STAT

TRANSLATION

APPLICATION OF ATOMIC ENGINES IN AVIATION

(PRIMENENIYE ATOMNYKH DVIGATELEY v AVIATSII)

By G. N. Nesterenko, A. I. Sobolev, Yu. N. Sushkov

Military Press of the Ministry of Defense of the USSR
Moscow, 1957

STAT

STAT

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

POPULAR SCIENCE

LIBRARY

G.N.Nesterenko, A.I.Sobolev, Yu.N.Sushkov

APPLICATION
OF ATOMIC ENGINES
IN AVIATION

To The Reader:

The Military Press requests that you send your comments on this book to the following address: Management, Military Press, 18 Tverskaya Boulevard, Moscow 104

Nesterenko, Gennadiy Nikolayevich; Sobolev, Anatoliy Ivanovich;
Sushkov, Yuriy Nikolayevich
"Application of Atomic Engines in Aviation"

Editor Ya.M.Kader
Consultants to the Publisher:
Maj.Gen.Prof.Dr.Eng. G.I.Pokrovskiy of the Engineering and Technological Services
Col.Dr.Eng. M.L.Novikov, Engineer
Art Editor: G.V.Grechikho; Cover Artist: B.S.Ivanov
Production Editor: M.A.Strel'nikova; Proofreader: L.K.Tsvetkova

S.K.Timoshenko Printshop No.1
of the Management of the Military Press of the USSR Defense Ministry
3 Skvortsov-Stepanov Lane, Moscow K-6
Price 2 rubles 60 kopeks

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

INTRODUCTION

One of the most outstanding scientific achievements of our day has been the discovery of atomic energy and of practical methods of obtaining and applying it. We have already entered the Atomic Age. Atom, atomic energy, atom bomb, atomic power plant, atomic icebreaker: these are terms and words that may be heard everywhere today.

Atomic energy is having a major influence on the development of science and engineering.

As soon as it became clear that the chain reaction of fission of the uranium nucleus could produce an explosion of enormously destructive force, the imperialists hastened to apply this discovery to military purposes. During World War II the United States of America was able to gather "atomic secrets" from the entire capitalist world, mobilize scientists and engineers and, by the outlay of enormous funds, make the atom bomb.

The ruling circles of the United States marked the beginning of the Atomic Age by the barbaric destruction of the Japanese cities of Hiroshima and Nagasaki, although there was no military necessity for this whatever. The United States frankly made use of the termination of the World War II to proclaim the unprecedented power of the atomic weapon, to threaten the peoples of the world with a "new force", on which the United States seriously believed to have a monopoly. Everyone knows what happened to the "monopoly" of the atomic bomb and later of the hydrogen bomb. The

Soviet Union did not permit itself to be frightened by bombs of whatever kind, but, exercising constant concern for its security, it created its own atomic and thermonuclear weapons.

The Twentieth Congress of the Communist Party of the Soviet Union noted once again that the Soviet people, engaged in peaceful labors, is forced to reckon with the military preparations in the capitalist countries.

In the development of the Soviet Armed Forces we proceed from the conviction that the means and forms of war in the future will differ considerably from all wars of the past. If a war should come in the future, it will be characterized by mass use of military aircraft, a variety of rocket weapons, and various means of mass destruction such as atomic, thermonuclear, chemical, and bacteriological weapons.

However, the various types of the most modern arms, including the means of mass destruction, do not diminish the decisive significance of the ground, air, and naval forces. Without strong ground forces, and without strategic, long-range, and ground-attack aircraft and a powerful navy, it is impossible to wage modern war successfully.

Thanks to the constant concern of the Communist Party and the Soviet government with the defensive capability of our country, the Soviet Armed Forces have been basically reorganized and have advanced far in quality from the level they had attained at the end of the Great Patriotic War. The increasing capabilities of the Soviet economy and the major accomplishments of heavy industry in particular have made it possible to re-equip our army, air force, and navy with first-class military technology.

The share of the Military Air Forces in the total make-up of our Armed Forces has considerably increased. The Soviet Armed Forces are in possession of first-class aviation, and powerful rocket and jet armament of various classes, including long-range rockets.

In view of the continuing progress of science and engineering and the development of new means of destruction and new military technology, it is our duty constantly to perfect our knowledge, to study and master the most desirable methods and forms of the conduct of military operations under conditions in which modern means of armed combat - including the very latest - are employed.

Today's strategic bombers with chemical-fuel engines are capable of nonstop flights of many thousands of kilometers. They are capable of successfully solving military problems at a considerable distance from their bases, in the deep rear of the enemy. However, the range of modern bombers is limited by the amount of fuel that can be stored aboard. In this connection, aircraft with atomic engines, whose range will considerably exceed that of today's aircraft, are of particular interest.

In recent years, work on producing atomically powered aircraft has been done on a large scale in the capitalist countries. The significance ascribed to this work by the government of the United States now and in the past is obvious from an official report to the Congress of the United States on this matter: "In case of war ... atomic aircraft engines will play a role equal to that of the atom bomb itself. The limitations of range imposed by any chemical fuel greatly complicate the aerial delivery of atomic bombs over long distances. Therefore, if the United States possessed atomic aircraft engines in addition to the atom bomb, this would be a decisive factor".

Thus, after the creation of atom and hydrogen bombs, the American imperialists consider the next stage in their program the development of intercontinental bombers and rockets with atomic engines, to be used to deliver bombs of enormous destructive power to any point on the earth's surface.

In order to perform theoretical investigations in the field of atomic engines for aircraft, special plans and research organizations have been developed in the United States and England, and a number of major scientific research laboratories, scientists, and companies have been drawn into this activity.

At the present time more than ten aircraft engine manufacturers are engaged in

STAT STAT

the United States on the production of atomic aircraft engines and reactors: These include such important companies as General Electric, Pratt & Whitney, General Motors, and others. The Lockheed, Convair, Boeing and other aircraft-building firms are engaged in producing a glider for an aircraft, with an atomic power plant.

The overall control of all the work in this field is in the hands of the United States Atomic Energy Commission and the Command of the Air Force.

The Soviet Union has been compelled, in view of the military preparations of the capitalist countries, to develop armed forces capable of repulsing an attack by an aggressor at any time. Our scientists, designers, and engineers have been giving and are giving much effort to the reinforcement of the military strength of our homeland and to the uninterrupted perfection and progress of Soviet military science and engineering.

The Soviet people is moving successfully along the road of building communism in our country. An important step along that road is the fulfillment of the Sixth Five-Year Plan. Much attention is being given, during the Sixth Five-Year Plan, to the peaceful use of atomic energy. In the period from 1956 to 1960, new atomic power plants of large capacity will be built, atomic power plants for transportation purposes will be further developed, and an icebreaker with an atomic engine will be built.

Speaking before the Twentieth Congress of the Communist Party of the Soviet Union, Academician I.V.Kurchatov stated: "The use of atomic energy for transportation purposes has to be further expanded.

"During the present Five-Year Plan, work on atomic power plants not only for an icebreaker, but for other vessels, for air and land transport has to be developed on a large scale ...".

At the present time, science and engineering are on the verge of creating aircraft with atomic engines. The possibilities of such aircraft are being studied, the economic benefits, advantages and disadvantages of atomic aviation of the future

are being investigated, and a broad program of experiments and experimental work is being conducted. An increasing volume of literature, scientific and popular scientific books and articles, deal directly or indirectly with the problems of developing atomic power plants for aircraft and rockets. Extensive theoretical research is being done on the problem of the use of atomic energy for interplanetary flights.

The purpose of the present pamphlet is to systematize the scattered data in the literature on the utilization of atomic power plants in aviation and rocket engineering and to review these data in popular form, accessible to wide groups of readers.

STAT STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

CHAPTER I

PERSPECTIVES FOR THE USE OF ATOMIC ENERGY IN AVIATION

The discovery of atomic energy and, later, the development of practical means of producing and utilizing this energy is one of the most important scientific achievements of today. In order to conceive of the full significance of this remarkable discovery it is enough to remember that throughout all history the question of the sources of energy used for actuating machines has been one of the most important factors tending to either retard or accelerate the development of technology.

Thus, the appearance of the steam engine converting the energy of fuel into mechanical motion resulted in an industrial revolution leading to a development of science and technology without precedent to that day. The invention of internal combustion engines at the end of the Nineteenth Century made possible the creation and development of the automobile industry and aircraft. At the beginning of the Twentieth Century electrical energy began to play an enormous role.

Whenever a new source of energy has come into use, the productive forces of society have made giant strides forward.

At present, we are witnesses to the beginning of a new epoch in the history of human society, that of utilization of the energy locked in the atomic nucleus.

The prime source of all types of energy, and the source of life on earth has hitherto been solar energy. It is known that this energy is the result of nuclear transformations occurring in the enormous mass of the sun. Scientists believe that on the sun there occurs the fusion of hydrogen nuclei to helium nuclei, accompanied

by the release of colossal amounts of atomic nuclear energy. Modern science has begun to obtain and utilize atomic energy under terrestrial conditions, which has opened new possibilities for the development of productive power.

We are on the threshold of a new scientific, engineering and industrial revolution, far exceeding in significance the industrial revolutions that followed the discovery of steam and electricity.

The introduction of atomic energy into industry and transport will proceed by stages governed by the difficulty of the engineering and technical solutions of the problems encountered. The first stage, relatively simple and easy to reach, was the development of atomic power plants. The second stage was the formulation and solution of the problem of development of sea-going vessels with atomic power plants. The third stage is the use of atomic energy in aircraft engines. This problem has proved to be one of the most difficult for technical realization and therefore has not yet found a practical solution. Further serious efforts are required for its solution.

However, history has shown that when a new and more powerful source of energy is found, its practical application wherever it is most needed is something that will of necessity occur in the not-too-distant future. The present-day rapid development of nuclear physics and power engineering, the development of the atomic industry, the experience acquired in theoretical and experimental research on stationary atomic power plants have made it possible for Soviet and foreign scientists, engaged in the development of atomic aircraft power plants, to proceed even today from scientific and purely theoretical research to the engineering calculations and experiments required.

The development of aviation is primarily governed by the development of the aircraft engine industry. The speeds, altitudes, and ranges of aircraft attained are largely dependent upon the perfection of aircraft engines: their power, operational ceiling, economy, reliability in operation, weight, and dimensions. Figure 1

STAT STAT

presents an interesting graph, reflecting the opinions of a number of foreign scientists with regard to the development of aircraft engines. This graph shows that the potential possibilities of development of internal combustion and, later, of turbojet engines (TJE) have already been exhausted to a considerable degree, while the development of turboprop engines (TPE) is now rapidly under way, as is that of liquid-fuel jet engines and ram-jet engines (LJE and RJE). According to this graph,

Fig.1 - Graph of the Development of Aircraft Engines in Conventional Percentages

a) Percentage of potential development attained; b) Internal combustion engines; c) Turbojet engines; d) Turboprop and turbojet engines with after-burners; e) Liquid-fuel and ram-jet engines; f) Atomic engines

1955 may be regarded as the year of the beginning of development of atomic aircraft engines, and they should make their appearance in the very next few years. However, it is true that thus far it is difficult to assert whether the curve of development of atomic aircraft engines will continue as smoothly and sharply upward as indicated by the graph. It is still possible that there will be plateaus and uneven segments, depending on the success or failure of experiments under way, new discoveries, and other attendant factors.

Wherever the problem of the creation of a new type of engine arises, a new

question is posed: in what respect is it better and superior to those we already have at our disposal? Why do we need atomic aircraft engines?

This question may be answered if we examine certain general perspectives of the development of aircraft engineering: primarily the prospective increase in range of aircraft, and questions having to do with the supply of chemical fuels for aircraft.

Range of Aircraft Using Chemical and Nuclear Fuels

The constant effort to increase the range of aircraft and helicopters employing chemical fuel is encountering ever greater difficulties, sometimes insurmountable.

Fig.2 - Ratio of Weight of Aircraft to Range and Flying Speed

a) Weight in tons; b) Aircraft with atomic engines (over 2000 km/hr); c) Flying range in 1000 km

It is particularly difficult to provide adequate range for modern transonic and supersonic aircraft. The increase in speeds is attained primarily by increasing the engine power, and greater power results in greater fuel consumption. It suffices to say that a modern fighter aircraft weighing 6 - 8 tons and flying at supersonic speed, consumes 150 - 200 kg of kerosene per minute. Consequently, in an hour of

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

flight such a fighter aircraft requires 9 - 12 tons of fuel. It is impossible to store this much fuel in a fighter aircraft, and therefore the range and duration of flight of fighter aircraft operating on chemical fuels is difficult to increase.

Designers have long known the relationship between speed and range, on the one hand, and weight of an aircraft on the other. The study of an approximate graph of this relationship (Fig.2) shows that, in the attempt to increase the range at a given flying speed, the designer is compelled to increase the flying weight of the aircraft and the percentage of the fuel weight within the total weight. The heating value of modern chemical fuels such as kerosene and gasoline is 10 - 11,000 kcal/kg. This comparatively low heating value limits the range of aircraft, particularly of rockets, in which it is often necessary to have a large supply of oxidizer in addition to a large reserve of fuel. The overall heating value of rocket fuels (fuel plus oxidizer) is 2000 - 3000 kcal/kg. As a result, long-range aircraft have come increasingly to resemble flying tank cars. This is true of rockets to an even greater degree. We need only note that the total fuel capacity of a modern long-distance bomber is 50 - 100 tons and more. Tens of tons of fuel are required to fuel the latest transport and passenger aircraft equipped with powerful jet engines.

An approximate calculation of the range of supersonic aircraft now in the project stage shows that aircraft weighing up to 100 tons and flying at 2000 - 3000 km/hr will have a maximum range of 3000 - 5000 km. The heaviest aircraft (200 - - 250 tons) flying at these speeds will have ranges of 10,000 - 12,000 km, i.e., their radius of action will be 5000 - 6000 km. The weight of aircraft with atomic power plants, as shown in Fig.2, is relatively independent of the range and flying speed. According to opinions now held, the weight of the first aircraft with atomic engines will be 100 - 150 tons, and these aircraft will be able to fly any required distance over the surface of the earth.

Is it possible to increase the range of aircraft operated on chemical fuel? Yes, this is entirely possible. In recent years, numerous experiments have been

conducted in this field with the object of refueling aircraft in flight.

The idea is not new. As early as 1929, K.E.Tsiolkovskiy suggested that cosmic speeds can be attained by using so-called cosmic rocket trains instead of single rockets. A rocket train consists of a number of rockets each of which, as it becomes exhausted, transfers its residual fuel to the subsequent rocket, is then separated, and returned to earth. As a result, the last "car" of a rocket train, i.e., the final rocket, is enabled to attain cosmic speeds.

Refueling in air, as practiced today, is the application in aviation of the idea of this type of rocket train. The essence of this measure consists in classifying aircraft into groups - primary aircraft and tanker aircraft, which makes it possible to increase the range of the primary aircraft by transferring fuel to it from the tanker in the air at a given distance from the earth. Figure 3 illustrates a simplified variant of air refueling. Let us imagine three aircraft, each of which

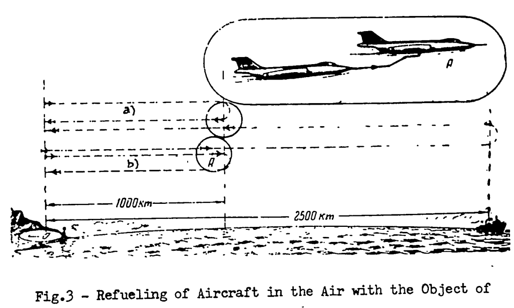

Fig.3 - Refueling of Aircraft in the Air with the Object of Increasing Its Range

a) Refueling rendezvous; b) Refueling pass

has a maximum range, at full tanks, of 3000 km. The first two completely fueled aircraft take off: a primary aircraft and a tanker. Having flown approximately

STAT

one-third of its total range, i.e., about 1000 km, the tanker establishes connection with the other aircraft by a special hose or flying boom and transfers one third of its kerosene to the latter. The tanker then returns to its home base on the remaining third of the fuel, while the primary aircraft, now again fully fueled, is capable of flying another 1500 km forward, accomplishing a military mission and returning to a rendezvous with the other tanker at a distance 1000 km from its home base. Here, tanker No.2, retaining two thirds of its own fuel, transfers one third to the primary aircraft, and the two return to the airfield together. Thus the use of two tankers makes it possible to increase the radius of action of the third aircraft by 60 - 65% under ideal conditions.

In order for aircraft in flight to rendezvous dependably, both in terms of location and time, and in order for the fuel to be transferred in flight, special training and high skill on the part of the air crews is necessary. Therefore, the refueling of aircraft in flight may be classified in the category of necessary half-measures which, in the first place, are exceedingly complicated and expensive and, in the second place, do not provide any significant increase in range. In addition, the refueling of aircraft in the air at supersonic speeds is a practical impossibility. Before being refueled, an aircraft must slow down to subsonic speed and then, in order to return to supersonic speed, it will require almost as much fuel as can be gained by refueling. Increases and decreases in the speed and altitude of supersonic aircraft very sharply reduce their range, since each successive acceleration and climb results in increased fuel consumption.

Considerable increase in range may be attained by aircraft, without refueling, only if nuclear-fuel-engines are used, since nuclear fuel contains approximately two million times as much energy per unit weight as does an equal unit weight of modern aircraft fuels.

The design, i.e., the calculated range of aircraft with atomic power plants is not determined by the fuel supply but by the engine life, i.e., by the number of

hours the engine can operate before wearing out or before failure of its weakest structural parts and also by certain other factors, such as fatigue of the crew, etc. According to certain data from other countries, the range of a single flight of an atomic aircraft is of the order of 90,000 - 100,000 km or more. Moreover, adjustments in the speed and altitude of the aircraft will not greatly effect its range, since the consumption of nuclear fuel under any conditions of flight is rather small.

