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AEC RESEARCH AND DEVELOPMENT REPORT

Appraisal of Possible Stellarator Blanket Systems

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Report written by:

Ernest F. Johnson

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APPRAISAL OF POSSIBLE STELLARATOR BLANKET SYSTEMS

SUMMARY

A variety of systems for blanketing stellarators are considered from the standpoint of the practical problems of handling materials and recovering tritium. One of the most promising possibilities among these systems is the combination of water as moderator and molten lithium nitrite as absorber. Both fluids in this system are non-corrosive and can be pumped inexpensively in magnetic fields. Tritium loss due to neutron absorption by the nitrogen in the nitrite is small and can be made up by small amounts of beryllium in the blanket, or it can be reduced greatly by substituting Li^6 for natural Li in the nitrite. The tritium would be generated as gaseous compounds with nitrogen and oxygen and should be easily recoverable in yields in excess of 99.9 per cent.

A simple cost study of an idealized recovery system indicates that the total installed plant cost for tritium recovery should be well under $1,200,000 and the annual operating costs should not exceed $400,000. The initial total accumulation of tritium in a blanket containing 10^5 kg lithium could be less than 1.0 kg.

I. INTRODUCTION

A. Outline of Problem

Neutrons generated in the reaction tube of a stellarator must be captured in a blanket system surrounding the reaction tube, not only to recover energy but also to produce tritium and at the same time shield the magnet. Protons in the blanket moderate the neutrons, and natural lithium absorbs the moderated neutrons, producing tritium and helium.

Since the overall economy of the stellarator as a power-producing device is greatly dependent on the efficiency with which thermal energy can be extracted usefully from the blanket and on the tritium recovery from the blanket, it is critically important that an optimal blanket system be chosen.

B. Purpose and Scope of Report

This report presents an appraisal of various schemes of blanketing stellarators. The appraisal is based primarily on an analysis of problems involved in recovering tritium from the blanket, but other factors which bear importantly on the choice of the blanket are examined also.

It is assumed that the blanket fluids will be confined in tubes much as described in AEC Report NYO-6047(6) with the exception that for certain combinations of moderator and absorbing medium somewhat simpler confinement arrangements may be possible.

C. Selection of Blanket Systems

The choice of a blanket system can be narrowed quickly from a consideration of the basic requirements for such a system. These requirements without regard to order of importance are:

1. Appropriate nuclear properties, i.e., moderation of neutrons and maximum generation of tritium; absence of undesirable nuclear reactions.
2. Thermal stability
3. Easy recovery of thermal energy released in the fluids.
4. High yield recovery of tritium at low concentration levels.
5. Minimal corrosive attack.

6. Minimal safety hazards.
7. Easy handling of fluid flows.
8. Minimal physical size of blanket.

Neutron moderation requires protons, and tritium generation requires natural lithium possibly enriched with Li^6 and possibly with the addition of neutron multipliers like beryllium to increase the production of tritium. In order to retain the smallest possible blanket depth the lithium density must be high, either by using the pure metal or by using compounds in which the atomic proportion is large. Atoms with undesirable capture cross sections for thermal neutrons must not be present.

Chemical stability at temperatures in excess of 400°C eliminates organic compounds as blanket components with the exception that certain compact, low molecular weight hydrocarbons might be considered for moderation. Cyclohexane, for example, at 350°C decomposes at a rate less than three per cent per month. Unfortunately, co-valent bonded compounds like organic compounds are liable to extensive radiation damage from the neutrons in the blanket.

Easy recovery of thermal energy requires that at least one constituent of the blanket be mobile and of high thermal capacity. Vaporization of that constituent to remove thermal energy from the blanket as latent heat would be advantageous in reducing the flow magnitudes and the sizes of equipment. Not only is the heat transfer between metal wall and boiling liquid much greater than that for a liquid flowing without phase change, but also much more thermal energy can be removed in the latent enthalpy absorbed by vaporization than can be removed by sensible heat in a single phase stream even with a substantial rise in temperature in that stream. Of course, for liquids near their critical temperatures or for supercritical fluids these advantages would disappear. An important requirement for schemes involving vaporization of a blanket constituent is that the tubes and tube headers be arranged to disengage effectively the vapors and any non-condensible gases.

