Energy Depot Concept

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Energy Depot - A Concept for Reducing the Military Supply Burden

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ONE OF THE MOST important factors in any combat operation is the ability to provide an adequate supply line. With ever increasing requirements for highly mechanized and highly mobile forces, fuel supply has become a critical consideration. Aside from the usual problems of logistics, maintenance of fuel supply in combat situations is further aggravated when rail and road transportation facilities are highly vulnerable or not available. Under these conditions, the maintenance of fuel supply can become very costly in terms of casualties to transportation personnel and equipment. This is particularly true when air supply must be used.

Modern armies can consume fuel at a voracious rate. Recent estimates indicate that even a small force of 1000 men can require several million pounds of fuel over a one year period. The same amount of energy could be produced by nuclear reactors weighing less than 1% of the equivalent fuel load. The weight advantage of nuclear energy supply can be directly translated into a reduction of transportation equipment and personnel. Furthermore, if the nuclear reactors could be used directly in the combat area, long and vulnerable supply lines between fuel manufacturing facilities and the combat zone could be eliminated.

Vehicle propulsion accounts for most of the fuel used in the Army. Consequently a number of studies were made to determine if nuclear reactors could be installed directly in military vehicles. These studies indicated that direct use of nuclear reactors was not practical for most vehicles. Therefore, an Army-sponsored program was initiated at Allison in July 1961 to determine if a method could be found for indirect use of nuclear energy as a source of vehicle propulsion power. The concept conceived for this purpose was termed the energy depot.

CONCEPT DEFINITION

In planning the initial study at Allison, the energy depot was visualized, as shown in Fig. 1, to consist of a nuclear powerplant and an associated energy conversion and storage system. The combined system would provide a means for fragmenting the available nuclear energy in a form suitable for vehicle propulsion. The overall system was to be capable of being packaged so that it could be transported by land, sea, or air. A nuclear powerplant suitable for the overall system was already under investigation in an AEC/Army program being conducted at Allison. Therefore, primary effort in the initial energy depot study was directed towards a definition of feasible processes for conversion, storage, and utilization of energy from the nuclear powerplant.

ABSTRACT

This paper reviews objectives, approach, and current status of energy depot studies conducted by the Allison Div. of General Motors.

An evolutionary concept is described for near term applications wherein nuclear energy, air, and water can be combined to produce a fuel for use in conventional vehicle engines. Fuel manufacture and engine operation studies are discussed. For longer term use, a revolutionary concept is described whereby a nuclear power source can be used to recharge an electric vehicle propulsion system. Both the evolutionary and revolutionary concepts are shown to provide important logistics advantages for military operations.

INVESTIGATION APPROACH

As shown in Fig. 2, a very broad approach was taken in the study of feasible processes for the energy depot. Consideration was given to storage of reactor output in its basic form of heat and radiation, as well as to the conversion of basic output for storage in the form of mechanical or chemical energy. Direct storage of reactor output would eliminate losses associated with the conversion of energy from one form to another. However, all methods for storage of heat and radiation were found to be too bulky for vehicle applications. Similarly, no reasonably compact method was found for storage of energy in mechanical form. Thus, it was concluded early in the study that nuclear energy would have to be converted and stored in chemical form in order to obtain a feasible system. It should be noted here that so-called electric storage batteries derive their energy from chemical reactions and were, therefore, considered in the chemical energy storage class.

The analysis of chemical energy storage systems was divided into two categories. One classification, called chemical manufacture, considered approaches in which fuels would be synthesized from locally available materials with a nuclear reactor as the power source for fuel manufacture. However, it was required that the fuel materials be universally available in substantial quantities in common earth, air, and water. For such systems, the reaction products from the energy utilization device would not be saved since the source of fuel materials was considered essentially limitless.

The second classification, called chemical regeneration, considered techniques that would permit complete freedom from local fuel material supply requirements. To achieve this, a given quantity of reactants would be taken into the field. After use in a power producing device, the products of reaction would be stored and subsequently regenerated to obtain the original reactants. Power for regeneration would be provided by an on-site nuclear powerplant.

Both thermochemical, or conventional combustion engines, and electrochemical devices were considered for energy utilization methods.

REGENERATIVE FUEL SYSTEMS

In the study of regenerative fuel systems, the use of combustion engines was considered impractical because of the difficulties associated with collection, compression, and/or liquefaction of the exhaust gases in order to reduce their storage volume prior to regeneration. Thus, primary effort in this area was directed toward fuel cells where the reaction products as well as the reactants could be obtained in liquid form for maximum compactness of storage.

