try adding minus one to the denominator. — Max Planck (1900)*

DeWitt, D.P. and R.S. Hernicz. "Theory and Measurement of Emittance Properties for Radiation Thermometry Applications." In *Temperature; Its Measurement and Control in Science and Industry*, Vol. 4, Part 1. New York: American Institute of Physics, etc. Excellent discussion of both the basic concepts of radiation physics and the dependence of a materials radiative properties on wavelength, surface characteristics, and environmental influences. It is crucial to understand these effects whenever using emissivity data in temperature measurement.

Heinisch, Roger P. "The Emittance of Blackbody Cavities." In *Temperature; Its Measurement and Control in Science and Industry*, Vol. 4, Part 1. New York: American Institute of Physics, etc. Describes a measurement technique for determining the directional spectral emittance of blackbodies and applies this technique to right circular cylindrical cavities of various length-to-diameter ratios and inner wall coatings.

Kerlin, Thomas W. and Robert L. Shepard. *Industrial Temperature Measurement*. Research Triangle Park, NC: The Instrument Society of America, 1982. This volume was designed for engineers as a comprehensive overview of industrial temperature measurement. Section 13 is a good basic introduction to pyrometry. The rest of the manual is also quite helpful. At the time of publication, Kerlin was at University of Tennessee and Shepard was at ORNL.

Leeds & Northrup Company. *Nos. 8621, 8622, and 8623 Optical Pyrometers*. Direction Book 77-1-0-3. Philadelphia: Leeds & Northrup Company, sometime BC. The direction book for the state-of-the-art pyrometer that is being used for the temperature measurement for the materials test stand. Personally, I like this antique.

Leeds & Northrup. *8627 Series Optical Pyrometers*. 177720 *REV* E, Leeds & Northrup Instruments Technical information on the Leeds & Northrup Pyrometers. Contains some emissivity data, but this should be used with care, since surface and environmental characteristics can have a large affect on these values.

Matthews, E.K. and G.J. Kilford. "Operating Experience with an Emissivity Measuring Laser Based Infra-Red Pyrometer." International Test and Tranducer Conference; Sensors and Systems, Oct. 1989 Some techno-lit courtesy of the folks at Pyrometer Instrument Company. The skinny was that this method would not work well on a small "target", e.g. the blackbody cavity. Also, consider whether IR is the most sensitive part of the spectrum at temperatures around one grand Celsius.

Matthews, Edward K. "Industrial Applications of a Fiber Optic Emissivity Measuring Infrared Pyrometer." At SPIE – The International Society for Optical Engineering, Sept. 1993. More of the above, but with a optical fiber added? Really should consider whether this would be a good option again.

Implantation/Release Experiments

Diffusion, Theory of

Andersen, M.L., O.B. Nielsen and B. Scharff. "Diffusion of Rare Earths through Tantalum." *Nuclear Instruments and Methods* 38 (1965) 303–305. Study of diffusion, including temperature effects, of radioactive rare-earth activities produced by bombarding a 0.2 mm tantalum foil with 600 MeV protons in the CERN synchrocyclotron.

Borg, Richard J. and G.J. Dienes. *An Introduction to Solid State Diffusion*. New York: Academic Press,

Inc., 1988. Looks like a very thorough, clear introduction to the theory of diffusion. Probably would be helpful in measurement and interpretation of diffusion data for target materials. Also has very good list of additional references at the end of each chapter. Many of these references and comments are contained below.

Chandrasekhar, S. "Stochastic Problems in Physics and Astronomy." *Rev. Mod. Phys.* 15 (1953) 1. Borg and Dienes: "...Chapter 1, pages 1–20, is one of the best and most rigorous derivation of the relations between diffusion and random walks."

Crank, J. *Mathematics of Diffusion.* Oxford: Clarendon Press, 1975. Borg and Dienes: "As the title states this volume deals exclusively with the solution of differential equations appropriate to various boundary conditions , i.e., the mathematics of diffusion. It does not deal with the physics or chemistry of the diffusion but is an invaluable reference for the practitioner."

Fujioka, M. and Y. Arai. "Diffusion of Radioisotopes from Solids in the Form of Foils, Fibers and Particles." *Nuclear Instruments and Methods* 186 (1981) 409–412. Summary of formulae for diffusion indicated in title in limiting case of vanishing surface density.

Girifalco, L.A. *Atomic Migration in Crystals.* Blaisdell, 1964. Borg and Dienes: "...provides a lucid discussion of the basic physics with an absolute minimum of mathematics."

Jost, W. *Diffusion in Solids, Liquids, Gases, 3rd ed.* New York: Academic Press Inc., 1960. This is one of the classics on diffusion. Borg and Dienes, above, say "...still the most comprehensive treatise on diffusion and includes treatment of liquids and gases as well as solids. Chapter 1 introduces the fundamental equations for diffusion. Overall the author prefers to treat the subject in a phenomenological rather than model dependent manner."

Manning, J.R. *Diffusion Dinetics for Atoms in Crystals.* Van Nostrand, 1968. Borg and Dienes: "Chapters 1 and 2 give derivations of the fundamental equations including the relation between diffusion and random walks. The mathematics are nicely related to atomic motion in a clear, understandable way."