In order to recover the tritium in high yield at the lowest practicable levels the lithium-containing part of the blanket should be free of protons so that there is no possibility of interchanges between the tritium and hydrogen. Preferably the tritium should combine quickly to a single compound on release from the lithium, and that compound should be readily separable from the blanket fluids and readily decomposed to the desired pure tritium.

Minimal corrosive attack requires that the compounds making up the blanket fluids be relatively nonreactive and nonsolubilizing toward their bounding walls at temperatures up to 400-600°C and higher.

Minimal safety hazards require that blanket fluids be chemically stable and nontoxic. For a blanket in which the moderating and capturing functions are separated it would be desirable that the separate fluids be unreactive with each other so that a single metal wall between them would suffice rather than the double tube system deemed essential for the water-lithium blanket.

For easy handling of any necessary fluid flows in the blanket system it is desirable that the flowing fluid be of low viscosity, homogeneous, and insensitive to magnetic fields. It is particularly desirable that the flowing fluids be electrically nonconductive to simplify pumping them through the magnetic field that surrounds the blanket. Fluids should have low melting points but also low vapor pressures at typical blanket temperatures.

Minimal physical size of the blanket system requires that the lithium concentration in the blanket volume be as high as possible consistent with safe containment of the blanket fluids.

II. POSSIBLE SYSTEMS

There is no blanket system which uncompromisingly meets all of the foregoing requirements, but there are a few systems which come close enough to warrant more detailed consideration. Some of the more important physical properties of possible blanket constituents are tabulated in Appendix A of this report.

A. Pure Lithium Metal

The simplest system is that proposed in AEC Report NYO-6047(6) in which pure liquid metal is confined by stainless steel tubes, and water as moderator is confined in adjacent tubes. This system has the advantages that the lithium is in a dense form and the tritium recovery is relatively simple. It has the disadvantage that the lithium can be pumped readily away from the magnets only at prohibitively large energy expenditures unless some means of insulating the tubes can be devised. A further disadvantage is that any leakage between the lithium and water might seriously damage the apparatus. If the lithium pumping problem is avoided by maintaining the lithium quiescent while pumping the moderator to remove energy, the lithium will have to rise to such high temperatures to maintain thermal flow at useful temperature levels that serious interaction between the lithium and the bounding walls may result. Iron and ferritic stainless steels (12-27 per cent chromium) can contain pure lithium up to 800°C, but the long range effects of the presence of small amounts of tritium cannot be gauged reliably.

The recovery of tritium from lithium where the tritium occurs as lithium tritide has been discussed in Technical Memorandum No. 25, NYO-6370 (3). On the basis of the few available data and extrapolation of related data it is probable that a high yield recovery of tritium at low concentrations can be effected by crystallizing out the tritide in cold legs, filtering it off, and retorting the solid.

If the lithium is maintained at temperatures in excess of 650°C in the blanket, the tritium can be pumped off as a gas along with the helium and vaporized lithium and subsequently recovered either by fractional distillation or by chemical reaction. From the standpoint of easy disengagement of the evolved gases it would be desirable to confine the lithium in the interstices external to the tubes containing the moderator rather than use another set of tubes for the lithium. This arrangement would eliminate the need for tube sheets at the two peaks of the reaction tube.

If the moderator is water or some other fluid readily attacked by lithium there might be some concern about the fact that only a single wall separated the two fluids, although the improved heat transfer would permit higher temperatures in the moderator, hence greater power output than could be attained with a double tube system.

The moderator, regardless of what it is, must be confined inside tubes because of its high vapor pressures at normal operating temperatures. If the lithium cannot be circulated for lack of any means of insulating it from the magnetic field, the total thermal energy released in the blanket will have to be removed by the circulating moderator. The most likely possibilities as moderators are water and compact hydrocarbons.

Of these, the former seems more desirable because of higher proton density (about double that of suitable hydrocarbons), much greater thermal stability, much greater resistance to radiation damage and higher heat capacity. Its only disadvantage is its reactivity with lithium.

B. Lithium in Compounds

Elements with absorption cross sections for thermal neutrons less than 3.0 barns and which may be combined with lithium are the following (the numbers in parentheses are the respective absorption cross sections in barns (2)): hydrogen (0.33); deuterium (0.00046); carbon (0.0032); nitrogen (1.88); oxygen (0.0002); fluorine (0.009); silicon (0.13); phosphorus (0.19); and sulphur (0.49). There are also a number of metals with low cross sections such as beryllium, aluminum, tin, barium, cerium, lead, and bismuth. Table III in the appendix summarizes the absorption cross sections for thermal neutrons of all elements of interest.