After analyzing a large number of reactants, it was concluded that the liquid metals offered greatest promise as regenerative fuel materials because they offered potentially high power-to-weight ratios for fuel cell systems. Further, the liquid metals could be regenerated in liquid form rather than in gaseous form as with other reactants. The latter advantage eliminated the added complexity of liquefying or compressing the regenerated products for storage. It was also concluded that air would be desired as the oxidant since it was readily available and thus did not have to be stored. The most common electrolytes used for the electrochemical reaction of liquid metals with oxygen are aqueous solutions. Ordinarily, the liquid metals would react violently with the

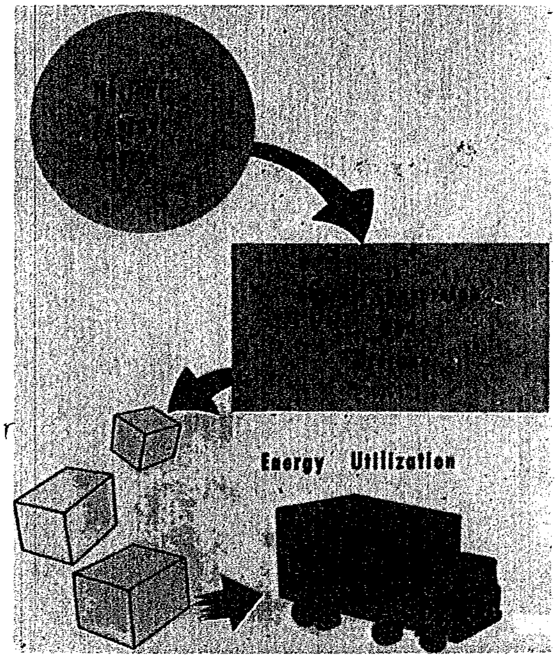

Fig. 1 - Energy Depot concept

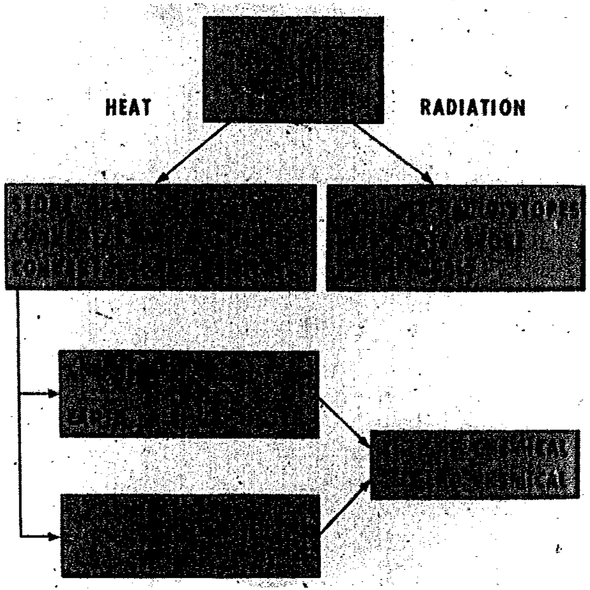

Fig. 2 - Approach

water in the electrolyte. To prevent this reaction, the liquid metals are combined with mercury in an amalgam before being fed to the reaction zone. The reaction product of the amalgam and air is an alkali hydroxide. This material could be returned to the depot and electrolytically regenerated to free the liquid metal for re-use. However, what was really desired was the ability to regenerate the fuel within the fuel cell in a manner similar to the recharging of a battery. This would eliminate the need for an electrolytic plant at the depot and the need to handle and store liquid metals.

The regenerative fuel cell system conceived for this study is shown in Fig. 3. Since it is a combination of two basic fuel cell types, it was termed the combined cell. In this system a fuel such as potassium would first be reacted with mercury. This reaction would produce electric power while forming an amalgam product. The amalgam would then be reacted with oxygen from air to form KOH. Mercury inventory would be minimized since it only serves to transfer K from one portion of the system to another. To recharge the system, the KOH would be pumped back into the amalgam cell and power would be supplied. This would electrolytically regenerate the K and return it to the amalgam. The oxygen would be liberated. The amalgam would then flow to the upper cell where it too would be electrolytically decomposed to return the K to the storage tank. Under an Army-sponsored program, laboratory studies were conducted at Allison to demonstrate the regenerative characteristics of this concept. On the basis of conceptual design studies, it was estimated that a powerplant of this type would be less than 1/10th the size and weight of an equivalent lead-acid battery. In contrast with a conventional battery, the range or operating time of this device is dependent only on its fuel storage capacity. Thus, it offered good potential as a power source for vehicles.