Shewmon, P.G. *Diffusion in Solids.* New York: McGraw-Hill, Inc., 1963. Borg and Dienes: "Chap. 1 provides a clear and concise introdustion to the diffusion equations including derivations."

RIB Overview

Target/Ion Source Issues at HRIBF

Alton, G. et al. "Studies of the release properties of ISOL-target materials using ion implantation." *Nuclear Instruments and Methods in Physics Research* B66 (1992) 492-502. Describes early release/implantation studies done at HRIBF (then OREBF.)

Alton, G.D., D.L. Haynes, G.D. Mills and D.K. Olsen. "Selection and design of the Oak Ridge Radioactive Ion Beam Facility target/ion source." *Nuclear Instruments and Methods in Physics Research* A328 (1993) 325–329.

Target/Ion Source Issues at Other Labs

Carraz, L.C. et al. "Fast Release of Nuclear Reaction Products from Refractory Matrices." *Nuclear Instruments and Methods* 148 (1978) 217–230. Studies of release of reaction products formed by 600 MeV proton irradiation of various targets at ISOLDE, CERN. Even though reaction is different than that at HRIBF, the results on diffusion through various targets should be relevant.

Decrock, P. et al. "Extraction efficiency of ^{13}N ($T_{1/2} = 9.96 min$) atoms from a graphite target: comparison between off- and on-line obtained results." *Nuclear Instruments and Methods in Physics Research* B70 (1992) 182-185. Study done at the Belgian RIB facility at Louvain-la-Neuve.

Dombsky, M. et al. "Targets and ion sources at the TISOL facility." *Nuclear Instruments and Methods in Physics Research* B70 (1992) 125–130. Includes discussion of a zeolite ($NaSiAlO_4$) target.

Hagebø et al. "New production systems at ISOLDE." *Nuclear Instruments and Methods in Physics Research* B70 (1992) 165–174. Tests of targets of carbides, metal/graphite mixtures, foils of refractory metals, molten metals and oxides are discussed.

Hoff, P., O.C. Jonsson, E. Kugler and H.L. Ravn. "Release of Nuclear Reaction Products from Refractory Compounds." *Nuclear Instruments and Methods in Physics Research* 221 (1984) 313–329. Studies of carbides, oxides, platinum-like metals and intermetallic compounds at CERN. Also reports effect of addition of BF_3, CF_4 and SF_6 on the release rate.

Kirchner, R. "On the release and ionization efficiency of catcher-ion-source systems in isotope separation on-line." *Nuclear Instruments and Methods in Physics Research* B70 (1992) 186–199. Description of implantation/release studies done at UNILAC, at GSI Darmstadt. Discusses contribution of diffusion and effusion to overall release, and give diffusion, effusion and ionization data for various combinations of ion sources (FEBIAD and TIS types), catchers, and implanted ions.

Ravn, H.L. et al. "Use of Refractory Oxides, Carbides and Borides as Targets for On-Line Mass Separation." *Nuclear Instruments and Methods in Physics Research* B26 (1987) 183–189. Studies of CaB_6, ScC_2, LaC_2, TaC, ThC_2, UC_2, MgO, CaO, BaO, and ThO_2 at CERN-ISOLDE.

Talbert, W.L., H.-H. Hsu and F.C. Prenger. "Beam heating and cooling of thick targets for on-line production of exotic nuclei." *Nuclear Instruments and Methods in Physics Research* B70 (1992) 175–181. Considers energy deposition rates and distributions, using the LAHET code, for beams up to 100μA of 500 MeV to 1.2 GeV protons on Au, Ir, La, Nb, Pb, Ta, Ti, Zr, UC_2, and MgO targets.

Winsberg, L. "The Determination of Transfer Times in an On-Line Isotope Separator." *Nuclear Instruments and Methods* 95 (1971) 19–22.

Winsberg, L. "The Determination of Cross Sections with an On-Line Isotope Separator." *Nuclear Instruments and Methods* 95 (1971) 23–27.

Production and Uses of RIBS

D'Auria, John M. "An ISOSPIN Laboratory for North America." *Nuclear Instruments and Methods in Physics Research* B70 (1992) 398–406.

Crawford, J.E. et al. "A Proposed Radioactive Ion Beam Facility at Triumf." *Nuclear Instruments and Methods in Physics Research* B26 (1987) 128–142.

Olsen, D.K. "Opportunities with accelerated radioactive ion beams." *Nuclear Instruments and Methods in Physics Research* A328 (1993) 303–320. Discusses methods of production, current and proposed facilities, and scientific opportunities presented by RIBs.

Ion Sources

Kirchner, R. and E. Roeckl. "Investigation of Gaseous Discharge Ion Sources for Isotope Separation On-Line." *Nuclear Instruments and Methods* 133 (1976) 187–204. Thorough description of the operating principles and behavior of the first FEBIAD ion source.

Kirchner, R. "Progress in Ion Source Development for On-Line Separators." *Nuclear Instruments and Methods* 186 (1981) 275–293.

Kirchner, R., K.H. Burkard, W. Hüller and O. Klepper. "The Ion Sources for the GSI On-Line Separator." *Nuclear Instruments and Methods* 186 (1981) 295-305.