Only a very few of the possible compounds involving lithium and one or more of the foregoing elements can meet the requirements of relatively low melting point and high thermal stability. Among the more practical possibilities are the amide, the hydroxide, the nitrate, and the nitrite, with respective melting points of 375°, 450°, 255°, and 223°C. Both the amide and the hydroxide contain hydrogen and hence are disadvantageous because of the possibility of interchanges between the hydrogen and tritium and subsequent complication of the recovery of the tritium. They are also disadvantageous in that their melting points are uncomfortably close to the proposed normal operating temperatures in the blanket.

The problem of high melting point can be circumvented in principle by mixing different lithium compounds to depress the melting point or by carrying the high melting compound suspended in a slurry with a low melting compound. Unfortunately few data are available on the solubility of suitable lithium compounds and their effects on melting point. Data for the system Li_2CO_3-$LiNO_3$ show only a 5°C melting point depression at the eutectic point because of the low solubility of the carbonate (2 mole per cent).

1. Slurry of Lithium Oxide in Lithium Nitrate or Nitrite.

From the standpoint of maximum lithium density in the blanket a suspension of the oxide Li_2O in the nitrate or nitrite would be ideal. The lithium densities of the oxide and nitrate in g. atoms Li/cu. cm at room temperature are 0.135 and 0.0345 respectively. By comparison the pure metal is 0.0764.

Slurries of oxide and nitrate (or nitrite) probably can be handled with little difficulty. The suspended solid is only slightly less dense than the liquid nitrate (2.013 g/cu. cm and 2.38 g/cu. cm respectively at room temperature).

Furthermore the difference in magnetic properties is small (magnetic susceptibilities in 10^{-6} cgs units are -0.48 and -0.57 for the nitrate and oxide,) hence only mildly turbulent flow characteristics are necessary to prevent separation of the phases in the suspension due to the effects of either the magnetic field or the gravitational field.

The tritium on formation presumably would combine immediately with the oxide, and the resulting tritoxide would dissolve in the nitrate. A small stream of the slurry would be drawn off continuously; filtered at say 500°C to remove the oxide; chilled to near the melting point of the nitrate; and filtered again to collect the tritoxide. Retorting would generate the tritium in essentially pure form. It is possible that occlusion of some tritoxide generated deeply within oxide particles would raise somewhat the level of average tritium concentration corresponding to economic recovery.

Some tritium would form from bombardment of the lithium in the nitrate (or nitrite) producing gaseous tritium nitrate (nitrite) decomposing to tritium oxide, oxygen, and various oxides of nitrogen, all of which would be pumped off with the helium and recovered by chemical means or fractionation and electrolysis.

The moderator for this system would be water recycled through tubes as highly compressed vapor.

To prevent deposition of the solids in the absorbing slurry it would be desirable to pump the slurry also through tubes. Thus with slurries a double tube system would always be required so long as the moderator and absorber were separated.

The oxide-nitrate slurry system is relatively noncorrosive and can be contained safely in a variety of metals. There is some evidence that the nitrate begins to decompose at temperatures only slightly above the melting point. Since the decomposition product is most probably the nitrite which is believed to be stable to temperatures above 700°C, (<u>4</u>), the decomposition is not disadvantageous. Furthermore, lithium nitrite has a lower melting point than the nitrate. Thus any decomposition to the nitrite would not be disadvantageous.

2. <u>Lithium Nitrate</u>.

The system lithium nitrate with water as moderator offers the advantages of low corrosivity and single tubes confinement. Again decomposition of the nitrate to nitrite poses no problem. Christofilos (<u>1</u>)

has considered lithium nitrate Li^6NO_3 as an absorbent, but as a concentrated aqueous solution rather than fused salt.

The reduction in numbers of steel tubes in the system resulting from confining the nitrate in the shell rather than in tubes offsets somewhat, but not entirely, the fact that the lithium density of the nitrate is less than that of pure lithium metal (0.0345 g atoms/cu.cm compared to 0.0764 g atoms/cu.cm).

Most of the tritium produced in this blanket would form the gaseous nitrate and would be pumped off with the helium as a mixture of tritium oxide, oxygen, and nitrogen oxides. Subsequent recovery of the tritium should not be difficult using chemical methods and/or fractionation plus electrolysis. Some tritium would form $LiOH^3$ in the melt, but this concentration could be repressed.