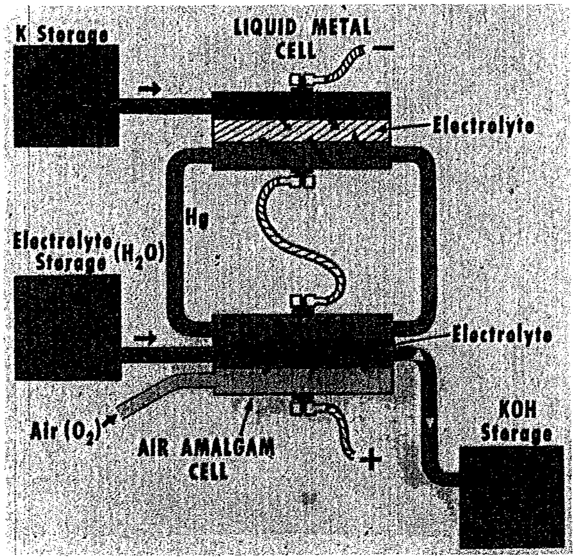

Fig. 3 - Combined cell schematic

A conceptual vehicle installation for the combined cell is shown in Fig. 4. Power from the cell would be fed to electric motors which would drive the wheels rather than the conventional engine and transmission system. The electrochemical processes used for both fuel regeneration and power production in this concept offer the highest efficiencies for conversion of chemical energy to other forms. This would provide a higher overall energy depot power conversion efficiency than any other system considered. Also in this concept, the energy depot proper would only consist of a nuclear powerplant which supplied electricity for recharging the batteries. This would improve Energy Depot mobility and would simplify energy depot operation. Or, in other terms, the combined cell approach would permit fewer depots for operation of a given number of vehicles.

As with other electrochemical devices, the combined cell is significantly larger and heavier than conventional engines of equivalent power output. As a result, its application would be limited to vehicles that can tolerate relatively low power-to-weight ratio propulsion systems. Therefore, consideration was also given to concepts which would utilize conventional engines in order to permit widest possible application of the energy depot concept.

MANUFACTURED FUEL SYSTEMS

In order to determine the feasibility for using conventional engines, first attention was directed to the characteristics and availability of potential fuel materials. Table 1 shows the distribution of elements in common earth, air, and water. An evaluation of materials available for fuel man-

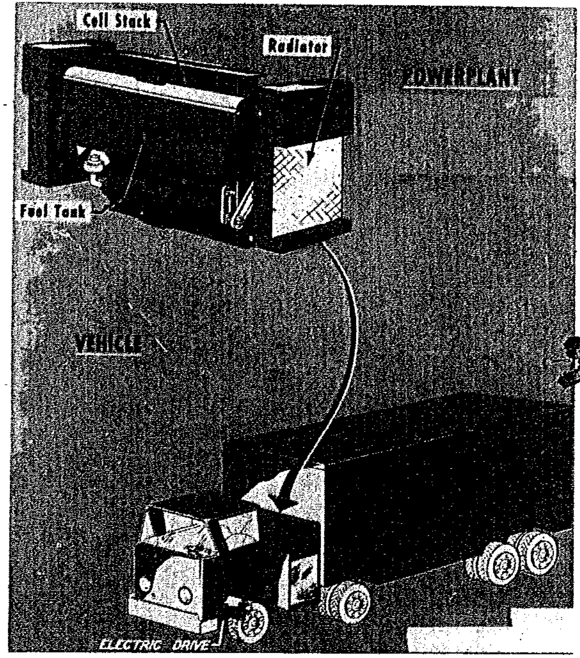

Fig. 4 - Combined cell powerplant

ufacture showed that common earth would not be a good source of supply. Silicon, a potential fuel material, can be found almost everywhere, but it is generally in oxidized forms that are difficult to break down. It would also be extremely difficult to use, because of its great affinity for oxygen.

Oxygen and nitrogen are readily available from air, but they are considered building blocks for fuels rather than fuels themselves.

Fortunately, hydrogen, an excellent fuel material, is readily available from water and was considered to be the key element in any field manufactured fuel.