Kirchner, R. "An Ion Source with Bunched Beam Release." *Nuclear Instruments and Methods in Physics Research* B26 (1987) 204–212.

Kirchner, R., K. Burkard, W. Hüller and O. Klepper. "Ion source development for the on-line isotope separator at GSI." *Nuclear Instruments and Methods in Physics Research* B70 (1992) 56–61. Discusses the FEBIAD-H ion source developed at GSI Darmstadt.

Top target candidates containing sulfur, nickel, or zinc.

	Compound	Melting Point °C	Vapor Pressure Torr	@	°C
NICKEL	NiO	1984	10^{-4}		1470
	Ni_3Zr	1710			
	Ni_4Zr	1638			
	Ni_3Ta	1549			
	NiZr	1474			
	Ni	1455	10^{-3}		1360
			10^{-6}		1071
ZINC	ZnO	1975	10^{-4}		1800
	ZnS	1830	10^{-4}		800
	ZnSe	1526	10^{-4}		660
SULFUR	CaS	2527	10^{-4}		1100
	CeS	2450	10^{-3}		1900
	BaS	2227	10^{-4}		1100
	MgS	2227			
	ScS	2227	5×10^{-4}		1400
	BeS	2200	10^{-4}		1525

binary sulfur compounds by MP

	A	B	C	E	F	G	H	I	J	K	L	M
1	element	Z	compound	stoichiometric	name	melting	melting point	vapor press.	v.p. at	temp (C) @	temp (C) @	
2				fraction S		point (C)	references	Torr at deg. C	2000 C	10-4 Torr	10-3 Torr	Comments
3									(Torr)			
4	calcium Ca	20	CaS	0.5	nat.	2527	2527 +- 50 *a	1x10-4 @ 1100 *d,*e		1100		
5	uranium U	92	US	0.5	uranium sulfide	2472	2472 +- 15 *a; > 2000 *b; 2000 *c					
6	cerium Ce	58	CeS	0.5	cerium sulfide	2450	2450 +- 100 *a, *c	1x10-3 @ 1900 *c; 1x10-3 @ 2000 *d			1900	
7	plutonium Pu	94	PuS	0.5		2350	2350 *a					
8	praseodymium Pr	59	PrS	0.5		2230	2230 *a					
9	barium Ba	56	BaS	0.5	barium monosulfide	2227	2227 +- 200 *a; 1200 *b; 2205 *c	1x10-4 @ 1100 *d,*e; 8x10-4 @ 1627 *a		1100		
10	magnesium Mg	12	MgS	0.5	magnesium sulfide	2227	2227 +- 200 *a; dec > 2000 *b					
11	scandium Sc	21	ScS	0.5	scandium sulfide	2227	2227 +- 200 *a	5x10-4 @ 1400, 2x10-2 @ 1900 *a				
12	beryllium Be	4	BeS	0.5	beryllium sulfide	2200	2200 *c	8x10-4 @ 1620, 4x10-3 @ 1730 *c; 1x10-4 @ 1525 *d		1525		
13	cerium Ce	58	CeS1.15	0.535		2200	2200 +- 75 *c					
14	lanthanum La	57	LaS	0.5		2200	2200 *a; 2300 *c	4x10-4 @ 1600, 3x10-3 @ 1900 *a			1724	
15	neodymium	60	Nd2S3 (gamma)	0.6		2200	2200 *a, *c; dec	1x10-3 @ 1900 *a				Nd2S3(s) -> 2Nd(l) + 1.5S2(g) *a
16	thorium Th	90	ThS	0.5	thorium sulfide	2200	> 2200 *a, *c	1x10-5 @ 1500, 6x10-4 @ 2000, 2x10-2 @ 2700 *a		1751	2084	
17	neodymium	60	NdS	0.5		2140	2140 *a, *c					
18	lanthanum La	57	La2S3 (hex)	0.6		2125	2100 - 2150 vac *b					
19	lanthanum La	57	La2S3	0.6		2125	2125 +- 25 *c					
20	lanthanum La	57	La3S4	0.571		2100	2100 +- 50 *a; 2100 *c					
21	praseodymium Pr	59	Pr3S4	0.571		2100	2100 +- 50 *a	3x10-3 @ 1700, 5x10-3 @1800 *a				
22	lanthanum La	57	La2S3 (gamma)	0.6		2080	2080 +- 30 *a					
23	yttrium Y	39	YS	0.5	yttrium sulfide	2060	2060 +- 40 *a; 2040 *c	3x10-3 @ 1800, 9x10-3 @ 2000 *a				
24	gadolinium Gd	64	GdS	0.5		2052	2052 *a	1x10-2 @ 2000 *a				
25	cerium Ce	58	Ce3S4	0.571		2050	2050 +- 50 *a; 2050 +- 75 *c	8x10-4 @ 1620, 1x10-3 @ 1840 *c; 1x10-3 @ 2000 *d				
26	neodymium	60	Nd3S4	0.571		2040	2040 *a, *c					
27	uranium U	92	U2S3	0.6		2027	2027 *a; ign *b	1x10-4 @ 1400 *d		1400		
28	strontium Sr	38	SrS	0.5		2000	> 2000 *b					
29	praseodymium Pr	59	Pr2S3 (gamma)	0.6		1995	1995 +- 30 *a					
30	terbium Tb	65	TbS	0.5	terbium sulfide	1970	1970 *a					
31	dysprosium Dy	66	DyS	0.5		1940	1940 *a					
32	samarium Sm	62	SmS	0.5	samarium sulfide	1940	1940 *a, *c					
33	europium Eu	63	EuS	0.5		1927	1927 *a	5x10-3 @ 1600, 3x10-2 @ 1900 *a				
34	titanium Ti	22	TiS	0.5		1927	1927 +- 20 *a	2x10-3 @ 1600, 1x10-2 @ 1900 *a			1534	
35	samarium Sm	62	Sm2S3 (gamma)	0.6		1900	1900 *a, *b, *c					
36	thorium Th	90	ThS2	0.67		1900	1897 *a; 1925 +- 50 vac *b; 1905					