3. Lithium Nitrite.

A blanketing system of lithium nitrite with separately confined water as moderator would have all the advantages of the nitrate system described in the preceding paragraph plus the advantages of higher thermal stability and lower melting point. Tritium recovery procedures would be similar to those for the nitrate blanket.

Both the absorbent and moderator would be circulated to promote high thermal transfers and effective degassing.

4. Lithium Nitrate-Lithium Nitrite.

A system with mixed lithium nitrite and lithium nitrate as absorber and water as moderator would have the advantage of lower salt melting point than either the nitrite or the nitrate, but decomposition of the latter would require continuing make-up of nitrate and withdrawal of nitrite to maintain the material balance.

Although the recovery process for this system is somewhat more complicated than the process for the system using lithium metal as absorbent, it is still relatively simple. Hot liquid nitrite from the blanket is pumped continuously through jet injectors into degassing chambers, then cooled in heat exchangers and recycled to the blanket. In the degassers a large continuous flow of essentially pure nitric oxide gas is recycled through the jet injectors to ensure intimate mixing of the nitric oxide and lithium nitrite. A fixed proportion of the gases recycling through the degasser is disengaged from any entrained liquid and sent to the recovery system through recombiners (simple reactors) and subsequent coolers, compressors and aftercoolers. In greatly reduced volume the gas flows slowly through large beds of anhydrous magnesium perchlorate, then through adsorption towers and/or absorption towers.

By proper choice of operating conditions and catalysts in the recombiners the gases to the recovery system will consist only of NO, NO_2, H^3_2O, and He. The water is removed quantitatively by the perchlorate and subsequently regenerated in pure form for electrolysis to tritium and oxygen. A rough separation of NO, NO_2, and He is made in the adsorption/absorption towers from which the NO is recycled to the degasser, the NO_2 is fed to a lithium burner to produce make-up lithium nitrite ($Li^6 NO_2$); and the helium is rejected to the atmosphere.

It is essential to the economic feasibility of this system that virtually all of the tritium produced in the blanket come out in the gas phase, preferably as water (H^3_2O) vapor, rather than remain in the nitrite either as dissolved water or $Li\ OH^3$. The solubility of water in lithium nitrite depends on the concentration of water in the gas phase which is in equilibrium contact with the nitrite and on the pressure and temperature of the system. At a concentration of 0.02 mole fraction water in the gas and a pressure in the degasser of 0.1 atm the ideal solubility of water at 400° C is less than 10^{-5} mole fraction, which corresponds to an inventory of less than 0.5 kg tritium in a blanket melt containing 10^5 kg lithium. At 600° C the solubility is even less. The low concentration level of water in the nitrite would ordinarily lead to supersaturation because of difficulties in nucleation, but the presence of large amounts of sweep gas intimately mixed with the liquid in the degasser prevents any appreciable supersaturation.

The formation of Li OH in the molten lithium nitrite may be regarded as taking place by the reaction.

$$2LiNO_2\ (l) + H_2^3O\ (g)\ 2LiOH^3\ (l) + NO\ (g) + NO_2\ (g).$$

In order to minimize the formation of LiOH the concentrations of NO and NO_2 should be large relative to the concentration of H_2O, and the pressure on the system should be high. From available and estimated free energies, heats of formation, and heat capacities, for the above compounds the equilibrium constant for the reaction at 600° C is estimated to be

$$K_{600^\circ C} = \frac{p_{NO}p_{NO_2}}{p_{H_2^3O}} \left(\frac{x_{LiOH^3}}{x_{LiNO_2}}\right)^2 = 2 \times 10^{-21}$$

where p are partial pressures and the x are mole fractions in the liquid phase. Since the mole fraction of the nitrite is very nearly unity, the mole fraction of $LiOH^3$ can be held at about 10^{-10} for total pressures of only 0.1 atm and a tenfold dilution of the gases with nitric oxide. Thus the inventory of tritium due to any $LiOH^3$ in the system is negligible.