Table 2 compares some potential energy depot fuels with gasoline. As shown, hydrogen obtained from water in gaseous form is not sufficiently dense to permit reasonable storage volume. In order to reduce volume, it was considered necessary to liquefy the hydrogen before it could be considered practical for vehicle propulsion. In addition, consideration was given to compounding the hydrogen with nitrogen and/or oxygen to increase its storage density. Of the many compounds investigated, the most promising was ammonia which could be prepared by combining hydrogen with nitrogen to form NH_3.

Thus the potential fuels were narrowed to liquid hydrogen and ammonia. In the final analysis, ammonia was selected in preference to liquid hydrogen as the recommended fuel for use in conventional engines. The selection was based on its ease of manufacture, ease of handling and storage, and greater safety in reciprocating engines.

After selection of a fuel, a conceptual design was prepared for an Energy Depot as shown in Fig. 5. This plant basically consists of a mobile ammonia manufacturing plant and an associated mobile nuclear powerplant. The conceptual design was based on a powerplant output of 3000 kwe. In the fuel manufacturing system, one module would be used to extract hydrogen from water by electrolysis. Another module would be used to obtain nitrogen from air by fractionation. The third module would combine the nitrogen and hydrogen under high pressure to produce anhydrous ammonia. The ammonia would be handled and stored in conventional, over-the-highway vehicles as used for com-

Table 1 - Chemical Fuels Source

			Per Cent
Earth			
Normal silicate rocks	- 95%	O_2	49.5
(includes sand)		Si	25.7
Shale	- 4%	Al	7.5
Sandstone Limestone	- 1%	Fe	4.7
		Mg	1.9
		Ca,	3.4
		Na	2.6
		K	2.4
Dry Air			
Gases and vapor traces		N_2	78.0
		O_2	20.9
		A	0.9
		CO_2	0.03
		Inert	
Water			
Salt and fresh water, snow		H_2	11.1
Ice (atmospheric vapor)		O_2	88.9

Table 2 - Comparison of Fuels

Fuel	Heating Value Btu/lb	Specific Density lb/ft^3	Fuel Plus Btu/lb	Container Btu/ft
Gasoline (ref.)	18,700	48.6	17,900	904,400
Hydrogen gas (70 F 2000 psia)	51,593	0.0065	2,220	32,800
Hydrogen liquid (-423 F 15 psia)	49,150	4.44	11,600	179,900
Ammonia liquid (70 F 125 psia)	7,492	42.6	7,340	247,400
Hydrazine liquid (70 F 15 psia)	6,723	62.8	6,450	409,500

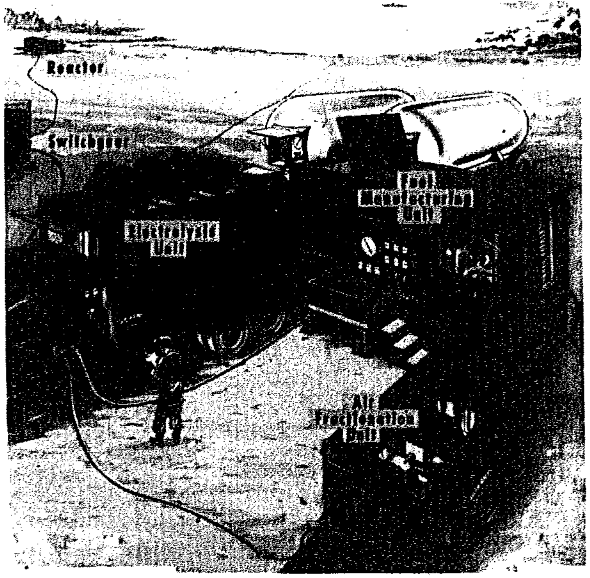

Fig. 5 - Energy Depot - mobile fuel manufacturing plant

mercial distribution of ammonia. This system could be moved by land, sea, or air to any battle zone and started up in a matter of hours.

The air fractionation and ammonia synthesis modules are based on current state-of-the-art equipment. However, the electrolysis unit is required to be an order of magnitude lighter than available commercial units. In order to achieve this objective, Allison has been developing a lightweight, compact unit under Army sponsorship.