Calculations show that an aircraft having a flying weight of 120 tons, cruising at 2000 km/hr at constant 20% efficiency, will consume approximately 25 grams of uranium ^{253} per hour. Therefore, a flight round the world (40,000 km in 20 hours) by such an aircraft would require the consumption of no more than 500 - 600 gm of nuclear fuel.

In order to make the same flight with chemical fuel, more than 1000 tons of kerosene, or 20 railway tank carloads would be required. The aircraft would have to make approximately 15 landings for refueling purposes. Due to the consumption of kerosene in flight, the amount of fuel needed per hour will decrease as the aircraft gradually becomes lighter. However, this apparent advantage is completely canceled by the increased fuel consumption for the next following take-off, for gaining altitude and speed after each landing en route.

The attainment of supersonic speeds by heavy aircraft requires exceedingly high thrust and power of the power plants. A power of the order of 150,000 - 200,000 hp and more is required. Designing aircraft engines of such power for use with chemical fuel encounters numerous difficulties. In principle, greater power may be attained more readily in atomic power plants than in conventional aircraft engines.

The prospects for the creation of high-power atomic aircraft engines and particularly the prospects for ensuring any desired range are naturally quite intriguing. However, they are misleading as far as military aircraft is concerned, where such problems as increased speed, altitude, and range will never cease to be important. The possibilities are even more appealing as far as use of such aircraft for peaceful purposes is concerned: passenger and transport aircraft. We will discuss these prospectives in greater detail in examining a number of projects for atomic aircraft; for the time being, we will draw the conclusion that to attain a further sharp increase in range of modern high-speed aircraft, engines operating on nuclear fuel will be required.

Preserving the World Petroleum Reserves

The second important problem compelling the use of atomic energy in aircraft engines is the problem of the excessive depletion of the world petroleum resources and the difficulty of providing an adequate supply of chemical fuels for aviation.

The modern jet engine is one of the most important consumers of the higher fractions of oil refining: kerosene and the best grades of gasoline. The intensified consumption of the world petroleum resources for combustion in transport and power-producing power plants is regarded by science as a matter of necessity and not at all of wisdom. Petroleum is a most valuable organic raw material for various branches of industry: mechanical, paint, and many others, including the food industry. Long ago, the great Russian scientist, D.I.Mendeleyev, spoke of petroleum as being "black gold" and, speaking of the barbaric inroads made on the resources of petroleum, said with deep emotion: "Let us rather burn our stock certificates".

The cost of producing, refining, and transporting petroleum, and the cost of aviation fuels derived from it, is comparatively high. In addition, the world resources of petroleum are not inexhaustable. Statistics show that at the present level of consumption of petroleum, the world reserves may be exhausted within 185 years. If we take into consideration the uninterrupted growth in the total capacity of power plants operated on chemical fuels, calculations show that the depletion of oil reserves will be felt within 25 - 50 years.

This type of calculation cannot, of course, claim to be completely correct and

accurate, since depth prospecting for oil is revealing new oil deposits, but the figures demonstrate nonetheless that the world reserves of petroleum are very definitely limited. If conversion of aviation from chemical to nuclear fuels is successful, the petroleum reserves will not be depleted as intensively: more petroleum will be freed for satisfying other pressing needs of the national economy.

The above facts raise the question of world resources of nuclear fuels, the cost of nuclear fuel, its capacity as a source of energy, and so forth.

Let us deal with these questions and attempt to analyze them. It need only be borne in mind that the process of discovery and assaying of the world resources of nuclear fuel and of its possibilities in terms of power generation is far from being complete. The dynamics of this process will become clear from a study of the relatively short but very exciting history of the discovery of the various sources of atomic nuclear fuel.

Two Major Methods of Obtaining Nuclear Energy

Despite the fact that the past several years have been marked by a rapid development of atomic power production, science does not have sufficiently complete data on the nature of the forces acting in the nucleus of the atom.

The single fact that the nature of nuclear force is not clearly understood or fully studied is no obstacle for the practical utilization of nuclear energy. The British physicist, O.Heaviside, once said, "Am I going to refrain from eating dinner just because I do not completely understand the process of digestion?" However, in order to understand the methods of obtaining atomic energy it is necessary to review briefly the properties of the atomic nucleus and atomic energy.

The atomic nucleus consists, as we know, of protons and neutrons which together are called nucleons. Nucleons are retained in the nucleus by special nuclear forces of attraction that keep them in fixed positions relative to one another. These forces are complex in nature. At present, all that has been firmly established is that nuclear forces are neither gravitational or electromagnetic. It is also known that nuclear forces are "short-range" forces and exist only in the nucleus itself. It is rather easy for us to conceive of the manner in which the molecules of liquid constituting a drop of liquid are mutually attracted. The forces within the nucleus are externally similar to the forces of molecular attraction in liquids. At the surface of the nucleus they create an effect similar to the surface tension in a liquid. This leads to the development in the nucleus of a kind of "surface tension" which gives the nucleus its spherical form. The nucleus is like a drop of positively charged liquid. But the forces of molecular attraction are tens of millions of times smaller than the forces of nuclear energy. Therefore, a comparison of the atomic nucleus with a drop of liquid is only a very crude approximation.

Now let us examine the energetics of nuclei and nuclear forces. Not possessing adequate information as to the nature of nuclear forces, modern science is nevertheless able to determine the nuclear binding energy, depending on the existence of these forces.

The nuclear binding energy – the energy which must be expended to perform the work of dissociating the nucleus into its component nucleons – has to overcome the action of nuclear forces.

In the reverse process, in the formation (fusion) of a nucleus from nucleons, a similar energy is released. Thus, the binding energy may be defined as the energy which is released in the formation of the nucleus from nucleons.

The unit most widely employed in nuclear physics is the electron-volt (ev). We will have to refer to this unit of energy repeatedly so that it is useful to familiarize ourselves with it. One electron-volt is equal to the energy acquired by a particle whose electric charge is equal to the charge on an electron as it passes through an electric field having a potential difference of one volt. In practice, larger units are employed more frequently. These units are derivatives of the electron-volt: 1000 electron volts (the kiloelectron-volt or Kev) and 1,000,000

electron-volts (the mega-electron-volt or Mev).

The binding energy possessed by a single nucleon is not identical for nuclei differing in atomic weight (Fig.4). The greatest binding energy possessed by a single nucleon is found in nuclei whose atomic weights range from 40 to 80. This is the atomic weight of the nuclei of iron, nickel, krypton, and certain other ele-

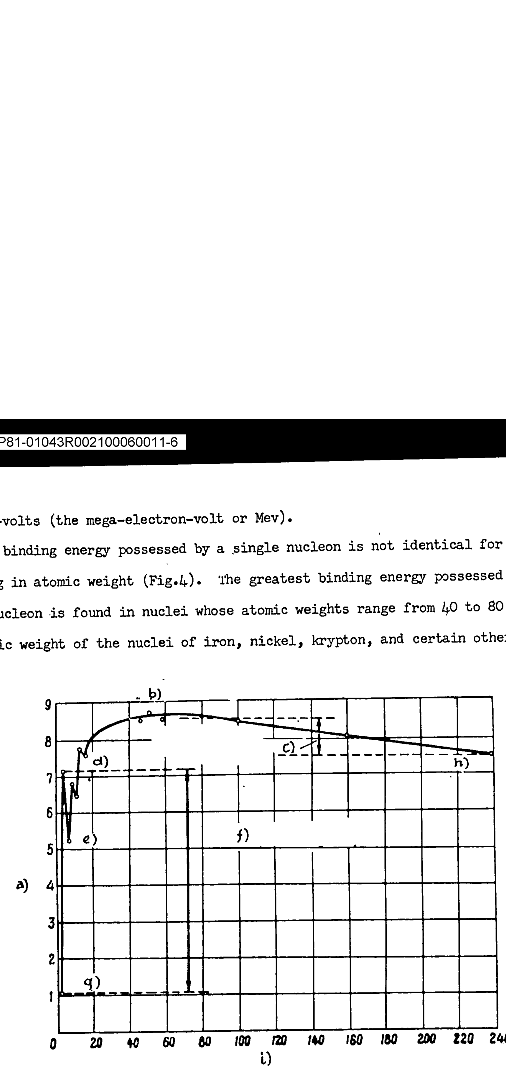

Fig.4 – Ratio of Energy per Particle in the Nucleus to the Atomic Weight
a) Binding energy per nucleon, in Mev; b) Fission "fragments"; c) Energy released in the fission of the uranium nucleus per nucleon; d) Helium; e) Lithium; f) Energy of nuclear fusion of helium from hydrogen per nucleon; g) Hydrogen; h) Uranium; i) Atomic weight

ments. The binding energy per nucleon of heavy hydrogen is approximately 1,000,000 electron-volts (one Mev). As the atomic weight increases, the binding energy per nucleon rises rapidly in the light elements to a maximum (about 8.75 Mev) in the elements having an atomic weight of about 60 (iron and nickel), and then

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

gradually declines to a value of the order of 7.5 Mev in the elements at the end of Mendeleyev's periodic table.

As shown by the graph (Fig.4) the binding energy per particle increases as it moves along the curve to the center from both sides, i.e., from the lighter and from the heaviest elements. The result is that there will be two basic types of nuclear transmutation (reactions), proceeding with the liberation of energy: the reaction of fusion of the nuclei of light elements taking the form of what is known as thermonuclear reactions, and the reaction of fission of heavy nuclei into nuclei of medium weight - the reaction of fission.

The energy released per unit weight of the initial product in thermonuclear reactions of the light elements is several times larger than that in the fission of nuclei of heavy elements. At present, it is fission reactions that man has learned to control. Control of thermonuclear reactions such as to permit their practical application has not yet been attained and is a matter for the future. Therefore, we will mainly discuss here fission reactions which dissociate various materials, their resources, and their power potentialities.

The major fissionable material (nuclear fuel) at present is uranium. Let us describe the basic properties of uranium that make it possible to use it as a "fuel" for transport power plants.

Uranium is a bright metal, softer than steel, with a specific gravity of 18.95, and can be worked by any mechanical method. A specific feature of uranium is its high susceptibility to oxidation. At a temperature as low as 100°C, uranium is capable of combustion and rapidly burns in an oxygen atmosphere. In an ordinary chemical reaction, the heat value of uranium is very low and does not exceed 1075 cal/kg. The fusing point of uranium in an inert medium is 1130°C. This comparatively low fusing point and the structural transformations occurring in uranium at various temperatures have caused considerable difficulty in designing high-temperature reactors for power plants for use in transport.

The fission reaction of the nucleus of uranium^{235}, shown in rough outline in Fig.5, takes place as follows: A free neutron penetrating the nucleus brings it into a state of excitation. This destroys the equilibrium of the nucleus, causing

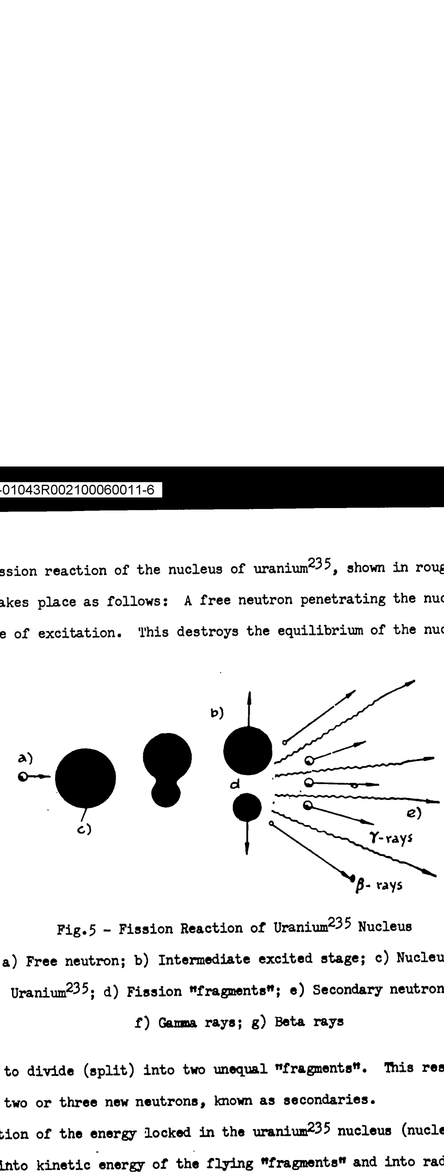

Fig.5 - Fission Reaction of Uranium^{235} Nucleus

a) Free neutron; b) Intermediate excited stage; c) Nucleus of Uranium^{235}; d) Fission "fragments"; e) Secondary neutrons; f) Gamma rays; g) Beta rays

it usually to divide (split) into two unequal "fragments". This results in an expulsion of two or three new neutrons, known as secondaries.

A portion of the energy locked in the uranium^{235} nucleus (nuclear energy) is converted into kinetic energy of the flying "fragments" and into radiant energy of various types. The Table given below provides an approximate picture of the energy balance of a nuclear fission reaction.

Thus the bulk of the energy, comprising approximately 166 Mev per fission, is that of the "fragments". The "fragments" fly off in various directions at tremendous speeds, collide with surrounding nuclei and, increasing the speed of their chaotic thermal motion, heat the medium in which the process of nuclear fission is taking place. Conversion of the kinetic energy of the "fragments" (at nuclear fission of 1 kg uranium^{235}) into units of heat energy produces approximately 17.4 bil-

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

lion kcal and the total energy release from the fission of one kilogram uranium^{235} is 19.7 kcal. Complete combustion of one kilogram of chemical aviation fuel (kerosene) yields only 10,300 kcal.

The tremendous difference in the quantities of thermal energy derived from nuclear and chemical reactions, respectively, is due to the fact that, in the ordinary combustion reaction, changes occur only in the electron shells of the atoms; no structural changes occur within the atomic nucleus. In nuclear reactions, a change (rearrangement) occurs in the nuclei themselves. Since the mass of a nucleus exceeds by thousands of times the mass of the electron shell of the atom of any element, the energy released in nuclear reactions is therefore greater. As early as 1905, the German physicist Einstein formulated a law that defined the quantitative mass-energy interrelation in nature. This law is expressed by the familiar equation

Table 1

Distribution of Energy of Fission of Uranium^{235} Nucleus

1. Kinetic energy of "fragments"	83%	166 Mev
2. Kinetic energy of secondary neutrons	3%	6 Mev
3. Total energy of direct gamma radiation	5%	10 Mev
4. Total energy of radioactive radiation of "fragments"	9%	18 Mev
	100%	200 Mev

$$E = mc^2,$$

in which E is the total energy of a body, in ergs;

m is the mass of the body, in grams;

c is the velocity of light, in cm/sec.

In accordance with this law, every change in the energy of a body involves a corresponding change in its mass, and vice versa.

In ordinary chemical combustion reactions, it is a practical impossibility to observe changes in the mass of the reacting substances. This is explained by the fact that the amount of energy being released is relatively small, and therefore the change in mass is negligible. For example, complete combustion of 100 tons of kerosene in an oxidation reaction involves the participation of approximately 1500 tons of air, and the total change in the mass of the combustion products due to the liberation of energy is only 0.03 grams. Naturally, to detect such a quantity in the total mass of reacting products (1600 tons) is impossible. However, the law of the mass-energy interrelation is demonstrated most strikingly in nuclear reactions, which are characterized by considerable changes in the energy of the nuclei and by a noticeable change in mass.

The law of the mass-energy interrelation is the basis of one of the methods of determining the "heating value" of nuclear fuel, and yields accurate quantitative results.

From the equation, $E = mc^2$, it follows that, for m = 1 kg, the theoretical value of the energy E (in thermal units) will be 21,600 billion kcal.

In the splitting (fission) reaction of nuclear fuel, the mass of the end products of fission is smaller than the mass of the initial substance by a definite magnitude, which may be called the mass defect (loss). Experimental and mathematical data have established that, for uranium^{235}, the mass defect per kilogram of substance is

$$\Delta m = 0{,}000914 \approx 0{,}001 \ Kg.$$

Thus, when all the nuclei in 1 kg of uranium^{235} have undergone fission, the mass of the end products of the nuclear reaction is almost one whole gram less than the mass of the initial substance before fission.

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

The amounts of energy released may thus be determined on the basis of the quantity of mass liberated (according to the mass defect). Since the total energy of 1 kg of the substance, as indicated above, is 21,600 billion kcal, the energy released in this case will be

$$Q = 21600 \cdot 0{,}000914 = 19{,}7 \text{ billion kcal}$$

This number is the heating value of uranium^{235}, i.e., the amount of energy released when all the nuclei in one kilogram of uranium have undergone fission.

It should be mentioned that the complete combustion of 1 kg kerosene liberates a total of 10,300 kcal, or approximately only $\frac{1}{2{,}000{,}000}$ as much.

A comparison of the heating value of nuclear fuel with that of modern chemical aviation fuels leads to the conclusion that the consumption of nuclear fuel will be a fraction of that of chemical fuel, for the same effective power of power plants. This fact offers the possibility of a considerable increase in the range of aircraft and rockets when using nuclear fuel.

Comparison of the World Resources of Chemical and Nuclear Fuels

On the basis of data published in the press, the prospected resources of chemical fuels and nuclear fissionable materials are approximately as follows:

Coal	2000 billion tons
Oil	25 billion tons
Uranium	0.01 billion tons

As we see, there is considerably less uranium in the earth than coal and petroleum. Nevertheless, despite this apparently unfavorable relationship in terms of weight, the margin of energy in uranium is approximately ten times greater than the margin of energy in coal and oil combined.