The flow rate of gas recycled through the degasser as sweep gas is set large enough to ensure intimate mixing with the total flow of nitrite through the blanket coolers. Neither of these flow rates is related to the desired concentration levels set by the recovery system. To maintain the low concentration of H^3_2O in the gas and consequently in the lithium nitrite, approximately 300 cu ft/min of the sweep gas must be withdrawn to the recovery system. This flow rate can be accommodated easily in 4 in. pipe. After the gas is compressed to 10 atm and cooled to 50° C the flow rate is less than 2 cu ft/min, and the whole scale of operation becomes small.

According to Smith (5) the equilibrium water vapor pressure of the dehydrate of magnesium perchlorate, $Mg(H_2O)_2(ClO_4)_2$, is zero for temperatures below 130° C. If we assume conservatively that the equilibrium vapor pressure is actually 10^{-10} mm Hg at typical operating temperatures of 30° C, and if we assume that all water removed by the perchlorate can be regenerated without loss, the recovery of tritium from the off-gas will exceed 99.999 per cent.

After removal of the water from the blanket off-gas a rough separation is made of the remaining NO, NO_2, and He. This separation is not critical, and a simple adsorptive or absorptive process should suffice. It is preferable to recycle NO rather than NO_2 to the degasser because the NO is probably less corrosive than the NO_2. From the standpoint of maintaining the desired chemical equilibrium there is little difference between the two gases.

A more precise economic appraisal might show that there is no advantage in attempting any kind of separation of the constituents in the dehydrated gas. The amounts involved are so small that it might be cheaper to purchase NO and Li^6NO_2 for make-up rather than produce them by regenerating absorbed NO and NO_2 and burning the latter with lithium (Li^6).

The total investment in the recovery system can be estimated roughly from an estimate of the total installed cost of the major equipment items. These items (excluding equipment not specifically chargeable to the recovery process) and conservatively high estimates of their installed costs are summarized below.

Equipment	Estimated Installed Cost
Degassers and Recombiners	$ 100,000
Degasser Injectors	30,000
Pumps and Compressors	20,000
Heat Exchangers	10,000
Perchlorate Dehydrators & Regenerators	20,000
Electrolytic Cell	20,000
Adsorber and/or Absorbers	20,000
Lithium Burner	10,000
Total installed cost	$ 230,000

For well instrumented fluid process plants the total fixed capital requirement is about three times the installed cost of major equipment. We shall assume for this case that the factor is more nearly five to allow for any special shielding, remote operation, and related instrumentation. The total fixed capital requirement then is 5 (230,000) or $1,150,000.

Annual operating expenses may be broken down as follows:

Plant depreciation (5-yr write-off)	$ 230,000
Operators: (8 man-years)	40,000
Supervisory and Office Overhead	40,000
Recovery Reagents	20,000
Power and Miscellaneous Services	20,000
Maintenance	50,000
Total annual operating expenses	$ 400,000

Unless there is some unforeseen major technological problem in the proposed process the actual fixed capital requirement and the operating expenses should be appreciably less than these estimates.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. Appraisal of Possible Systems.

On the basis of presently available data it is not possible to rank the foregoing systems in any absolute order of desirability.

Most advantages appear to lie with the blanket system consisting of lithium nitrite as absorber and water as moderator. This system is relatively stable both thermally and in regard to possible mixing of absorbent and moderator. It is non-corrosive and can be pumped readily in a magnetic field. Tritium produced in the salt is evolved as water, which can be recovered quantitatively and subsequently electrolyzed to generate pure tritium. The total investment in the recovery system and the operating costs should be low.

B. Recommendations.

A number of relatively simple studies can be made to provide a sounder basis for evaluating the possible blanket systems described in Section II. It is recommended that studies be initiated to determine the following items:

1. Basic physical and chemical properties of lithium nitrite, including density, thermal stability, corrosion characteristics, electrical conductivity, viscosity, and thermal conductivity, and the like over temperature ranges from the melting point to decomposition temperatures.

2. Phase behavior and physical and chemical properties of mixtures of interest, in particular the system, $LiNO_2$-$LiOH$-H_2O-NO-NO_2.

Although experimental data on the above properties are needed for more refined cost studies, there are theoretical studies which can be pursued to advantage. It is recommended that thermodynamic analyses and speculative design studies of blanket and recovery schemes now in progress be continued.

Appendix A (Data from Hodgman (2) - or computed from data in Hodgman except as noted)

Table I - Physical Properties of Various Absorbents.