The electrolysis unit will be comprised of a group of modules similar to the one shown in Fig. 6. Each module will contain a series of electrodes separated by plastic which also form the containment vessel when bolted together. An aqueous electrolyte will be fed into the unit. When power is supplied to the electrodes, the water in the electrolyte will be dissociated to form hydrogen and oxygen. The oxygen will be vented and the hydrogen will be fed to the ammonia synthesis unit. More than 150 electrodes were evaluated in order to determine the optimum composition for high efficiency and structural integrity. A laboratory prototype unit was fabricated and installed in the test rig shown in Fig. 7. Endurance and performance tests were conducted to evaluate power requirements, fluid flow characteristics, and mechanical design features. Results of the completed tests to date show that the proposed electrolysis unit will better the desired size and weight objectives for the energy depot system.

The next step in the investigation of the manufactured fuel approach was to determine the feasibility of using ammonia in conventional engines. Ammonia was known to have low flammability limits and high ignition energy re-

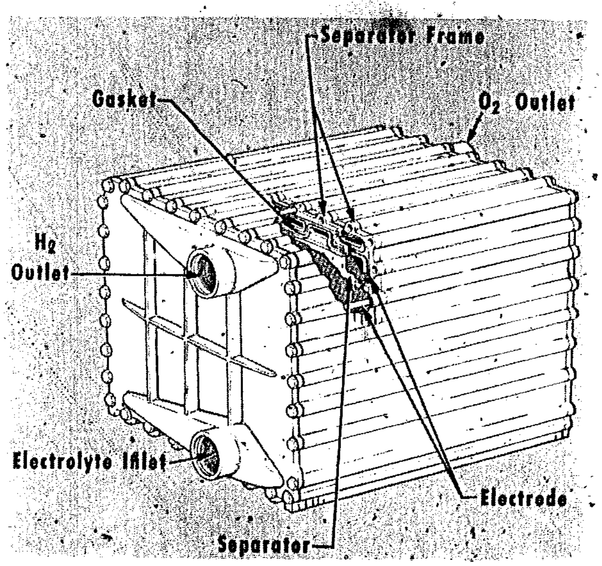

Fig. 6 - Electrolyzer module

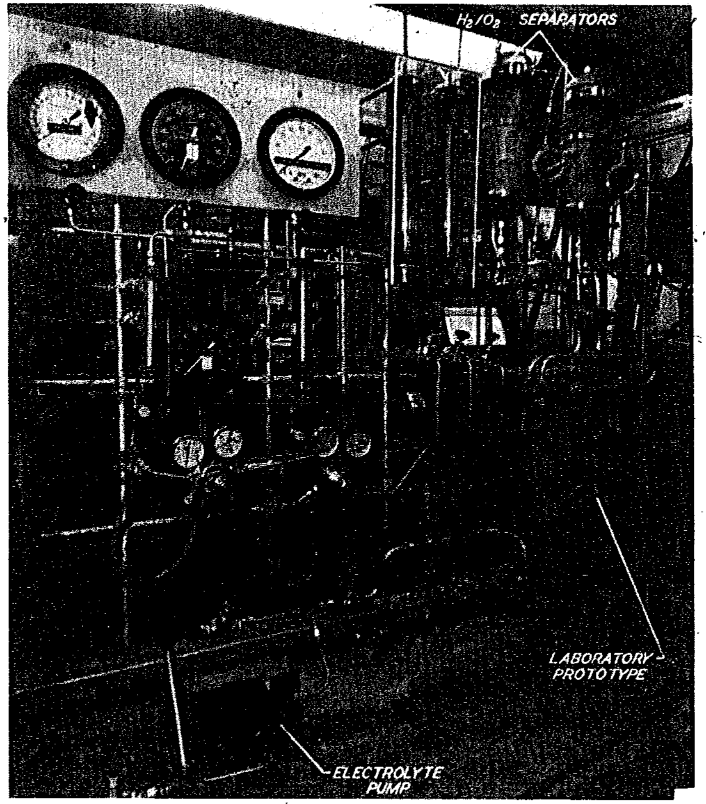

Fig. 7 - Multiple dynamic cell test rig

quirements. Although special engines might be developed to accommodate these characteristics, it was desired that modifications be held to a minimum so that existing engines could be operated on conventional fuel as well as ammonia. An extensive investigation was conducted to determine the feasibility of using ammonia in reciprocating engines. This program is described in an accompanying paper by the General Motors Research Laboratories.