In order to get an idea on the distribution of uranium in nature, let us examine the content by weight (in percent) of certain metals in the earth's crust.

Copper	0.010% (100 gm/ton of earth)
Uranium	0.007% (70 gm/ton of earth)
Zinc	0.004%
Lead	0.002%
Gold	0.0000001%

It will be seen from these data that uranium is an element more widely distributed in nature than zinc, lead, and gold combined.

Natural native uranium is obtained from ores and is a mixture of three isotopes: uranium^{238} (99.282%), uranium 235 (0.712%), uranium^{234} (0.006%).

Only uranium^{235} is available as a fissionable material satisfying the requirements of power production. Uranium^{235} is capable of self-sustaining (chain) nuclear reaction, i.e., of effectuating an uninterrupted release of energy. But the very small content of the 235-isotope renders natural uranium unacceptable for use in power plants for purposes of transportation. It is necessary either to separate the uranium^{235} in its pure form or to enrich natural uranium with this isotope.

The process of separating the isotopes of uranium is to this day one of the most expensive and complex processes in the atomic industry. The problem of widespread use of nuclear fuel for power production would be hopelessly insoluble, because of the small amount of natural uranium^{235} and the difficulties of obtaining it in pure form, if there had not been discovered methods of obtaining artificial nuclear fuels from the natural resources of uranium^{238} and thorium^{232}.

Artificial nuclear fuels now available include the following: plutonium^{239} (obtained in special breeder reactors from uranium^{238}), uranium^{233} (obtained in reactors from natural thorium^{232}) and certain others.

In view of the fact that methods have been obtained for the application of artificial nuclear fuels, permitting the use of uranium^{238} and thorium^{232}, calcula-

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

tions of the energy resources in nuclear fuels have been made on the basis of natural uranium and thorium (see Table 2).

This Table shows that the total margin of energy in nuclear fuels is approximately 22 times as great as the total energy resources in all organic fuels combined.

Table 2

World Resources of Energy in Various Types of Fuel

Type of Fuel	World Supply	Energy Content
Coal	3,482 billion tons	21.10×10^6 billion kw-hrs
Oil	197 billion m^3	2.22×10^6 billion kw-hrs
Natural gas	15,850 billion m^3	0.17×10^6 billion kw-hrs
Uranium + thorium	0.026 billion tons	519.00×10^6 billion kw-hrs

In addition, there is reason to expect a considerable increase in the sources of nuclear fuels as a result of the discovery of new methods of fission and fusion of the nuclei of other chemical elements. At present, science has already discovered the possibility of experimental work toward controlled thermonuclear reactions with the light elements. A controlled thermonuclear reaction makes it possible to obtain energy due to the formation of helium from heavy hydrogen (deuterium) which is widely disseminated in nature. Every ton of ordinary water in nature contains as much as 200 gm of heavy water, whose molecules contain atoms of heavy hydrogen. The conditions needed for fusion of hydrogen into helium have thus far been created only in the hydrogen bomb. Scientists are working to produce the conditions for a decelerated controllable course of thermonuclear reaction without explosion, so as to learn to control this reaction and use it for purposes of power generation. The solution of this most difficult and challenging task will increase the resources of energy at the disposal of man by hundreds of thousands of times.

The cost of nuclear fuel is still high but is decreasing gradually from year to year. Today, it is only in rare cases that nuclear fuel is cheaper and more desirable to use than chemical fuel, but as nuclear power generation and the atomic industry develop further, the cost of nuclear fuel will become considerably lower than that of chemical fuels.

The wide utilization of atomic energy in industry, transport, and all branches of the national economy is one of the most difficult, but at the same time most lofty and noteworthy undertaking of contemporary science and technology.

First Conception of Atomic Aircraft Engines

The first thoughts as to the possibility of wide-scale use of atomic energy begin to appear even before the discovery of nuclear fission chain reaction. For example, as early as January 1935, the journal "Tekhnika Molodezhi" (Technics for Youth) carried an article by O.Petrovskiy, which examined the problem of using atomic energy in the national economy, this being the energy obtained by fusion of helium nuclei from hydrogen nuclei.

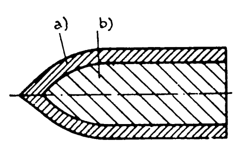

Fig.6 - Schematic Layout of a Hypothetical Nuclear Ram-Jet Engine
a) Reflector; b) Nuclear fuel

The practical introduction of atomic energy into the national economy was begun by the Soviet Union where the world's first atomic electric power plant was erected which has been working successfully since the summer of 1954. Then the question was posed, and has since been successfully solved, of developing atomic power plants for sea-going surface and submarine vessels. In the Soviet Union, a powerful atomic ice-breaker is under construction, and in the United States the first submarines with atomic engines have been tested.

The problem of using atomic energy in aircraft engines has proved to be one of the most difficult to realize from the point of view of engineering. This problem is complex primarily because of the fact that an aircraft presents exceedingly rigid specifications with respect to engine weight, engine power, and absolute reliability in operation. Let us evaluate the probable future trend in the application of atomic energy to aircraft engines.

At first glance, it would seem that the simplest atomic aircraft engine would be one making use of the direct reaction of "fragments" resulting from the fission of heavy nuclei. Such an engine would simply be a lump of atomic fuel, encased in a container which reflects neutrons (Fig.6). The fission products of the nuclear fuel in this case would move only in the one open direction, thus creating thrust due to reactive forces. This simple design of an atomic rocket entine comprises fundamental contradictions, which necessarily render it unrealizable. Only a very thin surface layer is capable of radiating decomposition products into space. The fission reaction has to take place throughout the entire mass of fuel, and heat will be liberated throughout this entire volume. This creates instantaneous heating, melts the nuclear fuel, and converts it into vapor. In other words, this hypothetical engine would necessarily explode instantaneously. It is impossible to conduct a chain reaction only in the thin surface layer.

Is it conceivable to convert atomic energy directly into electric power and then make use of electric motors rotated by propellers?

Direct conversion of atomic energy into electricity is possible with the aid of an atomic electric generator or atomic battery. This battery or cell (Fig.7) is arranged as follows:

A spherical metal shell constituting an electrode of the atomic cell contains a second spherical electrode, coated with a thin layer of radioactive substance which emits beta particles. The air is exhausted from such a device. The internal electrode emitting beta particles of negative electric charge, is given a positive charge. The outer shell, on which the beta particles collect, is given a negative

charge.

Such an atomic battery would be able to yield high-voltage currents, but the current strength would be very small. This is due to the fact that the charge is transmitted to the outer shell only by the beta particles emitted by a thin surface layer of radioactive substance.

An atomic electric cell might also be built on the basis of utilizing artificial radioactive isotopes in combination with certain semiconductors. However, such "batteries" would also be so weak in power as to make their use for feeding of electric motors impossible.

Fig.7 - Diagram of "Atomic Electric Generator" (Battery)
a) Nuclear fuel; b) Evacuated space; c) Shell; d) Insulator

Thus, direct conversion of atomic energy into electric energy cannot be employed today in power plants.

The reaction of the fission of heavy nuclei is accompanied, as we know, by the liberation of large amounts of heat. The question arises as to whether atomic energy cannot be utilized in a heat engine of some kind?

Let us take, for example, an internal combustion engine and instead of the fuel mixture let us charge a gaseous nuclear fuel of some kind into a cylinder. The engine must be so designed that, during the compression process, the density of the gaseous nuclear fuel is greatly increased and a nuclear chain reaction sets in. During the nuclear reaction, the emitted heat would be many times greater than that obtainable by the combustion of gasoline, so that such an engine would be much more powerful. However, an engine of this type is unrealizable since, in order for nuclear fuel to undergo a chain reaction in the gaseous form, even when compressed, an engine of colossal dimensions would be required.

Perhaps then solid nuclear fuel might be used in a two-cycle engine? To do this, a lump of nuclear fuel would be placed in the cylinder head, and another on the piston. When the piston reaches top dead center, the two lumps would approach so closely that a nuclear reaction would be initiated. The heat liberated would heat the air in the cylinder, thus starting the power stroke of the piston. In actuality, however, such an engine would explode the moment it is started. In fact, the atom bomb is designed in exactly this manner. Two pieces of the charge of $uranium^{235}$ are brought together, with the result that a charge of $uranium^{235}$ having greater-than-critical mass is produced, and a chain nuclear fission reaction results, causing an explosion.

Many similar fantastic schemes could be listed. Nevertheless we were justified in centering attention on heat engines, in view of the fact that more than 80% of the energy in the fission reaction is liberated in the form of heat.

Let us recall what an ordinary power plant for transport purposes comprises. Such a plant includes, as we know, an engine, a transmission, and a propulsive device. Within the engine, liberation of heat energy from the fuel and its conversion into mechanical energy takes place. These two processes may occur in a single system, as in an internal combustion engine, or in separate units as in a steam engine. The propulsive unit is the device that does the work of thrust created by the mechanical energy received from the engine. The wheels are the propulsive unit of an automobile; the propeller serves that function in an aircraft. The transmission transmits the energy from the engine to the propulsive device.

These three basic parts must by necessity be present also in an atomic power plant (Fig.8). Here the emission of heat occurs in a nuclear reactor as a result of the "combustion" of nuclear fuel as the nuclei undergo fission. In order to dissipate the heat from the reactor, it is honeycombed with channels through which a heat-transfer agent is propelled by pump. The heat-transfer agent may be either

fused metals of low melting point, gases (helium, nitrogen, carbon dioxide) or else ordinary or heavy water under high pressure. The heat-transfer agent, heated in the reactor as it passes through the heat exchanger, yields part of its heat energy to the substance actuating the engine and is returned to the reactor by a pump. Thus,

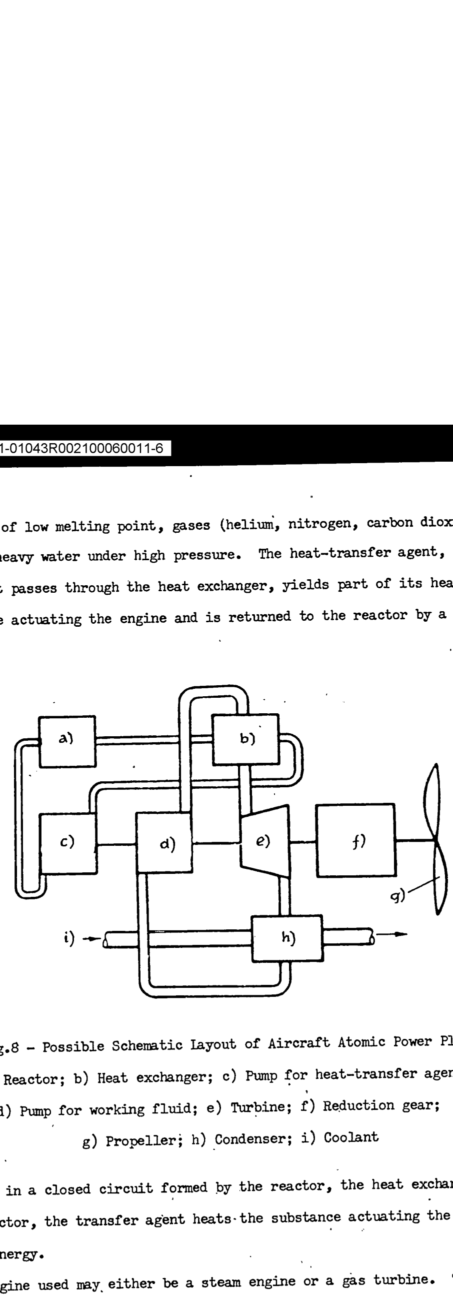

Fig.8 – Possible Schematic Layout of Aircraft Atomic Power Plant

a) Reactor; b) Heat exchanger; c) Pump for heat-transfer agent; d) Pump for working fluid; e) Turbine; f) Reduction gear; g) Propeller; h) Condenser; i) Coolant

circulating in a closed circuit formed by the reactor, the heat exchanger, the pump and the reactor, the transfer agent heats the substance actuating the engine, by way of atomic energy.

The engine used may either be a steam engine or a gas turbine. The actuating substance may be either water, mercury vapor, hydrogen, or helium, for example. Circulation of the actuating substance is by a pump, driven by the main or by an auxiliary turbine. For operation of the turbine, the exhausted steam must be discharged into a condenser. In the condenser the steam is condensed into liquid and is recycled to the heat exchanger by the pump. The coolant medium on ship installations may be water of the surrounding medium, while in aircraft it may be the relative airflow. A condenser is necessary also if the working substance is a gas. Thus, we get the following circulating pattern for the working substance: heat exchanger - - turbine - condenser - pump - heat exchanger.

The turbine is connected to the driver by a transmission. In aircraft power plants mechanical transmissions are generally used. Shipboard power plants use electric transmissions, in which a number of electric motors connected to propellers are fed from a single powerful generator.

Aviation is the area in which atomic power plants may have broadest application. In addition to the above designs in which the turbine shaft is connected to a propeller over a reduction gear, the various types of aircraft engines in use today may be adapted for operation on atomic energy.

The reactor is a component of all atomic power plants. Many designs include heat exchangers. An examination of these vital components of atomic power plants is the subject of the next Chapter.

CHAPTER II

NUCLEAR REACTORS FOR AIRCRAFT POWER PLANTS

A nuclear reactor is a device within which a controllable chain reaction involving the fission of nuclei of fuel, accompanied by the conversion of atomic into thermal energy, takes place. The rapid progress in nuclear engineering and reactor design in recent years has led to the result that today nuclear reactors are being built successfully not only for stationary power plants, but for power plants of ships of various types. The first success in the design of nuclear reactors for aircraft power plants, no doubt, is imminent. According to reports in the foreign press, nuclear reactors for atomic aircraft engines, to reach flying speeds of the order of 900 km/hr for heavy aircraft, are already being ground-tested and flight-tested on experimental aircraft.

Main Features of Aircraft Nuclear Reactors and Their Specifications

To make it possible for an atomic aircraft to fly at high speed, an aircraft nuclear reactor must develop extremely high power. The power of a nuclear reactor, like that of any source of thermal energy, is measured by the amount of heat liberated in unit time. For example, if 1 kcal of heat is liberated per second of operation of a reactor, the power of the reactor will be 1 kcal/sec, or 3600 kcal/hr. In today's literature, the heating value of nuclear reactors is most frequently given in kilowatts (1 kw is equal to 860 kcal/hr).

Let us cite an example indicating the power requirement of an aircraft reactor.

Let us assume that an atomic aircraft weighs 150 tons and has a very advanced aerodynamic form. Calculations show that, to enable this aircraft to fly at the speed of sound at an altitude of 11 km, the nuclear reactor must have a power of about 300,000 kw. This is ten times as high as the power of the nuclear reactor in the first Soviet power plant, and approximately twice as large as the reactor of the Soviet atomic ice-breaker. In order for the atomic aircraft to fly at an altitude of 11 km, at 1.5 times the speed of sound, the power of its reactor would have to be approximately 900,000 kw.

The high power of an aircraft nuclear reactor has to be obtained within the smallest possible dimensions. If its dimensions are large, it will be difficult to house the reactor within the aircraft, especially if the aircraft is to remain fully streamlined. In addition, the larger the dimensions of the reactor, the greater will be the weight of the casings and shields needed to protect the crew and passengers of an atomic aircraft from the effects of the harmful radiations from the reactor. The exceedingly great weight of the radiation-shielding system is today one of the main obstacles to the design of an atomic aircraft useful for military and civil purposes.

The nuclear reactor for an aircraft power plant must weigh as little as possible. This requirement is particularly important for an atomic aircraft and is again based on the exceedingly great weight of the "dead" load - the radiation-shielding system.

An aircraft nuclear reactor must be a high-temperature reactor. The higher the temperature in the reactor, the smaller can be its size and weight and the smaller will be the size and weight required to yield a given power. An increase in the temperature results in an increase in efficiency of atomic engines of any type. This is very important, since the greater the efficiency, the less must be the power of the reactor in order to yield the required engine power. If it is borne in mind that the entire system of radiation shielding is dependent upon the

dimensions and size of the reactor, the major importance of achieving high temperatures will become obvious. Approximate calculations show that, in order to obtain the same flight characteristics for atomic aircraft as for chemical-fuel aircraft now in series production, the reactor surfaces must be heated to not less than 1000°C.

A nuclear reactor for aircraft must be highly reliable in operation. The requirement of reliability in an aircraft reactor for the desired term of service life is considerably stricter than for reactors in fixed positions. Unlike stationary reactors, the aircraft reactor must function normally no matter what its position in space. The functioning of the reactor must not be affected by inertia loads developing on changes in speed or direction of the aircraft.

General Design of a Nuclear Reactor and its Main Processes

The major processes in a nuclear reactor comprise a controllable fission chain reaction and dissipation of the heat generated by this reaction. The portion of the nuclear reactor in which the fission reaction occurs is called the active section or core. As a rule, the core contains the following materials: nuclear fuel, the moderator, the heat-transfer agent, material of the control or regulator devices, structural materials, i.e., materials needed to reinforce and fix the various design elements in their mutually correct position, to seal the heat-transfer ducts, to protect the nuclear fuel from oxidation, etc. The core is usually surrounded by a layer of substance that reflects neutrons.

Figure 9 shows one of the possible principal layouts of a nuclear reactor. Nuclear fuel, in the form of cylindrical rods contained in protective metal casings, is placed in grooves within the solid moderator. The generated heat is dissipated by a liquid heat-transfer agent, whose flow is shown by arrows in the diagram. Control of the nuclear fission reaction is by means of a control rod made of a material that is a good neutron absorber. The core of the reactor is shown by the broken

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

line in the drawing. The reaction of fission of heavy nuclei and all the attendent phenomena, such as liberation of heat, escape of secondary neutrons, etc., have been

Fig.9 - Principal Schematic Layout of a Nuclear Reactor

a) Outer shell of reactor; b) Control or regulating rod; c) Retainer plate; d) Side reflector; e) Moderator; f) Protective shells; g) Hold-down rod; h) Rod of nuclear fuel

described in the preceding Chapter. Here we will deal with other processes in which neutrons participate.