binary sulfur compounds by MP

	A	B	C	E	F	G	H	I	J	K	L	M
37	thorium Th	90	Th2S3	0.6		1900	1847 °a; 1950 +- 50 °c					
38	cerium Ce	58	Ce2S3 gamma	0.6		1890	1890 +- 50 °a, °c; dec 2100 (vac) °b	1x10-3 @ 1840 °d			1840	
39	holmium Ho	67	HoS	0.5	holmium sulfide	1890	1890 °a					
40	erbium Er	68	ErS	0.5	erbium	1887	1887 °a					
41	gadolinium Gd	64	Gd2S3	0.6	.	1885	1885 +- 20 °a; 1885 °c					
42	uranium U	92	US2 (beta)	0.67		1850	1850 °c					
43	thulium Tm	69	TmS	0.5	thulium sulfide	1840	1840 °a					
44	zinc Zn	30	ZnS	0.5		1830	1830 °? (°b, probably)	1x10-4 @ 800 °e		800		
45	samarium Sm	62	Sm3S4	0.571		1800	1800 +- 50 °a; 1800 °c					
46	tungsten W	74	WS2 (beta)	0.67	tungsten sulfide	1800	> 1800 °a					
47	praseodymium Pr	59	PrS2	0.67		1780	1780 °a					
48	scandium Sc	21	Sc2S3	0.6		1775	1775 +- 20 °a					
49	neodymium	60	NdS2	0.67		1760	1760 °a, °c					
50	cadmium Cd	48	CdS	0.5	nat. greenockite	1750	1750 100 atm °b	1x10-4 @ 550 °d,°e		550		
51	samarium Sm	62	SmS2	0.67		1730	1730 °a, °c					
52	plutonium Pu	94	Pu2S3	0.6		1727	1727 °a					
53	cerium Ce	58	CeS2	0.67		1700	1700 °a, °c					
54	zinc Zn	30	ZnS (alpha)	0.5	nat. wurtzite (hex)	1700	1700 +- 20 °b					
55	erbium Er	68	Er2S3	0.6		1680	1730 +- 20 °a; 1630 °c					
56	uranium U	92	US2 (alpha)	0.67		1680	1680 °a; >1100 °b					
57	yttrium Y	39	YS2	0.67		1660	1660 °a, °c					
58	lanthanum La	57	LaS2	0.67		1650	1650 °a					
59	molybdenum Mo	42	MoS2	0.67	nat. molybdenite	1650	> 1227 °a; 1185, subl 450, *dec in* air °b; 1650 +- 25	1x10-4 @ 50 °d,°e		50		Heated in press to 1600-1900 C; melts with decomposition at 1650-1700 C. °c
60	yttrium Y	39	Y5S7	0.583		1630	dec 1630 +- 30 °a; 1630 °c					
61	erbium Er	68	Er5S7	0.583		1620	1620 +- 30 °a; 1620 °c					
62	yttrium Y	39	Y2S3	0.6		1600	1600 +- 20 °a; 1600 °c					
63	chromium Cr	24	CrS	0.5		1567	1567 °a; 1500 °b					
64	zirconium Zr	40	ZrS2	0.67		1550	1550 °a, °b					
65	dysprosium Dy	66	Dy5S7	0.583		1540	1540 +- 30 °a; 1540 °c					
66	*manganese*	25	MnS	*0.5*	nat.	1530	1530 °a; dec °b	1x10-4 @ 1300 °d,°e		1300		
67	hafnium Hf	72	HfS2	0.67	hafnium sulfide	1527	> 1527 °a					
68	niobium Nb	41	NbS2	0.67		1527	> 1527 °a					
69	tantalum Ta	73	TaS2	0.67	tantalum sulfide	1527	> 1527 °a; > 1300 °b; > 1300 (Ta2S4) °d					
70	dysprosium Dy	66	Dy2S3	0.6		1490	1490 +- 20 °a; 1480 °c					
71	titanium Ti	22	Ti2S	0.33		1487	1487 °a					