At Allison, a comprehensive analytical and experimental effort was made to define the extent of modifications required for turbine engine operation. Combustion studies were conducted in the test rig shown schematically in Fig. 8. These tests evaluated both liquid and vapor injection of ammonia in a variety of injector and burner configurations. Some typical injectors are shown in Fig. 9. The results indicated that the poor flammability and ignition characteristics of ammonia could be improved by mixing it with hydrogen. The hydrogen would be provided by partially dissociating the ammonia before it is fed to the combustor. Fig. 10 compares the combustion test performance of pure

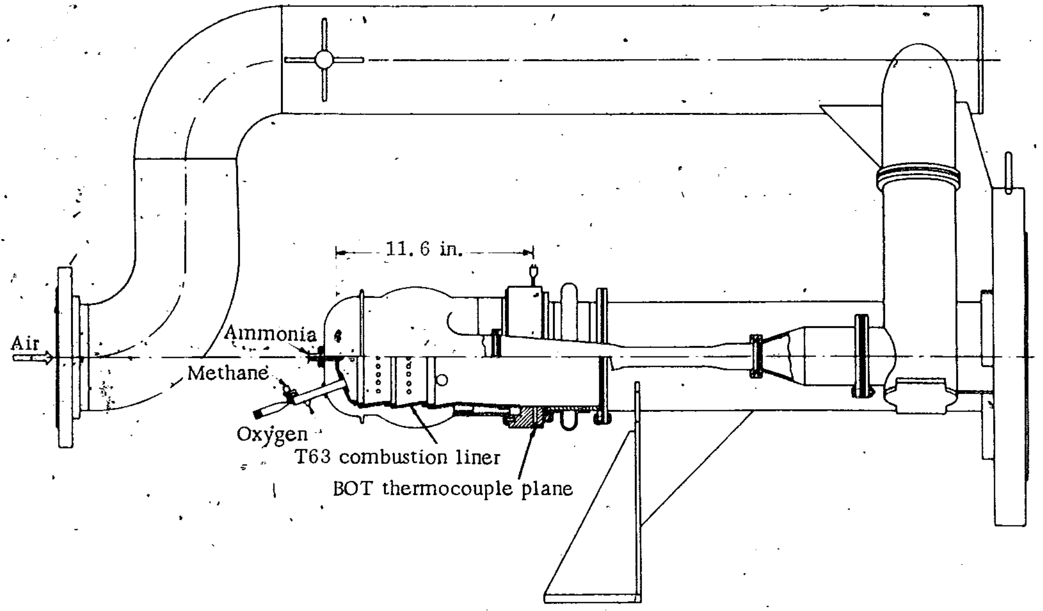

Fig. 8 - T63 combustion test rig schematic

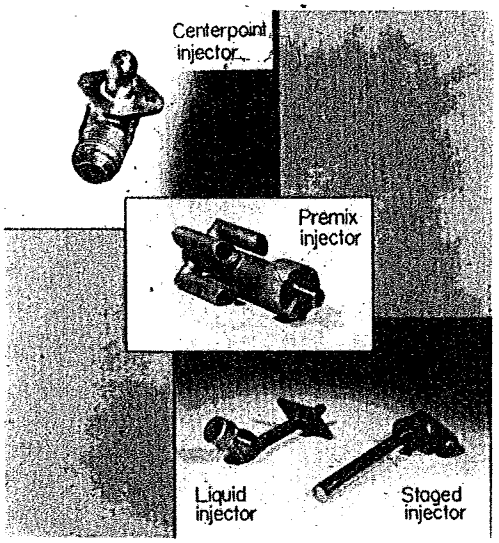

Fig. 9 - Ammonia injector designs

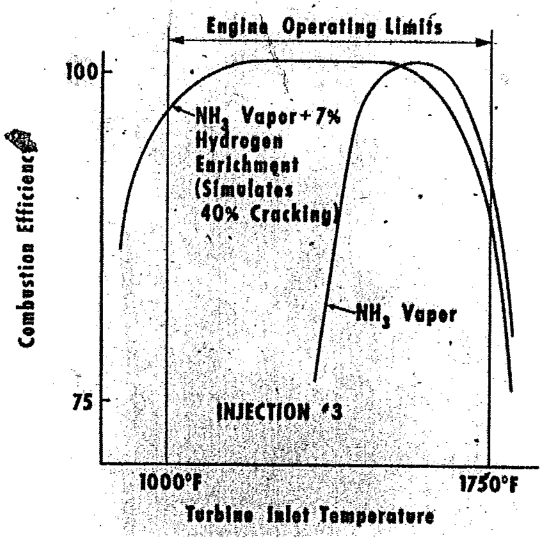

Fig. 10 - Hydrogen enrichment of ammonia vapor