Let us first examine the processes leading to variations in the kinetic energy of neutrons, i.e., the energy with which they move. The collision of neutrons with atomic nuclei of various materials, including nuclei of fuel, is not always accompanied by neutron capture. Often, the neutrons bounce off the nuclei, transferring to them a certain portion of their kinetic energy. As a result, the speed

of the neutrons decreases and, in addition, a change in the direction of motion takes place. This process has come to be called neutron scattering. The process of

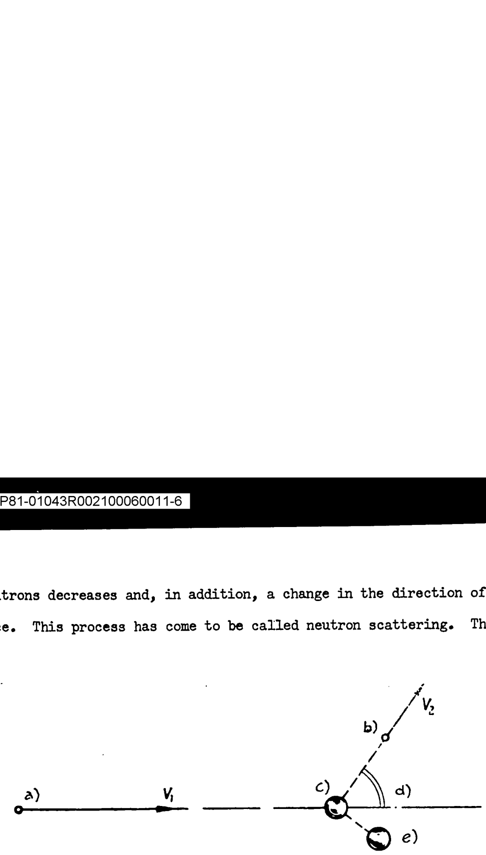

Fig.10 - Schematic Sketch of Neutron Scattering

a) Neutron before scattering; b) Neutron after scattering; c) Nucleus before scattering; d) Scattering angle; e) Nucleus after sc.

scattering is shown in schematic form in Fig.10. Here, V_1 is the speed of the neutron before collision with the nucleus, and V_2 is its speed after collision. At identical scattering angles, the magnitude of the kinetic energy released by the neutron depends upon the mass of the nucleus. The magnitude of the energy transmitted reaches a maximum when the mass of the neutron and the nucleus is identical. A case of this type may occur, for example, when a neutron collides with a hydrogen nucleus. Scattering, characterized by a considerable reduction in the energy of the neutron at each collision with the nucleus, is known as deceleration or moderation. The moderation of neutrons is a nuclear process artificially induced whenever a rapid reduction in neutron energy is required.

The secondary neutrons escaping on nuclear fission, possess a very high kinetic energy at their moment of "birth". The energy of the absolute majority of secondary neutrons lies within a range of 1 - 2 Mev corresponding to a speed of 14,000 - 20,000 km/sec. Neutrons of this velocity are called fast neutrons. In the course of the scattering process, particularly in the process of deceleration, the kinetic energy of neutrons may decline to a level corresponding to the energy of thermal motion of the particles in the surrounding medium. Such neutrons are called slow or thermal. Their energy depends upon the temperature of the surrounding medium. For example, at a temperature of + 20°C, this energy is approximately 0.025 ev. The mean velocity of neutrons in this case is approximately 2 km/sec. At a temperature of + 700°C, the neutron energy is approximately 0.085 ev, and their velocity is 4 km/sec. All neutrons with a kinetic energy lower than that of the fast neutrons and higher than that of the thermal neutrons, are called intermediate neutrons.

The kinetic energy of the neutrons governs the relative number of neutrons in each generation participating in any given nuclear process, or as the saying goes, the probability that one or another process will occur.

Fission of the nuclei of uranium^{235}, uranium^{233}, and plutonium^{239} may be effected by thermal, intermediate, and fast neutrons. However, the probability of fission increases with decreasing energy of the neutrons because of the fact that, in this case, the probability that a neutron will be captured by the nucleus increases. These are the properties that make uranium^{235}, uranium^{233}, and plutonium^{239} highly efficient nuclear fuels.

Capture of the nuclei of uranium^{238} and thorium^{232} by thermal and intermediate neutrons does not result in fission. The fission of these nuclei is induced only by certain fast neutrons. For this reason, uranium^{238} and thorium^{232} cannot serve as nuclear fuels. The chain reaction in any nuclear reactor occurs primarily due to the fission of the nuclei of highly efficient fuels.

Now let us review briefly the processes, useless for the fission reaction itself but resulting in neutron loss. These processes include:

Capture of neutrons by fuel nuclei without subsequent fission;

Capture of neutrons by nuclei of all other materials used in the reactor;

Capture of neutrons by nuclei of fission products accumulated during regular

operation of the reactor.

All these processes can be categorized by the single concept: neutron absorption. Like scattering, the absorption of neutrons is inevitable, in view of the

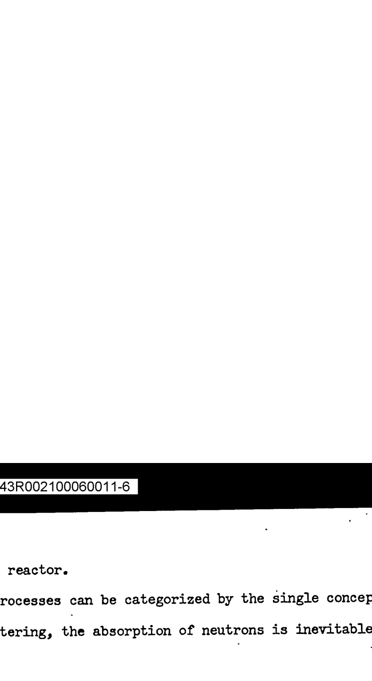

Fig.11 - Typical Graph of the Neutron Absorption Probability as a Function of the Energy of Their Motion

a) Absorption probability; b) Neutron energy

fact that all known materials absorb neutrons to some degree. At certain levels of neutron energies, which vary with the type of material, the absorption probability increases sharply. This phenomenon is known as resonance absorption. The phenomenon of resonance absorption is observed in a number of materials used in the manufacture of reactors, but it is most pronounced in the case of uranium^{238}.

Figure 11 gives a characteristic graph of the relationship between the probability of neutron absorption and their energy, for the case of uranium^{238}. The graph indicates that, at a neutron energy equal to E_{res}, neutrons are absorbed

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

particularly "avidly". The value of E_{res} is approximately 7 ev, corresponding to a neutron velocity of approximately 40 km/sec.

When a nuclear reactor is in operation, still another phenomenon resulting in a neutron loss is observed. A certain portion of the neutrons may escape from the bounds of the reactor, without undergoing fission. This phenomenon is called loss of neutrons by escape or neutron leakage. Neutron leakage is inevitable in any practical nuclear reactor.

The process of absorption and escape means that not nearly all neutrons generated during the fission process, actually participate in subsequent fissions. Therefore, the nuclear fission reaction can become a self-sustaining (chain) reaction only under certain circumstances.

The Critical State of a Nuclear Reactor

In order to make practical use of the atomic energy liberated during the fission of fuel nuclei, the prime requisite is that the fission reaction be self-sustaining. In other words, once having begun, it must continue spontaneously. The possibility of realizing such a reaction is based on the fact that, on splitting of each nucleus, two or three new (secondary) neutrons are produced; these are capable of inducing the fission of further nuclei. However, an attempt to realize this possibility is greatly hampered by the inevitable neutron loss: absorption and leakage. The minimum condition for realization of a self-sustaining fission reaction is that each generation of neutrons produced on nuclear fission gives rise to a new generation consisting of the same number as the preceding one. In other words, an identical number of neutrons participates in each successive act of fission, after the losses have been discounted. The condition of a reactor in which this requirement is met is termed the critical state.

The critical state is characterized by a neutron flux constant in time, by a constant number of fissions per second, and consequently by a constant quantity of

heat liberated per second, i.e., by a thermal capacity constant in time. The critical state is therefore also called the steady state, and the operating conditions of the reactor in this state are known as stationary or steady conditions. The amount of thermal power depends upon the number of fissions taking place in the reactor each second. It has been calculated that a power of one kilowatt represents 31,000 billion fissions per second.

What practical steps will have to be taken in order to attain the critical state?

Let us first consider the reaching of a critical state in a solid lump of highly effective nuclear fuel. We find that if the piece of fuel is exceedingly small, the nuclear reaction, after initiation, rapidly ceases. The main reason for this is the excessively large loss of neutrons by escape, due to the fact that, in a small lump, the collision probability with nuclei is very small. Neutron leakage occurs on the surface layer, while capture, resulting in fission, occurs throughout the entire volume of the lump. Consequently, neutron leakage may be reduced by reducing the ratio of surface to volume. For a given geometric form of the lump, this is attained by increasing its absolute dimensions, i.e., by the addition of nuclear fuel. As soon as dimensions of a certain size are reached, the leakage is reduced to the point that the same number of neutrons will participate in subsequent fission processes as in the preceding processes. This means that, in practice, the critical state in nuclear fuel is reached by bringing its quantity up to a certain definite size. The size and mass of a lump of nuclear fuel representing the critical state, are called the critical size and critical mass. Minimum critical mass of nuclear fuel will be obtained with lumps of spherical form, since a sphere represents the minimum ratio of surface to volume. For $uranium^{235}$, the critical mass of a spherical lump is approximately the mass weighing 1 kg.

In a practical nuclear reactor, the fuel is distributed more or less uniformly throughout the volume of the core. Loss of neutrons by escape, in this case, depends not only on the quantity of nuclear fuel but also on the dimensions and geometric shape of the core. In addition to fuel, the core contains other materials necessarily participating in the scattering and absorption of neutrons. The ability of these materials to scatter and capture neutrons varies with variations in temperature.

The properties of these materials, the relative quantity of each in the core, and the relative position of each determines the mean velocity of the neutrons at which the overwhelming majority of nuclear fissions of the fuel takes place. This velocity is the basis on which reactors are classified into thermal, intermediate, and fast-neutron reactors.

As we see, the condition of a practical nuclear reactor depends upon a number of circumstances, but in practice the critical condition is reached by charging a specific amount of nuclear fuel into the core, in view of the fact that all the other conditions are usually present to begin with. For example, the type of reactor is selected in the light of its purpose and the properties of the nuclear fuel available. The dimensions of the core are based on the conditions required to attain the desired power and, consequently, the necessary heat transfer per unit time. The operating temperature is based on the properties of the materials used, etc.

Thus, in an atomic power plant, it is necessary to have an adequate quantity of nuclear fuel only to permit utilization of a portion thereof to liberate the enclosed energy. In other words, an atomic power plant is capable of functioning, other conditions being equal, only so long as the quantity of unused nuclear fuel remains above the critical level. Further consumption of fuel is simply impossible. When it is stated that an aircraft with an atomic engine will burn 500 - 600 gm of nuclear fuel in the course of a flight around the world, this does not mean that such a flight can be performed with only 500 - 600 gm of fuel aboard the aircraft. These 500 - 600 gm can be consumed only if they represent merely a small portion of the mass (weight) of the total fuel aboard the aircraft and in the reactor.

As we shall soon see, the quantity of nuclear fuel required to maintain a critical state, does not remain constant during operation of the reactor, and increases as the temperature increases and also as fission products accumulate. In the very best reactors now in operation and under construction, the critical weight of highly efficient nuclear fuel at the end of the period of operation is not less than 80% of the weight after the initial charge. This means that not more than 20% of the initial charge can be consumed in the course of operation. This is one of the peculiarities of an atomic power plant as compared with those using chemical fuels. In the latter, as we know, the entire available fuel can be completely consumed.

Enormous amounts of labor and materials are required to obtain highly efficient nuclear fuels. It is natural therefore that tremendous efforts have been made by scientists and engineers of all countries working in the field of nuclear energy and reactor design, with the object of finding means of reducing the critical weight (mass) of nuclear fuel.

Reduction in the critical weight is facilitated by all measures that tend to diminish the neutron loss. One of these measures is the use, in the manufacture of reactors, of materials that absorb as few neutrons as possible. The minimum critical weight is obtained when the moderator and heat-transfer agent is heavy water, while zirconium is used as the structural material. However, the use of these materials is not always possible. Specifically, to attain high operating temperatures, it is sometimes necessary to use fused metals as the heat-transfer agent, and heat-resistant nickel alloys as the structural materials. Since these materials have high neutron-absorbing properties, the quantity of such materials used within the core must be reduced in order to lower the critical weight of the fuel.

The critical weight of nuclear fuel may be reduced by making provision to have the neutrons leaving the core reflected back into that core. If the core of a reactor is surrounded by a scattering substance, it will act as a reflector, i.e., a portion of the neutrons leaking from the core will be returned to there. This will result in a reduction in the loss of neutrons by leakage, and the critical state will be reached with a lower quantity of nuclear fuel than is the case when no reflector is used.

In selecting the material for the reflector, the following are the governing conditions: In the first place, the amount of neutrons returned is greater, the closer to the boundary of the core the point is located at which the scattering collisions of neutrons with nuclei from the reflector take place, and in the second place, the fewer the collisions resulting in neutron absorption. Consequently, in order to arrange for effective reflection, it is necessary to select a material for which the probability of neutron scattering would be as great as possible and the probability of absorption as small as possible. Heavy water is the best material for this purpose. Graphite, beryllium, ordinary water, zirconium, and certain other substances follow in order of diminishing the reflectivity.

Let us see what effect the thickness of a reflecting layer has on the process of reflection. Let us assume that we gradually increase the thickness of the reflector. The results are shown in the graph in Fig.12. The number of neutrons returned by the reflector into the core are laid off, on the vertical axis, while the thickness of the reflecting layer is plotted on the horizontal axis. The graph shows that, as the thickness of the reflector increases, the quantity of neutrons returned to the core also increases. The sharpest increase is produced by the layers closest to the core. The following layers, although they do return neutrons, do this to a lesser degree than the preceding ones. Finally, starting at some particular thickness, represented by the segment OA, the number of neutrons returned ceases to increase for all practical purposes. Any further increase in the thickness of the reflector is purposeless, since the bulk of the neutrons will be reflected or absorbed before the outer boundary of the reflector is reached. The thickness of the layer to which the reflection effect continues to increase substantially, is approximately as follows: 1.5 - 2.0 m for heavy water, 0.8 - 1.0 m

for graphite, and 0.45 - 0.5 m for beryllium.

When a reflector is used, there is an increase in the number of fissions of the nuclear fuel per second, immediately adjacent to the boundary of the core of the

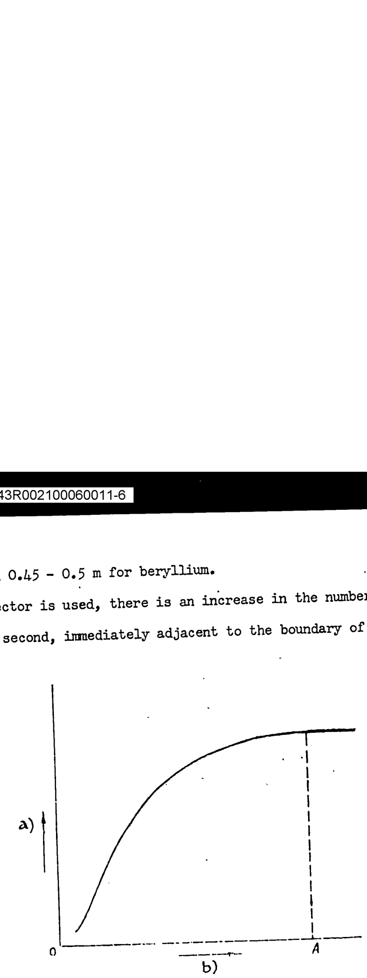

Fig.12 - Effect of Thickness of Reflecting Layer on the Process of Reflection

a) Number of neutrons returned to the core by the reflector;

b) Thickness of the reflecting layer

reactor. More efficient utilization of the peripheral zone makes it possible to obtain the desired quantity with a core of smaller dimensions than in a reactor not using a reflector. This is most important as far as aircraft reactors are concerned, in which the requirement of a reduction in dimensions of the core is of prime importance. It is true that the overall dimensions of the reactor are greater when a reflector is used than when it is not, but it must not be forgotten that the reflector, in any case, is an integral part of the shielding from the neutron stream. The thicker the reflector, the less will be the required thickness of the special shielding. In order for the reflector to form an effective portion of the

STAT

aircraft shielding system, it is preferable to use a material that slows neutrons effectively. The decelerated neutrons moving past the reflector will be completely absorbed in a relatively thin layer of special protective shielding.

In the nuclear reactors of modern stationary and sea-going power plants, water and graphite are the materials most often used for the reflector, since they are cheapest and adequately efficient. In high-temperature aircraft reactors, the use of water is impossible because of its low boiling point. Therefore, graphite is the only cheap material remaining. A reactor with reflector will have the smallest dimensions if metallic beryllium is used as reflector. Beryllium has a relatively high melting point (1315°C), is light, and inert to neutron irradiation. A disadvantage of beryllium is its high price.