binary sulfur compounds by MP

	A	B	C	E	F	G	H	I	J	K	L	M
72	vanadium V	23	V3S	0.25	vanadium sulfide	1400	1400 °a					
73	niobium Nb	41	Nb2S	0.33	niobium sulfide	1350	1350 +- 50 °a					
74	titanium Ti	22	Ti3S	0.25	titanium sulfide	1305	1305 °a					
75	ytterbium Yb	70	Yb2S3	0.6		1300	dec 1300 °a					
76	gallium Ga	31	Ga2S3	0.6		1255	1255 +- 10 °b					
77	tungsten W	74	WS2	0.67	nat.	1250	dec 1250 °b					
78	chromium Cr	24	Cr2S3	0.6		1227	> 1227 °a; -S, 1350 °b					
79	chromium Cr	24	CrS1.17 (gamma)	0.539		1227	> 1227 °a					
80	molybdenum Mo	42	Mo2S3	0.6		1227	> 1227 °a; dec 1100, vol 1200 °b					
81	vanadium V	23	V2S3	0.6		1227	> 1227 °a; dec > 600 °b					
82	iron Fe	26	FeS	0.5	nat. troilite	1196	1193-1199 °b					
83	sodium Na	11	Na2S	0.33		1180	1180 °b					
84	iron Fe	26	FeS2	0.67	nat. pyrite (cubic)	1171	1171 °b					
85	cobalt Co	27	CoS	0.5	nat.	1116	> 1116 °b					
86	lead Pb	82	PbS	0.5	nat. galena	1114	1114 °b	1x10-4 @ 550 °e		550		
87	aluminum Al	13	Al2S3	0.6		1100	1100 °b					
88	copper Cu	29	Cu2S	0.33	nat.	1100	1100 °b					
89	silicon Si	14	SiS	0.5		1090	subl 1090 °b	1x10-4 @ 450 °e		450		
90	indium In	49	In2S3	0.6	indium sesquisulfide	1050	1050, subl ca 850 in high vac °b	1x10-4 @ 650 °d; 1x10-4 @ 850 °e		750		
91	zinc Zn	30	ZnS (beta)	0.5	nat. sphalerite	1020	tr 1020 °b					
92	ruthenium Ru	44	RuS2	0.67	nat. laurite	1000	dec 1000 °b					
93	ruthenium Ru	44	RuS	0.5		1000	1000 °d					
94	gallium Ga	31	GaS	0.5		965	965 +- 10 °b					
95	palladium Pd	46	PdS	0.5		950	dec 950 °b					
96	silicon Si	14	SiS2	0.67		940	subl 940 °b					
97	lithium Li	3	Li2S	0.33	lithium sulfide	932	900 - 975 °b					
98	tin Sn	50	SnS	0.5	tin sulfide	882	882 °b					
99	potassium K	19	K2S	0.33		840	840 °b					
100	silver Ag	47	Ag2S (cubic)	0.33	nat.	825	825 °b					
101	gallium Ga	31	Ga2S	0.33		800	dec vac 800 °b					
102	germanium Ge	32	GeS2	0.67	germanium disulfide	800	ca 800, subl 430 °b					
103	palladium Pd	46	Pd2S	0.33		800	dec 800 °b					
104	nickel Ni	28	NiS	0.5	nat. millerite	797	797 °b					
105	nickel Ni	28	Ni3S2	0.4	heazlewoodit	790	790 °b					
106	indium In	49	InS	0.5	indium monosulfide	692	692 +- 5, subl vac 850 °b					
107	bismuth Bi	83	Bi2S3	0.6	nat. bismuthinite, bismuthglanc	685	dec 685 °b					
108	bismuth Bi	83	BiS	0.5		680	680 (in CO2) °b					
109	indium In	49	In2S	0.33	indium	653	653 +- 5 °b	1x10-4 @ 650 °e		650		
110	tin Sn	50	SnS2	0.67	mosaic gold	600	dec 600 °b					
111	mercury Hg	80	HgS (alpha)	0.5	cinnabar, vermillion	583.5	subl 583.5 °b	1x10-4 @ 250 °e		250		
112	mercury Hg	80	HgS (beta)	0.5	metacinnabar	583.5	583.5 °b					
113	barium Ba	56	BaS3	0.75		554	dec 554 °b					
114	antimony Sb	51	Sb2S3	0.6	nat. stibnite	550	550 °b	1x10-4 @ 200 °e		200		