Compound	Chemical Formula	Molecular Weight	Melting Point °C	Density g/cu cm	Li Density g atom/cu cm	Electrical Conductance (volume conductivity) ohm^{-1} cm^{-1}	Magnetic Susc. 10^{-6} cgs
				-(at 20°C)-			
Lithium*	Li	6.94	186	0.534	0.077	2.21×10^4 (230° C)	0.50 (16°C)
Carbonate	$Li_2 CO_3$	73.89	618	2.111	0.057	---	-0.413 (-)
Hydride	LiH	7.95	680	0.82	0.103	---	---
Amide	$LiNH_2$	22.96	374	1.178	0.051	---	---
Nitrite	$LiNO_2$	52.95	223	2.28$^+$	0.043$^+$	---	---
Nitrate	$LiNO_3$	68.95	255	2.38	0.035	1.59 (400° C)**	-0.48 (19°C)
Oxide	Li_2O	29.88	>1700	2.013	0.135	---	-0.57 (20°C)
Hydroxide	LiOH	23.95	450	1.43	0.060	---	---

* Natural Lithium: 92.6 at. per cent Li^7; 7.40 at. per cent Li^6

\+ Estimated values

**International Critical Tables 6 p. 149.

Table II - Physical Properties of Various Moderators and Other Compounds.

Compound	Chemical Formula	Molecular Weight	Melting Point° C	Boiling Point° C	Critical Temp° C	Critical Press atm	Critical Density g/cu cm	Hydrogen Density g/atom/cu cm
Water	$H^{1}_{2}O$	18.02	0.0	100.0	374	217.7	0.4	0.111
Heavy water	$H^{2}_{2}O$	20.03	3.82	101.4	371.5	218.6	--	--
2,2,4-trimethyl-pentane	C_8H_{18}	114.2	-107.4	99.3	271	25.5	0.237	0.109
Cyclohexane	C_6H_{12}	84.2	6.5	81.4	281	40.4	0.27	0.0934
Nitric Oxide	NO	30.01	-163.6	-151.8	-94	65	0.52	--
Nitrogen dioxide	NO_2	46.01	- 9.3	21.3d	158	99	--	--
(Nitrogen tetroxide	N_2O_4	92.02)						

Table III - Absorption Cross Section for Thermal Neutrons*

	Cross Section Barns	
Element	Absorption	Scattering
$_{1}H$	0.33	38
$_{2}He$	0	0.8
$_{3}Li$	67	1.4
$_{3}Li^{6}$	910	
Be^{9}	0.009	7
$_{6}C$	0.0045	4.8
$_{7}N$	1.78	10
$_{8}O$	0.0002	4.2
$_{9}F$	0.010	4.1
$_{14}Si$	0.13	1.7
$_{15}P$	0.19	10
$_{16}S$	0.49	1.1
$_{24}Cr$	2.9	3.0
$_{26}Fe$	2.43	11
$_{28}Ni$	4.5	17.5
$_{29}Cu$	3.6	7.2
$_{42}Mo$	2.4	7

*Data from Hodgman (2) and Glasstone, S., "Principles of Nuclear Reactor Engineering" Van Nostrand, Princeton, N.J., 1955.

For elements without superscripts the values are for natural mixtures of isotopes.

Table IV - Enthalpies and Free Energies of Formation of Various Compounds

(25°C and 1 atm except as noted)

Compound (State)	ΔH_g° k cal/g mole	ΔF_f° k cal/g mole
Li (c)	0	0
*fusion 186°	0.76	-
Li (g)	37.07	29.19
LiH (c)	-21.61	-16.72
$LiNO_2$ (c)	-96.6	(-87.)
$LiNO_3$ (c)	-115.28	(-106.)
*fusion 250° C	6.1	-
Li_2O (c)	-142.4	(-132)
LiOH (c)	-116.45	-106.1
NH_3 (g)	-11.04	-3.976
NO (g)	21.60	20.72
NO_2 (g)	8.09	12.39
*HNO_3 (g) (18°C)	-34.4	(-34.)
HNO_3 (l)	-41.40	-19.10
H_2^1O (g)	-57.80	-54.64
H_2^2O (g)	-59.56	-56.07

Notes:
(c) crystalline solid
(g) gas
(l) liquid
* data from Bichowsky, F.R., and Rossini, F.D., "Thermochemistry of Chemical Substances" Reinhold Publishing Co., New York, 1936.

Values in parentheses are estimated.

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