Unstable Operating Conditions of Nuclear Reactors

A steady state, in which the neutron flux and the capacity of the reactor remain constant in time, is observed when the reactor is in the critical state by the fact that the neutron multiplication constant K is equal to unity. The multiplication constant K is the ratio of the number of neutrons undergoing fission in a given generation to the number of neutrons that have fissioned in the preceding generation. If the multiplier deviates from unity for any reason, the neutron flux, the number of fissions per second, and the power of the reactor will also vary with time, increasing or decreasing accordingly. The operating conditions of a reactor in which its power changes with time are called nonstationary or unstable.

The multiplication constant is equal to unity when the amount of nuclear fuel within the reactor core is exactly equal to the critical quantity for the given operating conditions. A change in the multiplication constant occurs when this equality is violated.

If the weight of the nuclear fuel within the core is less than critical, the multiplication constant is less than unity. This condition is called subcritical,

and the power of the reactor will drop steadily so long as this is the case. In actuality, the reactor is converted to subcritical conditions when it is necessary to reduce the generated power or to shut down the reactor.

If the reactor contains more than the critical amount of nuclear fuel, the multiplication constant will be greater than unity. This is called the supercritical state of the reactor and is characterized by a constant increase in power, in view of the fact that the fission reaction now becomes a virtual avalanche. In actual operation, a reactor is placed in the supercritical state for the purpose of "racing it", i.e., to increase its power. A special case of racing or "riding up" is the starting of a nuclear reactor.

Thus far we have spoken of fission reactions, without discussing how they are initiated. Let us make good this omission. It will be found that, in any nuclear reaction, there is always a certain number of free or, as they are called, stray neutrons. A percentage of these are generated as the result of the spontaneous fission of fuel nuclei*, another portion is knocked out of the nuclei by particles of cosmic radiation. Although the number of stray neutrons is small, it is quite sufficient to start a chain fission reaction. In order for an inoperative reactor to "come alive", it is enough to bring the multiplication constant to a quantity slightly larger than unity.

A most important characteristic of unstable operating conditions is the time rate of change in power. It is most important to know the rate of increase in power in the supercritical state of the reactor. An excessively rapid progression of the reaction creates difficulties in controlling it. Modern systems of automatic control, no matter how quick-acting they may be, require a certain amount of

* The phenomenon of spontaneous fission of the uranium nucleus was discovered by the Soviet scientists, G.N.Flerov and K.A.Petrzhak. They showed that in one gram of natural uranium there occur on the average 23 spontaneous fissions per hour.

STAT

time to function. It may happen that, during this time, the liberation of heat in the reactor will greatly exceed the removal of heat, so that the reactor will melt. An excessively slow increase in power is also not always desirable, particularly in an aircraft reactor. An aircraft reactor must have good pickup, i.e., it must be able to change rapidly from one steady state to another.

The rate of increase in power is greater, the greater the so-called excess reactivity or the reactivity of the reactor. By excess reactivity k_{ex} we mean the degree to which the multiplication constant is greater than unity

$$K_{ex} = K - 1.$$

For example, if the multiplication constant is 1.05, the excess reactivity is 0.05. The amount of excess reactivity indicates the relative increase in the number of neutrons fissioning from one generation to the next. In the given case, this increase is 5%.

The rate of increase in power also depends on the type of nuclear reactor. In a fast-neutron reactor, it is greater than in a thermal-neutron reactor. To anticipate the discussion for a moment, it should be mentioned here that different types of reactors will not always exhibit a significant difference in rate of acceleration.

Let us define the rate at which the power of a reactor increases. Let us assume that we are dealing with a thermal-neutron reactor in the critical state and developing some given power. Let us assume that we have effected a sudden increase in the multiplication constant to K = 1.1, i.e., that we have introduced a reactivity k_{ex} = 0.1. Calculations show that, at this reactivity, the power of the reactor will increase in two thousandths of a second by a factor of 2.7; in one hundredth of a second it will increase by 1500 times, and in two hundredths of a second by approximately 20,000 times. A breakdown is therefore almost inevitable. In a fast-neutron reactor, at k_{ex} = 0.1, the power increases approximately 150,000 times

in one millionth of a second. This rate of evolution of a chain fission reaction is close to that occurring in an atomic explosion.

The rapid increase in the power of a reactor of any type is explained by the fact that the velocity of motion, even of thermal neutrons, is sufficiently large for this to occur, while the distance traversed by the neutrons before collision with nuclei is small. As a result, very small intervals of time elapse from the instant of generation of a neutron to the instant when the neutron is captured by a nucleus of the fuel. Under these conditions, the process of fission rapidly encompasses an enormous number of nuclei.

The rate of acceleration may be reduced by lowering the reactivity, but even if this rate is reduced to 0.01, it still is not possible to control a nuclear reactor. As soon as the reactivity drops below 0.01, the picture changes sharply. The point is that, during the exceedingly brief period of time required for the act of fission, only 99% of the total number of secondary neutrons escape. These are known as prompt neutrons. The remaining neutrons (approximately 1%) appear in groups, with a delay of up to 80 sec. These are the so-called delayed neutrons, which are emitted in "fragments" of the fissioned nuclei, as they undergo radioactive decay. If the degree of radioactivity is equal to or smaller than the percentage of delayed neutrons, then an increase in the number of fissions in each generation will result only due to the delayed neutrons. In this case, the rate of increase in power is determined chiefly by the time during which the delayed neutrons appear. The time required for the neutrons to travel from the instant of their generation to the instant of their encounter with the nuclei of the fuel is not a significant factor, since this time is exceedingly short relative to the time lag of the neutrons. As a consequence, the rate at which the reactor is accelerated will be considerably less, although for reactors of various types it is approximately identical at identical reactivity.

More exactly, the percentage of delayed neutrons is given by the figure 0.00755.

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

Therefore, in order to guarantee safe operation during the startup or power increase of the reactor, the reactivity introduced must be less than 0.00755 and comprise approximately 0.005 – 0.006. At this reactivity, a thermal-neutron reactor will require approximately 6 sec to increase its power by a factor of 2.7, and will require 30 sec to increase it by 500 times. The increase in the power of a fast-neutron

Fig.13 – Time Rate of Change in the Power of a Reactor, when "Raced" or Shut Down

a) Reactor power; b) "Racing" ($k_{ex} = 0.0025$);
c) Shutdown ($k_{ex} = -0.0025$); d) Time

reactor takes place at approximately the same rate. Reliable regulation of a chain reaction is completely assured at this rate.

Along with the increase in the time required to raise the power, the presence of delayed neutrons results in a decline of the rate of reduction of power when a reactor is in the subcritical state. In practice, the power cannot be reduced more

rapidly than is "permitted" by the delayed neutrons. Figure 13 illustrates the changes in power as a function of time when a reactor is accelerated or shut down at a given steady state. The excess reactivity, in absolute value, is 0.0025. The broken line shows a number of new steady states that can be attained as a result of increasing or diminishing the initial assigned power.

What are the causes of the variations in the reactivity of a reactor?

In the first place, the reactivity may be changed at the discretion of the person controlling the reactor. This includes the actions of automatic devices which, set up by man, will substitute for his action. One of these actions is the shifting of the control rod made of a material that is highly neutron-absorbent. When the rod is pushed into the core, the neutron loss by absorption increases. If, prior to the introduction of the rod, the reactor had been in the critical state, it will become subcritical after introduction. Under the new conditions, the amount of nuclear fuel in the core will be insufficient to sustain a critical state. When the rod is withdrawn from the core, on the other hand, the neutron losses decrease and the reactivity increases.

Secondly, when a nuclear reactor is in operation, spontaneous changes in reactivity may occur. One of the causes of this is the "combustion" of the nuclear fuel, with the result that its amount in the core drops and the reactivity is reduced. In order to prevent spontaneous shutdown of the reactor, it is necessary either to provide for a constant refueling or in some way to reduce neutron loss during operation of the reactor.

Another reason for the reduction in reactivity is the accumulation of reaction fission products that are strong neutron absorbers, or as the saying goes, reactor poisoning. Poisoning results in an increase in the loss of neutrons by absorption and consequently in an increase in the required critical weight. In terms of any specific reactor, the degree of drop in reactivity due to poisoning is greater, the greater the power level at which the reactor has been operating. The poisoning ef-

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

fect is most noticeable in reactors using thermal neutrons, insofar as thermal neutrons are avidly absorbed by the nuclei of certain fission products.

Spontaneous changes in the reactivity of a reactor also occur when the core temperature is changed. An increase in temperature usually results in a decrease in reactivity. When overheating occurs, the density of all materials declines, i.e., there is an increase in the distance between the atomic nuclei. This leads to a reduction in the collision probability between neutrons and nuclei, to a decrease in the number of fissions, and an increase in neutron leakage. When the temperature is decreased, the nature of the phenomena is the opposite, and the reactivity of the reactor increases.

The fact that such a relationship exists between reactivity and temperature has a positive effect on the functioning of a reactor and makes it easier to control. Let us assume that, for some reason, the reactor has spontaneously entered a supercritical state. This causes the number of fissions per unit time to increase, thus also increasing the liberation of heat. Consequently, the temperature of the core increases. However, when the temperature increases, the reactivity begins to drop with the result that the further development of a chain reaction is somewhat slowed. In some cases, when the accidental fluctuation in the reactivity of a reactor is small, the reactor may spontaneously, without the intervention of a control system, return to its previous power level. The thermal effect is most marked in reactors using thermal neutrons, particularly if uranium^{238} is a constituent of the fuel.

As temperature increases, there is an increase in the kinetic energy of the thermal neutrons. As a result, the probability of fission of nuclei of highly efficient fuels becomes less, while the probability of absorption by the nuclei of uranium^{238} increases. In order to provide for maintenance of a steady state during temperature fluctuations, some means of compensating the change in reactivity, occurring under these conditions must be provided.

Controlling the Nuclear Reactor

Control of a nuclear reactor consists of sustaining the desired power or changing it in a desired direction. To control a reactor, provision must be made for varying the reactivity of the reactor. This problem may be solved by the following methods:

- By varying the amount of nuclear fuel in the core or by changing the mutual arrangement of the components;
- By changing the quantity of moderator;
- By changing the effective area or thickness of the reflectors;
- By changing the position of external neutron sources relative to the core;
- By changing the position of the regulating (controlling) means, made of materials that are good neutron absorbers.

At present, the last of the methods listed has come into wide use as being the simplest in terms of design and as being adequately effective, particularly for reactors using thermal neutrons. The controlling means most often take the form of cylindrical rods. The material used for these rods may be cadmium, boron, boron carbide, or boron steel. Cadmium is the most avid neutron absorber but has a rather low melting point (about 321°C), and is therefore less frequently used. An advantage of boron, aside from its high absorptivity and high melting point, is the virtually complete absence of induced radioactivity due to absorption of neutrons. As mentioned before, the change in reactivity obtained by means of the control rods, is due to change in the loss of neutrons of each generation by absorption. Introduction of the rods into the core reduces the reactivity of the reactor, while withdrawal of the rods increases it.

The reactor core is so designed that the weight of the initial charge of nuclear fuel will exceed the minimum critical weight. A portion of the excess fuel represents a reserve against consumption, i.e., it may be expended in producing thermal energy. The other portion, the so-called reserve against poisoning and temperature effect, is not consumed in operating the reactor. This portion of the fuel is used to sustain the critical condition in the reactor during accumulation of fission products and increase in temperature.

The excess or reserve reactivity due to the fact that the amount of nuclear fuel present is greater than the minimum critical amount, is compensated by the control rods and may be eliminated if necessary. The degree of reactivity freed when the rod is completely withdrawn from the core, is known as the compensating capacity of the control rod. The compensating capacity depends upon the material of the rod, its diameter, and its position in the core. Rods passing through the center of the core have the greatest compensating capacity. The total compensating capacity of the control rods of a reactor must exceed the initial reserve reactivity.

Let us next discuss the principal operating conditions of a control system. In order to proceed from one steady state to another in which the power is greater, the rod must be withdrawn from the core. When this is done, the power of the reactor begins to increase. As soon as a desired power level has been reached, the rod must be returned to a position corresponding to zero reactivity. If the changeover to the new operating conditions is completed within a very short period of time and is not accompanied by significant changes in the temperature of the core, the rods will be returned almost to their initial position.

In order to reduce the power level, the rods must be inserted deep into the core, and, after the desired level has been reached, be returned to their initial position. The degree of displacement of the rods determines the degree of reactivity, i.e., the time rate of change in power. Compensation for the reduction in reactivity due to consumption of the fuel and poisoning of the reactor, is accomplished by gradual withdrawal of the control rods from the core.

Maintenance of the assigned operating conditions of the reactor is automatic. A deviation of the power of the reactor from the required level causes a change in the neutron flux in the reactor, which is immediately recorded by ionization

counters mounted around the core. The signals from these counters, magnified by means of electronic systems, are transmitted to the electric drives which effect the necessary change in the position of the control rods. In modern nuclear reactors, the assigned power is maintained with an accuracy to within one tenth of a percent.

In addition to the rods controlling the reactor in normal operation, emergency protective rods must be provided. Their purpose is to stop the nuclear fission reaction under conditions in which even the briefest delay in shutdown might cause breakdown of the reactor. Such conditions include:

Very rapid increase in power during startup;

Rise in temperature of the core above the permissible level;

Drop in pressure of the heat-transfer agent, indicating a leak in the system or failure of the pump; and several other cases.

The emergency rods usually are introduced automatically. In the majority of reactors for stationary installations, the emergency rods are vertical. If necessary, they are "dumped" into the core. The speed of free fall of the emergency rods is sufficient to stop the chain reaction in time. In aircraft reactors, the emergency rods must necessarily be provided with an independent drive. This is necessary to assure rapid insertion no matter what the conditions of flight. The simplest, lightest, and most reliable drives are spring-actuated or use compressed gas or a powder charge.

Types of Nuclear Reactors

Above we have already indicated some specific features of various types of reactors. In the following, we will discuss other peculiarities and will attempt to draw certain conclusions as to the applicability of various reactors for aircraft power plants.

Thermal-Neutron Reactors. The development of nuclear reactors for use with thermal neutrons, was triggered primarily by the attempt to use natural and low-

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

enriched uranium as the nuclear fuel. The point is that it is impossible to cause a chain reaction in a lump of natural uranium, even if the size of the piece were increased to infinity. This is because of the low probability of fission of uranium^{235} by high-energy neutrons and the exceedingly high losses of neutrons due to resonance absorption by the nuclei of uranium^{238}.

The fission reaction in natural uranium can become a chain reaction only if thermal neutrons are used. The probability of capture of thermal neutrons by the neutrons of highly efficient fuels, and resultant fission, is much higher. At the same time, there is a reduction in loss of neutrons by absorption since a rapid drop in energy results in a considerable increase in the number of neutrons which "jump" regions of resonant energies.

In order to decelerate the neutrons, a neutron moderator is placed in the reactor core. The moderator is made of a material comprising chemical elements with the lightest possible atomic nuclei. These are the elements at the very beginning of Mendeleyev's periodic system. The lighter the nucleus of the moderator, the more energy is lost by the colliding neutrons and, consequently, the greater is the probability of skipping the energy levels at which resonance absorption into uranium^{238} takes place.

However, a pronounced reduction in the energy of the neutrons during a single collision is of no value if the collisions are very rare. In this case, the loss of neutrons by leakage will be very great.

Moreover, the nucleus of the moderator must not be a powerful neutron absorber. Thus, the moderator must consist of light nuclei, having the greatest scattering probability for neutrons and the least absorption probability. Only a few good moderators are known: heavy water, graphite, beryllium, beryllium oxide (BeO). In high-temperature nuclear aircraft reactors, it is apparently possible to use only graphite, beryllium and its oxide.

The use of natural and even low-enriched uranium in nuclear reactors for atomic

aircraft does not seem possible thus far, since this would require reactors of excessive dimensions and weight. The simplest calculations show that, at present, the designing of an atomic aircraft flying at a speed somewhat higher than the speed of sound is possible only if the fuel used is uranium enriched at least by 50%. The design of aircraft with atomic engines for still higher supersonic speeds will require a greater degree of enrichment.

Nuclear reactors for thermal neutrons have one great advantage over all other types of reactors - minimum critical weight for the nuclear fuel. When the fuel is diluted by the moderator, there is a decrease in loss of neutrons by leakage, because of the fact that, the lower the energy of the neutrons, the greater will be the probability of their capture by the fuel nuclei. On the other hand, there is an increase in the loss of neutrons by absorption by the nuclei of the moderator. Up to a given degree of dilution, which is called optimum, the saving in neutrons due to a reduction in leakage is greater than the loss by absorption, so that the critical weight of the nuclear fuel decreases. At the optimum ratio of the amount of fuel to that of moderator, the critical weight of a given fuel will reach a minimum. On further dilution, this weight increases because since reduction in leakage is insufficient to compensate for the reduction of neutrons due to absorption.

Figure 14 gives a graph showing the change in the critical weight of nuclear fuel and the critical dimensions of the core of a reactor, on gradual dilution of the fuel by a moderator. The solid line is the change in the critical weight of the fuel (P_{cr}), while the broken line represents the change in the critical size of the core (R_{cr}). We see that the critical weight of nuclear fuel (P_{min}) is considerably less than the critical weight of the undiluted fuel (P_o). True, the size of the core in this case is greater than the deficiency in moderator.