	A	B	C	E	F	G	H	I	J	K	L	M
115	germanium Ge	32	GeS	0.5	germanium monosulfide	530	530, subl > 600 °b					
116	rubidium Rb	37	Rb2S	0.33		530	dec 530 vac °b					
117	arsenic As	33	As2S5	0.714		500	subl, dec 500 °b					
118	cobalt Co	27	Co3S4	0.571	nat. linneite, cobalt	480	dec 480 °b					
119	potassium K	19	K2S2	0.5		470	470 °b					
120	cesium Cs	55	Cs2S2	0.5	cesium disulfide	460	460 °b					
121	iron Fe	26	FeS2	0.67	nat. marasite (rhombic)	450	tr 450 °b					
122	thallium Tl	81	Tl2S	0.33		448.5	448.5 °b					
123	rubidium Rb	37	Rb2S2	0.5		420	420 °b					
124	boron B	5	B2S5	0.714		390	390 °b					
125	boron B	5	B2S3	0.6	boron trisulfide	310	310 °b	1x10-4 @ 800 °e		800		
126	phosphorus P	15	P4S7	0.636		310	310 °b					
127	arsenic As	33	As2S2	0.5	nat. realgar.	307	307 °b					
128	arsenic As	33	As2S3	0.6	nat. orpiment	300	300 °b	1x10-4 @ 400 °e		400		
129	iridium Ir	77	IrS2	0.67	iridium disulfide	300	dec 300 °b					
130	phosphorus P	15	P2S5 (or P4S10)	0.714		288	286-90 °b					
131	polonium Pl	84	PoS	0.5		275	dec 275 °b					
132	sodium Na	11	Na2S4	0.67		275	275 °b					
133	thallium Tl	81	Tl2S3	0.6		260	260 (in N2) °b					
134	potassium K	19	K2S3	0.6		252	252 °b					
135	sodium Na	11	Na2S5	0.714		252	252 °b					
136	gold Au	79	Au2S	0.33		240	dec 240 °b					
137	platinum Pt	78	PtS2	0.67		237	dec 225 - 250 °b					
138	rubidium Rb	37	Rb2S5	0.714		225	225 °b					
139	cesium Cs	55	Cs2S3	0.6	cesium trisulfide	217	217 °b					
140	rubidium Rb	37	Rb2S3	0.6		213	213 °b					
141	cesium Cs	55	Cs2S5	0.714		210	210 °b					
142	potassium K	19	K2S5	0.714		206	206 °b					
143	rubidium Rb	37	Rb2S6	0.75		201	201 °b					
144	gold Au	79	Au2S3	0.6		197	dec 197 °b					
145	cesium Cs	55	Cs2S6	0.75		186	186 °b					
146	nitrogen N	7	N4S4	0.5		178	dec 178 °b					
147	silver Ag	47	Ag2S (rhombic)	0.33	nat.	175	tr 175 °b					
148	phosphorus P	15	P4S3	0.429		174	174 °b					
149	cesium Cs	55	Cs2S4	0.67		160	dec 160 °b					
150	potassium K	19	K2S4	0.67		145	145 °b					
151	sulfur S	16	S8	1		120	ca 120 °b	1x10-4 @ 57 °e		57		
152	selenium Se	34	SeS	0.5		118	dec 118 - 119 °b					
153	copper Cu	29	CuS	0.5	nat. covellite	103	tr 103 °b	1x10-4 @ 500 °e		500		
154	antimony Sb	51	Sb2S5	0.714		75	dec 75 °b					
155	nitrogen N	7	N2S5	0.714		10	10 - 11 °b					
156	carbon C	6	C3S3	0.5		-0.5	l -0.5 °b					
157	hydrogen H	1	H2S5	0.714		-50	l -50 °b					
158	hydrogen H	1	H2S3	0.6		-52	l -52 °b					
159	hydrogen H	1	H2S4	0.67		-85	l -85 °b					
160	hydrogen H	1	H2S	0.33		-85.5	l -85.5 °b					
161	hydrogen H	1	H2S2	0.5		-89.6	l -89.6 °b					
162	carbon C	6	CS2	0.67	carbon disulfide	-110.8	l -110.8 °b					
163	carbon C	6	CS	0.5		-160	dec -160 °b					
164	actinium Ac	89	Ac2S3 °b	0.6								

	A	B	C	E	F	G	H	I	J	K	L	M
223	*a T. Ya. Kosolapova, Handbook of High Temperature Compounds: Properties, Production, Applications, Hemisphere Publishing Corporation, 1990.											
224	*b CRC Handbook of Physics and Chemistry, 1994-1995, 75th Edition, Ed.in Chief David R. Lide, CRC Press, 1994.											
225	*c Thermophysical Properties of High Temp. Solid Materials.											
226	*d Batch											
227	*e Thin Film Evaporation Source Reference, R.D. Mathis Company (Note: no references given)											
228	car78 (see JourRef)											
229	jac89											
230	juergen											
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Table 1: UNISOR measurements

target	bell jar	FEBIAD
Al2O3	melted at 2070 C	stable in on-line conditions
Ga2O3	melted at 1460 C	
ZnO	evaporates at 1250 C	killed ion source
MgS	heated to 1700 C	killed the ion source; anode and outlet plate shorted
CeS	outgased at 1400 C	stable in on-line conditions
BeO		ok, (m.p. 2570 C, v.p. 10^{-3} torr at 2000 C)
NiO		poor ion source performance (m.p. 1984 C)
SiO2		ok (m.p. 1435 C)
AlB		killed the ion source (m.p. no information)
Zr5Ge3		stable in on-line conditions, possible reduction in ion source efficiency
Zr5Si3		stable in on-line conditions, possible reduction in ion source efficiency
BN		stable in on-line conditions