The use of thermal-neutron reactors in aviation is advantageous in cases in which the greatest possible area of heating surface of the core is required. In practice, this occurs in the design of ram-jet and turbojet atomic aircraft engines,

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

with direct heating of the air stream in the reactor. The emission of heat into the air stream is characterized by a comparatively low coefficient of heat transfer, of

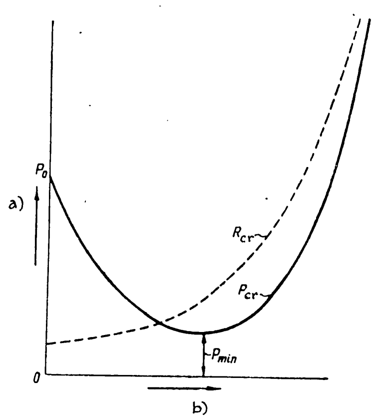

Fig.14 - Variations in the Critical Weight of Nuclear Fuel and Critical Dimensions of the Core of a Nuclear Reactor as a Function of the Ratio of Fuel and Moderator Amounts

a) Critical weight of nuclear fuel and critical dimensions of core;

b) Percentage content of moderator in mixture with fuel

not more than 600 - 800 $\frac{\text{kcal}}{\text{m}^2/\text{hr} \cdot \text{deg}}$. Therefore, the area of heating surface is usually inadequate, without dilution of fuel. The use of a moderator results in an increase in heating surface.

The mutual arrangement of the fuel and the moderator in a thermal-neutron reactor may vary. If the nuclear fuel is uniformly distributed throughout the moderator, dissolved, or intermixed, the reactor is known as a homogeneous reactor. A

homogeneous active mass may be solid, liquid, or gaseous. A liquid mass, in turn, may be a solution of fuel in a moderator, or a suspension, i.e., a uniform distribution of solid fuel particles in a liquid moderator. A general advantage of homogeneous reactors is the simplicity of design of their cores.

Actually, this is the simple and reliable design applied in the boiling homogeneous reactor designed by the Academy of Sciences of the USSR. The design of this reactor is shown in Fig.15. The active mass, consisting of a solution of uranium salts in heavy water, is encased in a metal tank of spherical shape. The heat liberated as a result of the fission reaction causes the liquid to heat up and boil. High-pressure steam is tapped for use in steam-powered devices. The condensate from the steam-powered device is returned to the reactor by pump. A fundamental shortcoming of homogeneous reactors is the comparatively high probability of absorption of neutrons by nuclei of uranium^{238}. Therefore, the realization of a self-sustaining fission reaction, using natural uranium as the fuel, is possible only if a better moderator than heavy water is used.

If nuclear fuel in the form of separate and rather large rods or blocks is placed in an undiluted moderator, the device is called a heterogeneous reactor. Heterogeneous means nonidentical. The distance between the blocks is so selected that the energy of the neutrons exceeds the resonance levels in the spaces between the blocks. One of the possible designs of heterogeneous reactors has already been described and was shown in Fig.9. The design of the core of such a reactor is more complicated than that of a homogeneous reactor, but the limitations of the latter, with respect to possible moderator materials, do not exist here. In modern reactors of stationary power plants, graphite and ordinary water are in wide use as moderators. These materials are considerably cheaper than heavy water.

The nuclear reactor of the first Soviet power plant is a heterogeneous reactor using thermal neutrons. Its core is a cylinder 1.5 m in diameter and 1.7 m in height. Graphite is used as the moderator and reflector. The heat-transfer agent is ordinary water. The nuclear fuel is metallic uranium enriched by its isotope 235. The degree of enrichment is 5%. The initial fuel charge is about 550 kg.

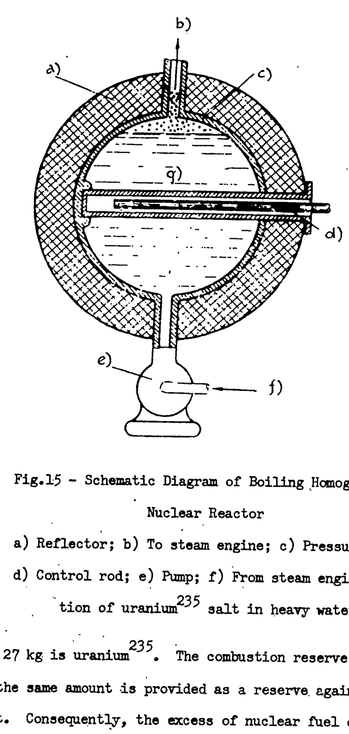

Fig.15 - Schematic Diagram of Boiling Homogeneous Nuclear Reactor

a) Reflector; b) To steam engine; c) Pressure vessel; d) Control rod; e) Pump; f) From steam engine; g) Solution of uranium^{235} salt in heavy water

Of this, about 27 kg is uranium^{235}. The combustion reserve is approximately 3.5 kg. Approximately the same amount is provided as a reserve against poisoning and temperature effect. Consequently, the excess of nuclear fuel over the minimum critical weight is about 7 kg. The initial reactivity reserve is 0.13. In order to compensate for excess reactivity and for inaccurate control of the reactor, 18 com-

pensating rods of boron carbide are provided in the core. Another four rods are provided for precise automatic control, plus two emergency protective rods for stopping the reactor under emergency conditions. The overall compensating capacity of the regulating rods is about 0.16. The compensating capacity of the emergency rods is 0.02. The thermal capacity of the reactor is estimated as 30,000 kw.

The advantage of heterogeneous reactors in that they reduce resonance absorption within uranium^{238} is not significant for aircraft reactors. The selection of some system of placing the fuel and the moderator in the aircraft reactor is based primarily on the requirement of obtaining a simple reactor, reliable in operation. Taken into consideration here are the type of aircraft engine to be driven by the reactor, the high thermal load of an aircraft reactor, the possibilities of uneven heating and fluctuations in temperature, the need to assure reliable dissipation of heat no matter what the position of the reactor in space, and a number of other factors.

Several authors in other countries have proposed using so-called porous homogeneous reactors in rocket-type atomic aircraft engines. The core of such a reactor is an assembly of conical tubes extruded from a homogeneous mixture of highly efficient nuclear fuel and powdered graphite. The tube walls are honeycombed with an enormous number of fine channels, through which a fluid or gaseous heat-transfer agent flows. This agent functions at the same time as the working substance of the rocket. The design for such a reactor, housed in a rocket, is shown in Fig.16. The porous reactor has the following important advantages: a large surface area for heating, combined with comparatively small dimensions of the core and a possibility of reaching working temperatures above the melting point of the nuclear fuel. However, a porous reactor in the form in which it is proposed has the following important disadvantages which constitute an obstacle to its practical application, specifically as a high-temperature reactor: A highly complex technology is required for the manufacture of the solid homogeneous mixtures, and the probability of destruction of the solid mixture due to irregularity in the heating of the various segments and fluctuations in temperature is great. In addition, clogging of the

Fig.16 - Design of an Atomic Rocket Aircraft Engine with a Porous Homogeneous Uranium-Graphite Reactor

a) Control rod; b) Delivery of heat-transfer agent from pump; c) Porous active mass; d) Shell; e) Jet nozzle

capillary channels by particles of the active mass and by "fragments" of the fissioned nuclei may occur during operation of the reactor. Clogging of the channels over even a short distance results in local overheating and, in the long run, in breakdown of the entire reactor.

The use, in thermal-neutron aircraft reactors, of a homogeneous active mass consisting of an alloy of metallic uranium and metallic beryllium offers good possibilities. The active mass is housed in thin-walled cans of heat-resistant material, which may be cylindrical or tubular (with double walls), or else spherical, etc. A portion of the active mass with its can is called the heat-producing element or fuel element. The cans protect the mass from oxidation and shield the heat-transfer agent from contamination by the radioactive fission products, and also impart mechanical strength and rigidity to the heat-producing elements at high temperatures. The fuel assembly, with the individual elements attached to each other and to the shell of the reactor, forms the structural essentials of the core.

Figure 17 shows one of the possible design variants of a core using uranium-beryllium alloy. The design of the heat-producing elements and the method of combining them into a single whole is readily understood from the drawing. A reactor of this type may be used to heat a flow of air passing through its axis or a gaseous intermediate heat-transfer agent. If the material of the containers holding the heat-producing elements permits this, the working temperature can be raised above the melting point of the active mass.

Still another variant of a possible design for the core of a uranium-beryllium reactor, intended for direct heating of the airflow through the engine, is presented in Fig.18. Here the uranium-beryllium alloy is housed in a hermetically sealed cavity, penetrated by a large number of thin-walled metal tubes. The active mass occupies the space between the tubes. The air to be heated moves along the tubes to the reactor. To obtain a hermetic seal of the front and rear surfaces of the reactor, the ends of the tubes are connected by welding. Usually the core of this type of reactor consists of a number of sections. The edges of one of the sections are shown as a broken line in the left half of the drawing. Such a sectional design greatly simplifies the engineering required in making and assembling the core.

In order to lower the neutron leakage, a solid outside reflector is provided.

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

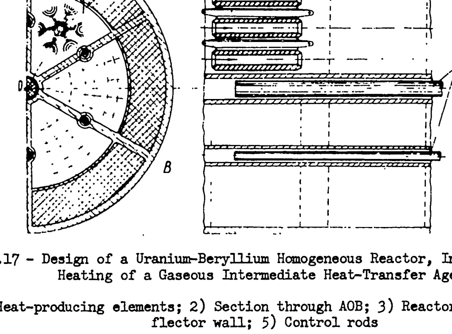

Fig.17 - Design of a Uranium-Beryllium Homogeneous Reactor, Intended for the Heating of a Gaseous Intermediate Heat-Transfer Agent

1) Heat-producing elements; 2) Section through AOB; 3) Reactor shell; 4) Reflector wall; 5) Control rods

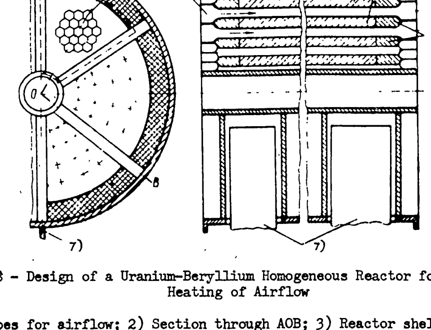

Fig.18 - Design of a Uranium-Beryllium Homogeneous Reactor for Direct Heating of Airflow

1) Tubes for airflow; 2) Section through AOB; 3) Reactor shell; 4) Outside reflector; 5) Active mass (uranium-beryllium alloy); 6) Rear face of reflector; 7) Control plates

To reduce the cross-sectional dimensions of the reactor, it is desirable to use metallic beryllium as the reflector material. Unfortunately, in this case it is impossible to use continuous-end reflectors. A certain amount of reduction in neutron leakage through the end surfaces is obtained by applying a layer of pure beryllium between the tubes at the front and rear surfaces of the reactor. In order not to crowd the access to and the exit from the reactor, the control devices are placed between the sections of the core and are displaced along the radius of the cylinder.

Let us review some data on a reactor designed on this basis. These data are obtained from approximate calculation based on familiar formulas derived from the theory of jet engines and the theory of nuclear reactors. The purpose of a reactor is to provide direct heating of air in an atomic turbojet aircraft engine, developing maximum static thrust at sea level of 32,000 kg. The maximum thermal capacity of the reactor is 300,000 kw, corresponding to a liberation of 258,000,000 kcal/hr. The maximum temperature of the heating surface of the core is 1100°C. The air is heated to a temperature of 950°C. The reactor core is cylindrical in form. The core is 1.9 m in diameter and in length, while the thickness of the side reflector, made of beryllium, is 15 cm. The thickness of the layer of pure beryllium of the front and rear surfaces of the reactor is 10 cm. The number of airflow tubes is 17,000. The inside diameter of each tube is 10 mm. The tubes are made of heat-resistant nickel alloy. The initial uranium^{235} charge is 70 kg. The combustion reserve, ensuring continuous operation at full capacity for 500 hrs, is 6.5 kg. The weight of the metallic beryllium, alloyed with uranium, is about 2000 kg. The combined weight of reactor and reflector is 9500 kg.

All three above designs assume the use of a homogeneous active mass. The use of heterogeneous nuclear reactors in aviation offers more limited possibilities, particularly for the direct heating of air. The core of a heterogeneous reactor, in this case, is complex in design and not very reliable in operation.

A shortcoming of nuclear reactors employing thermal neutrons is the necessity

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

of using only materials that are weak absorbers of thermal neutrons. Otherwise, the critical weight of the nuclear fuel increases considerably, and the most important advantage of thermal-neutron reactors may be canceled completely. In addition, reactors using thermal neutrons require cores of the largest critical size, relative to other types of reactors.

Fast-Neutron Reactors. These reactors use no moderators at all. This explains the major advantage of fast-neutron reactors, namely the fact that they have the smallest critical size of all types of reactors. However, this is not all.

We already know that the probability of useless capture of neutrons by the nuclei of various elements, during an increase in energy of the neutrons, decreases more rapidly than the probability of capture by nuclei of fuel available for fission. Therefore, the relative effect of poisoning in fast-neutron reactors is less than in thermal-neutron reactors. The lowered probability of absorption of neutrons of high energy permits a freer selection of materials for the working process in the reactor. Liquid metals may often be used as the intermediate heat-transfer agent, and the structural materials may consist of the best modern heat-resistant metals and alloys, regardless of their chemical composition.

In practice, the use of fast-neutron reactors in aviation is advantageous in cases in which there is a possibility of attaining high temperatures of the heating surface of the core, while liquid metal heat-transfer agents are used to dissipate the heat. Dissipation of heat in a stream of liquid metal is characterized by very high coefficients of heat loss, attaining $30{,}000 - 40{,}000 \frac{\text{kcal}}{\text{m}^2/\text{hr} \cdot \text{deg}}$. Calculations show that even at a temperature of the heating surface of 1000°C, the critical dimensions of the core of a fast-neutron reactor are in good agreement with the dimensions required for heat dissipation if liquid metal is used as the heat-transfer agent.

Consequently, the use of fast-neutron reactors with liquid metal heat-transfer agents makes it possible to obtain greater power per unit volume of core than with

any other type of reactor or, what amounts to the same, with the smallest dimensions of core for each given power level. This is extremely important from the

Fig.19 - Diagram of a Fast-Neutron Nuclear Reactor Using Molten Metal Cooling

a) Heat-producing elements; b) To heat exchanger; c) From pump; d) Retainer plates; e) Control rod; f) Cover of shell; g) Reactor shell

viewpoint of convenience of shielding the reactor and reducing the weight of the shields.

Figure 19 shows one of the possible designs of the core of a fast-neutron nuclear reactor using liquid-metal heat transfer. In the given case, there is no reflector. The core of the reactor is cylindrical in form and consists of two drums, each of which in turn consists of two retainer plates and an assembly of heat-producing elements. There is a gap of predetermined size between the two drums.

The resolution of the core into individual sections slightly increases the critical weight of the nuclear fuel but ensures a more reliable functioning of the reactor at high thermal loads. The shorter the length of the heat-producing elements at a given diameter, the less will they sag under their own weight, the less will be the deformation at nonuniform heating, and the less will be the vibration.

The shell of the heat-producing element is a tube with thin double walls. The nuclear fuel is housed in the hermetically-sealed space between the walls. The fuel elements are inserted in accurately machined apertures in the retainer plates, during assembly of the drums. Rigid mounting of these elements to the plates is provided only on one side, the outer plate side. The heat-producing elements rest freely in the holes in the inner plates. This permits unrestricted expansion on heating.

The liquid-metal heat-transfer agent is forced into the gap between the drums by means of a pump, at a definite pressure. Here the current of heat-transfer agent divides in two. Moving through the tubes in an axial direction, the heat-transfer agent enters the front and rear chambers of the reactor. Both chambers are connected to the inner portion of the drums of each by means of channels in the lower portion of the outer plates. Through these channels, the heat-transfer agent enters the space between the plates from where it moves upward. Thus it washes the external surfaces of the heat-producing elements in a transverse direction.

In flowing over the inside and outside surfaces of the fuel elements, the heat-transfer agent is heated to a high temperature and enters the heat exchangers from the two upper chambers of the reactor. There it yields the heat obtained in the reactor to the air stream. From the heat exchangers, the cooled heat-transfer agent is recycled by pump to the reactor. The pressure in the reactor should be such as to prevent the heat-transfer agent from boiling within the core.

By means of equations familiar from the theory of heat exchange and the theory of nuclear reactors, it is not difficult to make approximate calculations for a

reactor designed on this basis. Below we derive certain data for such a calculation: The thermal capacity of the reactor is 300,000 kw. The fuel is uranium enriched by a 50% addition of the 235 isotope. The heat-transfer agent is fused lithium (melting point 180°C, boiling point at normal atmospheric pressure 1320°C). The maximum temperature of the heating surface is 1000°C. The lithium is heated from 750°C to 950°C. The diameter of the core is 0.8 m, and its length is the same. There are 8000 heat-producing elements. The outside diameter of each fuel element is 8 mm, and its inside diameter is 4 mm. The thickness of the shell is 0.5 mm. The thickness of the fuel layer is 1 mm. The material of the shell is heat-resistant nickel alloy. The weight of the structural materials in the core is about 900 kg. The initial charge of enriched uranium is 1100 kg. One half this quantity, i.e., about 550 kg, represents $uranium^{235}$. The combustion reserve is 6.5 kg. The total initial reserve of $uranium^{235}$, with allowance for reserves for poisoning and temperature effects, is about 9 kg. The initial reactivity excess is 0.012. The duration of continuous operation of the reactor at full capacity, determined by the reserve of fuel for combustion is 500 hrs. The dry weight of the nuclear reactor, without the reflector but including the control system, is 4000 kg. The weight of lithium in the reactor is 1500 kg. The average pressure of the heat-transfer agent in the reactor is about 20 atm.

The above example shows that the critical weight in the fast-neutron reactor is considerably greater than that of a thermal-neutron reactor. This is the major shortcoming of fast-neutron reactors and can be explained by the excessive neutron leakage. The necessity for high-enriched fuels and a large initial load places a certain limitation on the wide use of fast-neutron reactors in stationary power plants.

Nevertheless, the use of such reactors is very profitable since it creates the possibility of producing not only energy but highly effective nuclear fuel in a quantity greater than the amount actually burned.

STAT STAT

If the core of a fast-neutron reactor is surrounded by a relatively thick layer of uranium^{238} or thorium, the loss of neutrons by leakage is no longer negligible. The absorption of these neutrons by a nuclei of uranium^{238} or of thorium^{232} results in the formation, respectively, of plutonium^{239} or uranium^{233}. In this case, as soon as the amount of newly formed highly efficient nuclear fuel is equal to the amount of "combusted" fuel, the reactor becomes a regenerative reactor, and as soon as this amount is exceeded, it becomes a breeder reactor. In aviation, such reactors cannot be used because of their exceedingly great weight.

Reactors Using Intermediate Neutrons. In such reactors, the quantity of the specially provided moderator is inadequate to moderate the neutrons down to thermal velocities. In their properties, such reactors are somewhere midway between thermal and fast-neutron reactors. By using a certain level of fuel dilution by a moderator, it is possible to make use of the advantages of both extreme types of reactors while eliminating their shortcomings to some degree. The dilution of nuclear fuel by a moderator results in an increase in the dimensions and weight of the nuclear reactor and slightly complicates the problem of protection from radiation; however, at the same time it reduces the needed initial charge of expensive nuclear fuel.

In addition, an increase in the dimensions of the core when dilution of fuel is used means primarily an increase in the area of heating surface. As a result, the same amount of heat may be transferred at a lower temperature. In the above-discussed reactor, using fast neutrons, a certain degree of dilution makes it possible to heat lithium to 950°C, at wall temperatures of the fuel elements differing from 1000°C (for example, 975°C). A reduction in the maximum temperature of the wall increases the reliability of operation of the heat-producing elements. Thus, if we dilute the fuel with a moderator, we may obtain an optimum combination of the engineering and economic possibilities for the development of an aircraft reactor. According to the foreign press, the majority of aircraft reactors now in the design stage are, as a matter of fact, in the class of intermediate-neutron reactors.

Calculations show that such a reactor is the most profitable for aviation if helium is used as the intermediate heat-transfer agent. The heat-transfer coefficient from the heating surface to the helium stream in high-temperature aircraft reactors is approximately $5000 \frac{\text{kcal}}{\text{m}^2/\text{hr} \cdot \text{deg}}$.

The design of the core of a reactor using intermediate neutrons depends upon the heat-transfer agent used and does not differ greatly from the above-described designs.

Major Difficulties in Developing Aircraft Nuclear Reactors

The development of nuclear reactors for use in high-speed atomic aircraft is hindered by the necessity to overcome a number of serious difficulties.

To begin with, to create high-power reactors despite small dimensions and weight, a large amount of very expensive material is required. The most costly material is the nuclear fuel. Above it was noted that the initial charge of high-efficiency fuel in a fast-neutron reactor amounts to several hundred kilograms. Today this figure is quite high, since the resources of high-efficiency fuels are still very limited. However, the production of nuclear fuel is being developed rapidly, processes of separating the isotope 235 from natural uranium are being perfected, and stockpiles of artificial, highly perfected fuels (uranium^{233} and plutonium) are being accumulated. Therefore it may be stated with confidence that in the not-too-distant future, the production of high-efficiency fuels will be adequate to permit the operation of a large number of aircraft reactors.

The progress in aircraft reactor design is also facilitated by large-scale development of regeneration or recovery (purification, rehabilitation) of nuclear fuel. We know that, of the total fuel charged into the reactor, only a small portion is expended. Thus, in the fast-neutron reactor examined above, of 550 kg of uranium^{235}, only 6.5 kg is "burned" during 500 hours of operation at top speed. The remaining fuel becomes unsuited for further use, due to contamination with fission products. Regeneration, i.e., purification of the nuclear fuel from the contaminating impurities, makes most of it useful for re-use in reactors.

Serious difficulties are encountered in solving the problem of removing heat from the reactor. Moreover, the process of heat dissipation determines all major characteristics of an atomic power plant aircraft and the flying characteristics of an atomic airplane.

One of the difficulties consists in attaining high temperatures of the heating surface of the reactor core. The most widely used nuclear fuel, uranium, has proved a very capricious material. When metallic uranium is heated to over 660°C, the atoms in its crystal lattice undergo rearrangement, accompanied by a change in volume, density, and mechanical properties. In the temperature interval of 660 to 800°C, uranium is brittle, while above 800°C it is very soft and weak. Frequent heating and cooling causes progressive changes in the shape and dimensions of uranium blocks. A similar phenomenon results from the effects of irradiation and in particular of the intensive bombardment of the uranium nuclei by fission "fragments" and neutrons. The above properties of uranium cause serious difficulties in developing reliably operating fuel elements for high-temperature reactors.

To reduce the stresses in the materials constituting the shell of the heat-producing elements, set up as the fuel volume increases, the layer of fuel used must be as thin as possible. The effect of radiations on uranium may be weakened by alloying it, i.e., by fusing it with other metals, for example aluminum or beryllium. A uranium-beryllium alloy containing relatively little uranium is remarkably stable to radiation. The change in volume undergone by this alloy is negligible, even under very intensive bombardment by fission "fragments" and by neutrons.

The maximum temperature which can be attained in a reactor depends upon the choice of the material for the shells of the heat-producing elements. When heat-resistant steels are used, reaching a temperature above 700°C is practically impossible, since the main component of steel (iron) forms an alloy with metallic

uranium that fuses at a temperature of 725°C. The use of heat-resistant alloys based on nickel makes it possible to attain temperatures at the surface of the fuel elements of the order of 1000 - 1100°C. A shortcoming of nickel alloys is their high absorptivity for neutrons.

Good results can be obtained by the use of molybdenum (melting point, 2627°C). The probability of neutron absorption by molybdenum is second only to that of zirconium among the refractive metals. A shortcoming of molybdenum (violent oxidation on heating) is overcome by coating it with a spray-deposited silicon film. If an inert gas such as helium is used as the intermediate heat-transfer agent, no coating of the molybdenum shells is required. In this case, the temperature of the heating surface of the core may be raised to the order of 1500°C.

Even higher temperatures may be obtained if the fuel used is uranium oxide (UO_2) or uranium carbide (UC_2) and if the shells of the heat-producing elements consist of ceramic materials on the basis of aluminum, silicon, zirconium, etc.

The material of the shells of the heat-producing elements of an aircraft reactor has to work under exceedingly severe conditions. Temporary stresses are set up by the flow of heat-transfer agent and high-temperature stresses, due to uneven heating, are created in such materials. At high temperatures, oxidation and corrosion processes are activated and the destruction of structural materials by the flow of heat-transfer agent is accelerated. As a result of intensive irradiation by neutrons, the mechanical properties of the material are impaired, rendering the material more brittle. True, in an aircraft reactor, the effect due to irradiation is considerably weakened during heat-up of the material of the shells to high temperatures.

These causes have the effect that the period during which an atomic aircraft power plant can operate continuously becomes limited not so much by the possible reserve of nuclear fuel to compensate for the burned fuel, but by the length of re-

STAT

liable operation of the shells of the heat-producing elements of the reactor. We may hope that the best modern heat-resistant materials will result in a service life for aircraft reactors, not shorter than that presently attained by gas-turbine engines for aircraft.

Considerable difficulties are encountered in the selection of a heat-transfer agent. Gases, liquid metals, fused salts, high-pressure water, and other materials may be used for this purpose. The highest power per unit volume of core is obtained when liquid metal heat-transfer agents are used. In order for a nuclear reactor to function steadily and reliably, the stream of heat-transfer agent must consist of a single phase, without significant fluctuations in density, and the excess pressure in the reactor must be as low as possible. Therefore, the metals used as heat-transfer agents must have high boiling points. Conversely, in order to eliminate the possibility of consolidation in various portions of the circulatory system, the metals used must have a low fusing point. The heat-transfer agents must be chemically stable and have the lowest possible probability of neutron absorption.

Lead, bismuth, mercury, sodium, potassium, and lithium are among the metals that have these properties to a greater or lesser degree. Of the metals listed above, it would appear that lead and bismuth are the best. They have the highest boiling point (1740°C for lead and 1480°C for bismuth), have high chemical stability, and the lowest probability of neutron absorption. Alloys of lead and bismuth have in addition, an adequately low fusing point (somewhat less than 150°C). However, the use of lead, bismuth, and alloys of bismuth and lead, as well as of mercury as intermediate heat-transfer agents for atomic aircraft power plants has not yet proved possible. The low specific heat capacity and the high specific gravity of these metals has the final result of an extremely high total weight of the required quantities.

Approximate calculations show that, for flight of an aircraft weighing 150 tons at a height of 11 km at the speed of sound (M = 1), when the temperature of the

heating surface of the reactor is 1000°C, the weight of the liquid lead within the power plant has to be about 70 tons, i.e., almost one half the total flying weight. If we take into consideration that the weight of the shielding system is also about 70 tons, the impossibility of developing an atomic aircraft with this type of reactor becomes obvious. The use of lead and bismuth in atomic aircraft will become possible when science discovers more efficient methods of shielding from nuclear radiation, making possible a reduction in the weight of the shields to one fifth of the present level, with a simultaneous increase in the temperature of the reactor by at least 50%.

The use of mercury, moreover, leads to the necessity of providing high positive pressures in order to attain high temperatures, which leads to an even heavier power plant and a reduction in its reliability of operation. In addition, mercury is a highly avid neutron absorber. Calculations show that mercury can be used today only as the working medium in steam turbines designed to drive propellers for atomic turboprop engines or for air compressors of atomic ram-jet engines. However, it is only possible to produce a power plant of suitable weight if the vaporization of mercury takes place directly in the reactor. The problem of producing such a reactor, suitable for installation even on a subsonic aircraft, is exceedingly complex.

The use of sodium, potassium, lithium, and their alloys as intermediate heat-transfer agents makes it possible to reduce the weight of the metal in the system as compared to lead by a factor of more than 10, thus creating factual possibilities for the development of aircraft power plants operating on nuclear fuel. However, these metals are chemically highly active. They oxidize rapidly in air, and react violently with water. A general shortcoming of all liquid metal heat-transfer agents is the radioactivity that develops on irradiation with neutrons.

The weight of an atomic power plant may be lowered, and the difficulties due to the high chemical reactivity and radioactivity of the heat-transfer agents may be reduced by using gaseous intermediate heat-transfer agents or by direct heating of the airflow in the reactor. Helium is the gaseous heat-transfer agent that offers the greatest possibilities. Helium is an inert gas of very low specific gravity, high specific thermal capacity, and almost nonexistent absorptivity for neutrons. The main difficulty in the practical use of helium is that of adequate sealing which will reliably prevent this substance from leaking from the system.

Direct heating of the air stream in a nuclear reactor makes it possible to eliminate this difficulty, but other and no less complex problems arise instead. We will discuss these below.

Obviously, the use of any heat-transfer agent involves certain specific difficulties. Which of the possible heat-transfer agents might be the preferable type? Today it is very difficult to answer this question. A correct answer might be possible only after a careful study of practical data in the development and operation of atomic aircraft power plants of various types with various heat-transfer agents and types of nuclear reactors.

Considerable difficulties are encountered in developing systems for the control of aircraft reactors. The problems of controlling stationary reactors have now been successfully resolved. The remaining problem is that of perfecting the existing systems, i.e., reducing their weight and dimensions and increasing their reliability and precision of operation.

The most serious difficulties are those in controlling fast-neutron aircraft reactors. Generally speaking, a fast-neutron reactor is more dangerous to use than a thermal-neutron reactor. If, for any reason, the reactivity reaches a value of 0.00755, the fission reaction will proceed at such a speed that the existing systems of emergency protection will no longer be able to prevent breakdown of the reactor.

However, a number of factors make an aircraft reactor, using fast neutrons, completely safe if the most elementary rules of operation are obeyed. The point

is that the initial reserve of reactivity in a fast-neutron aircraft reactor is very small. This is due to the relatively low possible operating period of an aircraft reactor and, consequently, the small reserve of fuel to replace the burned fuel. The reactivity reserve to compensate for poisoning and temperature effects is also small in a fast-neutron reactor. For example, to keep a 300,000 kw fast-neutron reactor operating for 500 hrs, the initial reactivity reserve need only be 0.012. In order for fission in this reactor to occur with prompt neutrons, more than half of the entire reactivity reserve must be engaged in the reaction, i.e., all control rods must be pulled out half-way.

The main difficulty in developing control systems for the operation of fast-neutron reactors lies in the problem of designing the control devices. To control such a reactor by means of fine absorption rods is not possible, as all known materials are weak absorbers of fast neutrons. One of the methods of control may be variation in the position of a certain portion of the nuclear fuel relative to the core. In this case, the control devices take the form of rods of nuclear fuel enclosed in protective metal cans and having an independent cooling system. A significant shortcoming here is the need to dissipate large amounts of heat from the control devices, leading to a considerable complication of design.

The low compensating capacity required by the control devices of a fast-neutron aircraft reactor permits a considerable simplification in their design. One of the possible designs for a control device is shown in Fig.20. The control device is in the form of a rod whose material is a good retarding agent, for example, graphite or beryllium. The rod is housed in a can consisting of a material that is a good absorber of slowed neutrons. When the rod is withdrawn, the fast neutrons pass through the thin walls of the can and participate in the fission reaction. If the rod is introduced into the core, a portion of the neutrons passing through it will be decelerated and will then be absorbed by the material of the can. The can may form a part of the channel wall rather than of the rod itself. The smallest

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

diameter per unit compensating capacity is provided by a beryllium rod. The material used for the rod may either be boron or boron carbide. In this case, the

Fig.20 - Design of Control Rod for a Fast-Neutron Reactor
a) Core; b) Rod consisting of moderator; c) Can of material with good absorptivity for delayed neutrons

control rods of fast-neutron reactors differ from the rods of thermal-neutron reactors only in having a somewhat greater diameter. Cans are not necessary, since the boron, being a good moderator, is also a good absorber of delayed neutrons.

Above, we have examined only the major difficulties encountered in the development of aircraft nuclear reactors. Scientists, engineers, and designers working in the field of aircraft reactor construction, are often faced with the necessity of solving a number of other problems and of overcoming of other difficulties in the field of design, engineering, and operation. However, no matter how great these difficulties may appear at any moment, they are not insuperable.

Heat Exchangers

The heating of the working medium of an atomic engine directly in the reactor is often unprofitable and sometimes impossible.

In the reactor, it is possible to heat an intermediate heat-transfer agent

which yields its heat in a heat exchanger to the working medium of the engine. The presence of an intermediate heat-transfer agent of circulating pumps, and of heat exchangers results in an increase in the weight of the power plant. Therefore, an analysis of the system for the intermediate heat-transfer agent is of considerably greater importance for an aircraft atomic power plant than for any other type.

The intermediate heat-transfer agent system must primarily provide for dissipation of all the heat liberated in the reactor. Then this heat has to be transferred to the heat exchanger and there again transferred to the working medium of the engine. Let us examine, in sequence, how these problems are solved. In order to prevent fluctuations in the temperature of the reactor, exactly as much heat as is liberated must be dissipated. If more heat is liberated than is removed, the reactor temperature will rise. The automatic control will go into operation to reduce the liberation of heat in the reactor, and the desired reactor temperature will be restored. If, on the other hand, more heat is removed than liberated, this same temperature control will increase the liberation of heat to equalize it with the heat dissipation.

Thus, the reactor will produce exactly as much heat as the heat-transfer agent is able to remove from it.

The ability of the heat-transfer agent to accumulate heat is measured by its thermal capacity, i.e., by the amount of heat required to raise the temperature of 1 kg of heat-transfer agent by one degree. The amount of heat removed from the reactor per second is determined by the formula

$$Q = cm(t_{fin} - t_{in}),$$

where Q is the amount of heat absorbed per second;

c is the thermal capacity of the heat-transfer agent;

m is the mass of the heat-transfer agent passing through the reactor per second;

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

t_{fin} is the final temperature of the heat-transfer agent;

t_{in} is the initial temperature of the heat-transfer agent.

The final temperature to which the heat-transfer agent is heated is limited by the mechanical strength or the corrosion properties of the reactor material. The initial temperature of the heat-transfer agent, i.e., the temperature at which it enters the reactor and the heat exchanger, is approximately equal to the temperature to which the working medium of the engine is heated. The greater the thermal capacity of the heat-transfer agent, the less of it will be needed to transfer the amount of heat which must pass through the reactor per second. When a heat-transfer agent of high thermal capacity is used, the total amount of heat-transfer agent in the system and its rate of flow can be reduced or, in other words, pumps of lower delivery can be used.

In order to transfer as much heat into the heat-transfer agent within the reactor as it is capable of absorbing, the reactor must have an adequate heating surface. The ability of the heating surface to transmit heat to the heat-transfer agent is measured by the coefficient of heat transfer. The coefficient of heat transfer indicates the quantity of heat that will be transmitted to the heat-transfer agent by 1 m^2 of heating surface in the course of an hour, when the temperature difference between the heating surface and the heat-transfer agent is one degree. The coefficient of heat transfer from a metal heating surface to air, under the service conditions in an aircraft reactor, amounts to several hundred $kcal/m^2 \cdot deg \cdot hr$, while to helium it is several thousand $kcal/m^2 \cdot deg \cdot hr$, and to liquid metal it is several tens of thousands of $kcal/m^2 \cdot deg \cdot hr$.

In order to provide for the transfer of heat to the heat-transfer agent, the area of heating surface of an aircraft reactor must be several hundred square meters. To have so large an area in a reactor of small dimensions, several thousand channels must be provided, through which the heated heat-transfer agent may branch out.