Table 2: Effusion Problem

Exp.	Beam	$T_{1/2}$	ΔHa (on Ta)	t_a	$\tau_{eff}=\chi t_a$	Comments
N	^{10}C	20 s	9.97 theo	1.3E11 s	6.1 mily	?
A A	^{14}O ^{15}O	1.1 min 2 min	9.74	3.4E10 s	1.6 mily	NO ?
A	^{17}F	65 s				AlF?
N	^{24}Al	2.1 s	5.1	0.035 s	53 s	problem
A, N A	^{26}Si ^{27}Si	2.2 s 4.2 s	7.2 theo	9377 s	162 d	problem
A, N A	^{30}S ^{31}S	1.2 s 2.6 s				SO ?
A A	^{33}Cl ^{34}Cl	2.5 s 32 min				
N	^{58}Cu	3.3 s	4.05 exp	69 µs	0.1 s	ok
N	^{63}Ga ^{64}Ga	32 s 2.6 min	3.8 exp 4.3 theo	15 µs 304 µs	0.02 s 0.46 s	ok ok
N N	^{65}Ge ^{66}Ge	31 s 2.3 h	5.4 exp 6.0 theo	0.21 s 7.5 s	316 s 3.1 h	too short ok
N	^{69}As	15 min	5.75 exp 6.1 theo	1.7 s 13.5 s	42.2 min 5.6 y	maybe
N N	^{71}Se ^{72}Se	4.7 min 8.4 d				
N	^{73}Br	3.4 min				

$t_a = t_0 \exp\left(\frac{\Delta Ha}{kT}\right)$; mean sticking time per wall collision

with $t_0 = 2.4 \times 10^{-15} s$; $k = 8.625 \times 10^{-5} eVK^{-1}$; $T = 1950K$

$\tau_{eff} = \chi t_a$; effusion delay time,

where χ = no. wall collisions in ion source

here $\chi = 1500$

ΔHa = enthalpy of adsorption, pretty close to the activation energy of desorption

ΔHa ^{exp} from Kirchner, ΔHa ^{theo} from Eichler

Table 3: Release Data

Beam	Target	implantation depth	Hot position 1700 C	Cold position 1200 C	τ release time	η_s separation eff.	η_{real} release eff.
^{35}Cl	Ta	3.2μm (1.5 mm)	x		10 - 30 s	1.0 - 2.4 %	23 - 38 %
	Ta	15.2μm (1.5 mm)	x		60 - 170 s	0.9 - 1.0%	12 -15 %
	Ta	0.9μm (1.8μm)	x		32 s	1.1 %	
	C	6.9μm (160μm)	x		220 s	1.1 %	
	BN	5.0μm (2 mm)	x		70 s	0.7 %	
^{37}Cl	Ta	3.2μm (1.5 mm)	x		7 - 11 s		8 - 9 %
	Ta	15.2μm (1.5 mm)	x		200 s	0.5	8 %
	CeS	2.6μm (3mm)	x		160 s	0.8	11 %
	CeS	34.3μm (3mm)	x		700 s	1.4 %	20 %
	Zr_5Si_3	26μm	x		13 s	0.25 %	87 %
^{69}Ga	Ta	1.5μm (3μm)		x	2 - 3 s	0.6 - 2.5 %	8 - 10%
	Ta	0.9μm (1.8μm)	x		190 s	17 %	
	C	6.8μm (160μm)	x		2 s	23 %	
	BN	5.9μm (2 mm)	x		110 s	2 %	
^{81}Br	Ta	2.6 μm (3μm)		x	110 s	0.11 %	1 %
	Ta	4.4μm (3μm)		x	20 s	0.03 %	0.3 %
^{79}Br	Zr_5Ge_3	16μm	x		7 s	1.8 %	61 %
	C	6.8μm (160μm)	x		220 s	3 %	
^{75}As	Zr_5Ge_3	18μm	x		39 s	0.66 %	24 %

	Ta	0.9µm (1.8µm)	x		300 s	9 %	
	C	6.8µm (160µm)			no release		
	BN	6.3µm (2 mm)	x		1000 s	1.3 %	
^{78}Se	Zr_5Ge_3	15µm	x		25 s	0.14 %	27 %
	Zr_5Ge_3	18µm	x		40 s		5 %
	Ta	0.9µm (1.8µm)	x		>450 s	1.6 %	
	C	6.8µm (160µm)	x		no release		
	BN	4.9µm (2 mm)	x		2000 s	0.7 %	
Cu	NiO						
	Ta	0.9µm (1.8µm)	x		69 s	6.8 %	
	C	6.8µm (160µm)	x		<1 s	7.7 %	
	BN	6.5µm (2 mm)	x		30 s	1 %	
^{19}F	Al_2O_3		x				

separation efficiency $\eta_s = \frac{I_{out}}{I_{in}}$

release efficiency $\eta_{rel} = \frac{I_{out}}{I_{in} \cdot \eta_{trans} \cdot P_{element}}$

transmission efficiency $\eta_{trans} = 80\%$

ionization efficiency of element $P_{element}$

$$P_{element} = \sqrt{\frac{M_{element}}{M_{Xe}} \cdot \frac{n_{e-element}}{n_{e-Xe}}} \cdot \exp[0.3358(I_{P_{Xe}} - I_{P_{element}})] P_{Xe}$$

M = mass; n = effective outer shell electrons; I_P *= ionization potential*

Table 4: Comparison EBP with FEBIAD

	EBP	FEBIAD	Comments
Efficiency	≈ 15 % at UNISOR	≈ 30 % at UNISOR	needs a modification of EBP; Anode etc.
Temperature	≈ 2000 C higher T, but longer transfer tube	≈ 1500 C	which source has faster effusion time?
Lifetime	Problems with cathode	cathode very long life time (several months)	maybe not important because lifetime determinec by target
Cost	$ 30,000	$ 20,000	cost maybe comparable
Weight	very heavy, can maybe be reduced	light, will depend on new housing	weight is mainly determined by housing
Operation	relative easy if cathode works	relative easy	
Assembly	not so easy	easy	
Disassembly	difficult	easy	
Outgassing	1 week	> 1 week	outgassing of BN in FEBIAD is very large
distance between target and ionization	10 cm, delay long if sticking	1 cm, delay short	check calculation
cathode	changes shape, needs more work	better design, easy to control emission surface (flatness)	FEBIAD clearly better
Anode	orientation difficult, needs modification	gap very easy to change	
Outlet plate	not available	energy filter for better mass resolution	
Outlet plate hole	to be modified like EBGP (OASIS) ?	1 mm best (Kirchner)	
Experience	little	several years, IS parameters better investigatd (Kirchner)	
Remote handling	finished in design	has to be designed	FEBIAD lighter, easier a cheaper handling
Power supplies	big currents	small currents	
Target, transfer line	integrated (includes heating), cooling has to be designed	needs to be designed and tested	
Radiation	stainless steel parts has to be reduced	effects on BN? Housing out of Al?	radiation has to be confi makes it expensive
ORIC beam alignment w. target	difficult to mount, no reference point	easy, rotational symmetry,	
heat shield	complex	simple, small, cheap	
What has to be done	needs target cooling increase efficiency gain experience	needs new housing (magnets); needs target (cooled and heated) extractor extension remote coupling	

Table 5: target choice

Beam	$T_{1/2}$	Reaction	Target	% of target	Target test	Target Problems	other
^{10}C	20 s	$^{10}B(p,n)$	BN	10		ok	sticking
			AlB	10	off-line	killed ion source	
^{14}O	1.1 min	$^{14}N(p,n)$	BN	50		ok	sticking
^{15}O	2 min	$^{14}N(d,n)$	BN	50		ok	deuterons, sticking
^{17}F	65 s	$^{16}O(d,n)$	Al_2O_3	60	on-line	might decompose	sticking
		$^{16}O(d,n)$	MgO	50		Isolde ok	sticking
		$^{16}O(d,n)$	BeO	50	off-line	ok	sticking
		$14N(\alpha,n)$	BN	50		ok	sticking
^{24}Al	2.1 s	$^{24}Mg(p,n)$	MgO	40		Isolde ok	
^{26}Si	2.2 s	$^{27}Al(p,2n)$	Al_2O_3	40	on-line	might decompose	sticking, 50MeV protons
^{27}Si	4.2 s	$^{27}Al(p,n)$	Al_2O_3	40	on-line	might decompose	sticking
^{30}S	1.2 s	$^{28}Si(^3He,n)$	SiO_2	62	off-line	ok in cold position	sticking
			Si_3N_4	17			sticking
			Zr_5Si_3		on-line	ok, check again	sticking
^{31}S	2.6 s	$28Si(\alpha,n)$	SiO_2	62	off-line	ok in cold position	sticking
^{33}Cl	2.5 s	$^{32}S(d,n)$	CeS	47.5	on-line	ok	release time
			MgS	47.5	off-line	killed ion sourcee	
			BeS	47.5		toxic, flamable ?	
^{34}Cl	32 m	$^{34}S(p,n)$	CeS	2.1	on-line	ok; isotp. enrichment	release time
^{58}Cu	3.3 s	$^{58}Ni(p,n)$	NiO	34	on-line	burned hole in it	
^{63}Ga	32 s	$^{64}Zn(p,2n)$	ZnO	24.3	off-line	killed ion source	50MeV protons
^{64}Ga	2.6 m	$^{64}Zn(p,n)$	ZnS	24.3			
^{65}Ge	31 s	$^{64}Zn(^3He,2n)$	ZnO	24.3	off-line	killed ion source	
^{66}Ge	2.3 h	$^{64}Zn(^3He,n)$	ZnO	24.3	off-line	killed ion source	
^{69}As	15 m	$70Ge(p,2n)$	Zr_5Ge_3	7.7	on-line	ok, check again	sticking; 50MeV protons
			Ge	20.5		Isolde ok	
^{71}Se	4.7 m	$^{70}Ge(^3H,2n)$	Zr_5Ge_3	7.7	on-line	ok, check again	
^{72}Se	8.4 d	$^{70}Ge(^3H,n)$	Zr_5Ge_3	7.7	on-line	ok, check again	
		$^{70}Ge(\alpha,2n)$	Zr_5Ge_3	7.7	on-line	ok, check again	
^{73}Br	3.4 m	$74Se(p,2n)$	La_2Se_3	0.5			

The objectives of this particular experiment were to determine whether the amount of crystal heating in this geometry would be significant, to gain more information on the accuracy of radiation pyrometry using a blackbody cavity, and to observe the high temperature behaviour of this particular ZnO target before testing it in an ion source. In this case, the amount of heating of the crystal was too great to be able to obtain the thickness information which is needed to calculate vapor pressures. This is shown by the decreasing thickness with increasing temperature. The relatively parallel behaviour of the three temperature curves indicates that the use of a blackbody cavity could provide uniform temperature measurement for a variety of test materials.

ZnO on Ta, 8/17/94
Ta–crystal distance: 7.5 cm