The transfer of heat from the heat-transfer agent to the working medium of the engine takes place in the heat exchanger. The heat-exchanging surface, at a heat-transfer agent and a working medium of specific parameters, is determined on the basis of the coefficient of heat transfer from the heat-transfer agent into the wall of the heat exchanger, of the coefficient of thermal conductivity of the heat-exchanger material, and of the coefficient of heat transfer from the walls of the heat exchanger to the working medium.

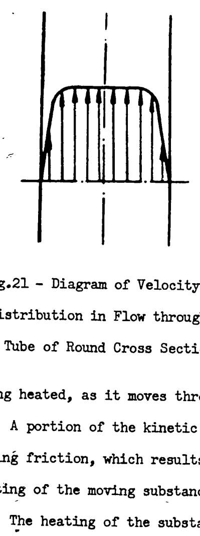

Fig.21 - Diagram of Velocity Distribution in Flow through a Tube of Round Cross Section

Both the heat-transfer agent in the reactor and the working medium in the heat exchanger are in motion and must overcome the force of friction with the heating substance. Figure 21 shows the velocity distribution of the flow of the body being heated, as it moves through a duct of round cross section.

A portion of the kinetic energy of the body being heated is expended in overcoming friction, which results in losses due to friction. The more intensive the heating of the moving substance, the greater will be the friction losses.

The heating of the substance driving an atomic engine, as we indicated above, is either effected directly in the reactor or in a heat exchanger. The design of the heat exchanger depends both on the heat-transfer agent used and on the working medium of the atomic power plant. But the general problem to be solved in all heat exchangers is that of providing a large heat-exchange surface in a heat exchanger of small dimensions and weight. The main types of heat exchangers of possible use in aircraft atomic power plants are the tubular (honeycomb) and the slotted types (Fig.22).

A tubular heat exchanger resembles the ordinary honeycomb radiator. It con-

STAT

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

sists of a large number of fine tubes in a single housing, with the tubes spaced at certain intervals. Through the tubes flows the working medium to be heated. The

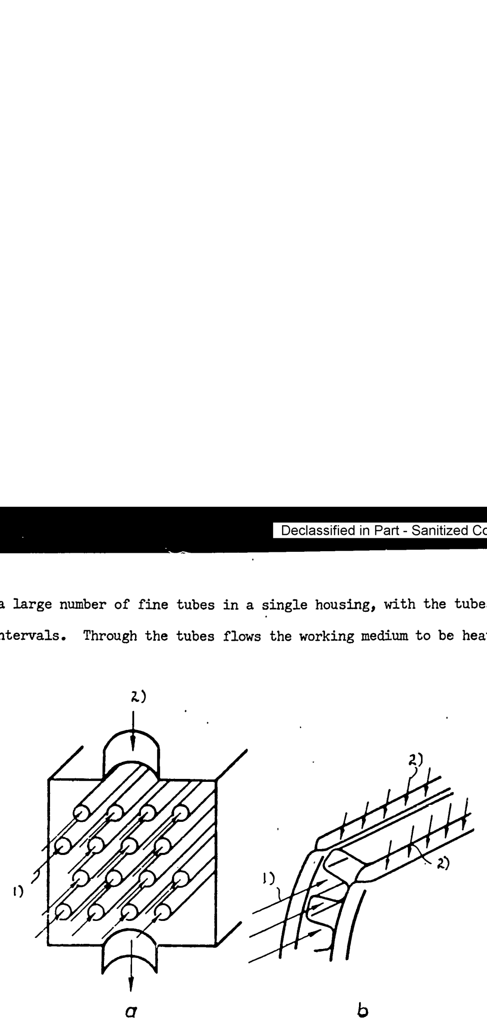

Fig.22 - Diagrams of Heat Exchangers: a) Tubular, b) Slotted

1) Air; 2) Helium

heat-transfer agent washes the outside of the tubes. The slot-type heat exchanger is a kind of "layer cake" whose successive layers are represented by the working medium of the engine and the heat-transfer agent. The layers are separated by thin sheets of metal, mechanically connected to provide rigidity of construction.

In both kinds of heat exchangers, the working medium of the engine and the heat-transfer agent may either be made to move in opposite directions or perpendicular to each other, or parallel in the same direction. It is obvious that the most effective form is that of opposing motion of the working medium and the heat-transfer agent, or what is known as countercurrent operation. In this design, the most uniform and highest heating of the working medium is obtained. In designing heat exchangers, an attempt is made to achieve the required heating of the working medium with the lowest possible friction losses.

A difficult problem is that of keeping the heat exchanger free of deformation due to temperature. On heating, as we know all metals expand, except for certain special alloys. The heating temperature of various portions of a heat-exchanger is not identical, so that the degree of heat deformation will vary. If no special measures are taken, the heat exchanger may break down. This danger is particularly great when the heat exchanger is heated and cooled along with the heat-transfer agent at the instant of starting and stopping the engine, when the inequality of heating is particularly great.

An important problem is that of developing reliably operating pumps for transferring the liquid-metal heat-transfer agents. The difficulties in providing reliable seals between the rotating shaft of the pump and its fixed housing, at exceedingly high temperatures, has led to the idea of substituting electromagnetic pumps for the usual mechanical pumps. The operating principle of electromagnetic pumps for liquid metals is based on utilization of the force of interaction of an electric current and a magnetic field. The tube with the liquid metal is placed within a magnetic field. Electrodes are inserted into the tube, and a current is sent through the metal. The liquid metal is thus subjected to an expulsive force and starts flowing through the tube.

The use of a liquid-metal heat-transfer agent requires an auxiliary system for heating the heat-transfer agent,since, at the usual temperatures of the ambient air particularly in winter, even the most fusible metal alloys available for use as heat-transfer agents will be in the solid state. This inconvenience is eliminated if gases are used as the heat-transfer agents. Hydrogen and helium, or a noncombustible mixture of hydrogen and helium, are particularly suited to this purpose. Less desirable are nitrogen, carbon dioxide, etc. In order to increase the coefficient of heat transfer and the volumetric thermal capacity of a gas, it has to be compressed to some tens of atmospheres.

An interesting special feature of the practical application of gaseous heat-transfer agents is the possibility of providing for their "self-circulation". The gaseous heat-transfer agent compressor may be used to start the rotation of a gas turbine, by using the energy of the heat-transfer agent itself. In this case, the gaseous heat-transfer agent moves first from the reactor to the turbine, then to the heat exchanger, and from there to the compressor which compresses the gas and returns it to the reactor. The result is the usual closed cycle of operation of a gas turbine, one specific feature of which is the fact that it does not perform useful mechanical work. This explains the negligible reduction in the temperature of the gaseous heat-transfer agent within the turbine. This reduction in temperature is particularly small with hydrogen and helium.

The use of metals in vapor form as heat-transfer agents makes it possible to utilize not only the thermal capacity but also the latent heat of evaporation to transfer heat.

The desirability of this will be shown in the following example. Each kilogram of gaseous sodium condensed at a temperature of 880°C, liberates about 1000 kcal in a heat exchanger. The temperature of the heat exchanger wall, during this process is equal to the temperature of condensation. In order to transfer the same amount of heat to the heat exchanger by means of 1 kg liquid sodium at the same wall temperature, the sodium would have to enter the heat exchanger at an initial temperature of 4200°C. If we take as the initial temperature of liquid sodium the more realistic value of 1200°C, it would require 13 - 15 kg of liquid sodium to equal the efficacy of 1 kg of sodium vapor.

If we refrain from transferring heat by means of the thermal capacity of gaseous metals and make use only of the latent heat of evaporation, then the temperature in the entire heat-transfer agent system will be virtually identical. This temperature may be set at maximum permissible level for the structural materials of the heat-transfer system. When this is the case, the mechanical strength of the material will be utilized to a much greater degree, and materials not in

such short supply can be used for the purpose. Thus, the use of vaporized metal heat-transfer agents is advantageous both in terms of weight and in terms of economics.

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

CHAPTER III

POSSIBLE DIAGRAMS OF AIRCRAFT ATOMIC POWER PLANTS (AAPP)

The structural design of an atomic power plant discussed in Chapter I (Fig.8) may be used both in aviation and in other fields of transport. To do so, it is necessary to replace the propeller by an electric generator and to use electric motors for rotating the propeller of a steamship, the driving wheels of an electric locomotive, etc.

It seems logical that atomic power plants of designs especially adapted for aviation will be developed to serve the modern types of aircraft engines. In accordance with the types of aircraft engines now in use, the possible types of AAPP may be divided into three major groups: 1) rocket engines; 2) three types of ramjet engines: a) true athodyds, b) turbocompressor engines, c) motor-driven compressors; and 3)turboprop engines.

Each of these groups contains a large number of engine designs differing in complexity in accordance with the needs of various types of aircraft. Obviously, certain designs will be realized in the comparatively near future. Others will require a longer period of development from the scientific, technological, and particularly from the metallurgical viewpoint before they can become a reality.

Certain designs will probably remain on paper only.

In this Chapter, we will review the most typical designs of aircraft atomic power plants and will discuss the possibilities of their application.

Atomic Rocket Engines

Rocket is the name given to reaction engines that do not require atmospheric air for their functioning. The simplest type is the powder rocket engine. This type comprises a powder-filled cylindrical chamber, terminating in a specially profiled jet nozzle (Fig.23). As the powder undergoes combustion, a large quantity of

Fig.23 - Schematic Sketch of Powder Rocket

a) Warhead; b) Powder charge; c) Jet nozzle

gases is generated, which press outward in all directions. The pressure of the gases on the side walls is balanced (Fig.24). The force of the pressure of the gases on the front wall is incompletely compensated, since the area subject to gas

Fig.24 - Schematic Sketch of the Pressure Distribution of Combustion Gases

pressure on the nozzle side is smaller and since the pressure of the gases in a jet nozzle decreases with increasing velocity. This excess gas pressure is the reactive force. A reactive force is produced only if there is a difference in surface areas, i.e., if one side of the rocket is provided with an aperture through which the powder gases can escape. The development of reactive force is impossible without an ejection of gases. The greater the gas pressure, the greater will be the velocity

CHAPTER III

POSSIBLE DIAGRAMS OF AIRCRAFT ATOMIC POWER PLANTS (AAPP)

The structural design of an atomic power plant discussed in Chapter I (Fig.8) may be used both in aviation and in other fields of transport. To do so, it is necessary to replace the propeller by an electric generator and to use electric motors for rotating the propeller of a steamship, the driving wheels of an electric locomotive, etc.

It seems logical that atomic power plants of designs especially adapted for aviation will be developed to serve the modern types of aircraft engines. In accordance with the types of aircraft engines now in use, the possible types of AAPP may be divided into three major groups: 1) rocket engines; 2) three types of ram-jet engines: a) true athodyds, b) turbocompressor engines, c) motor-driven compressors; and 3)turboprop engines.

Each of these groups contains a large number of engine designs differing in complexity in accordance with the needs of various types of aircraft. Obviously, certain designs will be realized in the comparatively near future. Others will require a longer period of development from the scientific, technological, and particularly from the metallurgical viewpoint before they can become a reality.

Certain designs will probably remain on paper only.

In this Chapter, we will review the most typical designs of aircraft atomic power plants and will discuss the possibilities of their application.

Atomic Rocket Engines

Rocket is the name given to reaction engines that do not require atmospheric air for their functioning. The simplest type is the powder rocket engine. This type comprises a powder-filled cylindrical chamber, terminating in a specially profiled jet nozzle (Fig.23). As the powder undergoes combustion, a large quantity of

Fig.23 - Schematic Sketch of Powder Rocket

a) Warhead; b) Powder charge; c) Jet nozzle

gases is generated, which press outward in all directions. The pressure of the gases on the side walls is balanced (Fig.24). The force of the pressure of the gases on the front wall is incompletely compensated, since the area subject to gas

Fig.24 - Schematic Sketch of the Pressure Distribution of Combustion Gases

pressure on the nozzle side is smaller and since the pressure of the gases in a jet nozzle decreases with increasing velocity. This excess gas pressure is the reactive force. A reactive force is produced only if there is a difference in surface areas, i.e., if one side of the rocket is provided with an aperture through which the powder gases can escape. The development of reactive force is impossible without an ejection of gases. The greater the gas pressure, the greater will be the velocity

STAT STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

of flow and the reactive force.

A powder rocket engine, in which the powder undergoes combustion within a few seconds, is useful for aviation only as an auxiliary engine as a take-off assist for heavily loaded aircraft.

In liquid-fuel rocket engines, the period of operation is considerably longer. This type of engine has a cylindrical combustion chamber equipped with a jet nozzle (Fig.25). Fuel and oxidizer are sprayed into the combustion chamber. The fuel burns, while the oxidizer sustains the combustion. This results in the generation of high-temperature gases which are ejected through the jet nozzle, resulting in a

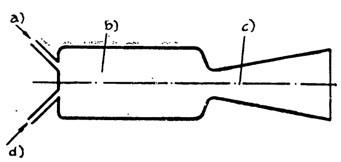

Fig.25 - Schematic Diagram of a Liquid-Fuel Rocket Engine

a) Fuel; b) Combustion chamber; c) Jet nozzle; d) Oxidizer

reactive force. The higher the temperature of the gases, the slower will be their discharge through the jet nozzle at the same pressure in the combustion chamber, i.e., at the same reactive force.

Obviously, the production of a reactive force in this type engine requires: 1) the production of a large quantity of gases compressed to high pressure; 2) the heating of these gases to the highest possible temperature; 3) the ejection of these gases through a jet nozzle at the highest possible velocity.

These same problems must necessarily be solved in an atomic rocket engine. The simplest design of such an engine is presented in Fig.26. A pump is used to deliver the working medium (i.e., the material for producing the gases) from the tanks to the reactor, under high pressure. Passing through the ducts of the reactor,

the working medium is converted to gas, heated to high temperature, and then ejected through the jet nozzle.

The period of operation of an atomic rocket engine is limited by the supply of working substance that can be housed aboard an aircraft. Because of the very high

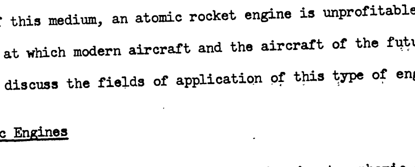

Fig.26 - Schematic Diagram of an Atomic Rocket Engine

a) Tank with working medium; b) Pump; c) Reactor; d) Jet nozzle;

e) Control rods

consumption of this medium, an atomic rocket engine is unprofitable for flights at the altitudes at which modern aircraft and the aircraft of the future customarily fly. We will discuss the fields of application of this type of engine in Chapter V.

Ram-Jet Atomic Engines

In ram-jet atomic engines, the working medium is atmospheric air heated by the combustion of a liquid fuel, usually kerosene. The consumption of kerosene is no more than 2 - 3% of the air passing through the engine, a ram-jet engine is able to function for a considerably longer period of time aboard an aircraft than a liquid-fuel rocket engine. Ram-jet engines include: pulse jets, true athodyds, turbojets, and engines with motor-driven compressors.

The intermittent ram-jet engine (Fig.27) is a cylindrical tube, whose front end is closed off by a valve-type grill and whose rear section ends in a jet nozzle. This engine functions in the following manner: The fuel (gasoline) is injected through nozzles and is immediately ignited by a sparkplug. The gasoline combustion

STAT STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

products and the hot air seek to escape through the jet nozzle. The pressure of the gases on the valve-type grill closes the valves and thus produces thrust. As the gases are ejected from the jet nozzle at high velocity, they continue to flow by inertia even after the pressure in the combustion chamber has returned to atmospheric

Fig.27 - Design of Intermittent Ram-Jet Engine

a) Fuel; b) Sparkplug; c) Jet nozzle; d) Valve grill;

e) Combustion chamber

pressure. This creates a vacuum in the combustion chamber and a new charge of atmospheric air is sucked through the valves. Then gasoline is again injected, and the cycle is repeated. A total of 80 - 100 cycles occur in this engine within one

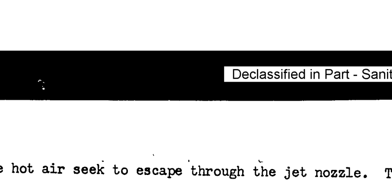

Fig.28 - Schematic Sketch of a Ram-Jet Engine

a) Diffuser; b) Fuel; c) Sparkplug; d) Jet nozzle;

e) Combustion Chamber

second, each accompanied by pressure surges or pulsations. Therefore this type of engine has become known as a pulse jet.

The ram-jet engine is simpler in construction (Fig.28) and requires no valve grill. However, in order for a ram-jet engine to function, the aircraft on which it is installed must fly at high speed. The relative air sucked into the nose of the ram jet, called the diffuser, is decelerated. Its velocity decreases, while the pressure increases. Fuel, ignited by a sparkplug, is injected into the air compressed by the velocity head. The combustion products mixed with air are ejected through the jet nozzle at high velocity. The reactive force results from the pressure drop between the nose (at the diffuser) and the rear (at the jet nozzle).

In 1929, B.S.Stechkin, member of the Academy, was the first in the world to develop and publish the fundamentals of the theory of ram-jet engines. In addition to a number of other important laws, he determined the relationship between the reactive force of a ram-jet engine and the velocity difference between the exhaust of gases from the jet nozzle of the engine and the flying speed:

$$P = G_a \frac{c_f - c_{fl}}{g},$$

where P is the reactive thrust;

G_a is the airflow through the engine;

c_f is the rate of flow;

c_{fl} is the flying speed;

g is the acceleration of gravity.

The equation permits determination of the reactive force, without knowledge of the gas pressure distribution within the engine, merely on the basis of the flying speed, the exhaust velocity of the gas, and the flow of air through the engine.

The greater the exhaust velocity, the greater will be the reactive thrust.

A major shortcoming of the ram-jet engine is the fact that it can create a reactive force only at high flying speeds. The turbojet engine (Fig.29) lacks this shortcoming. The operating principle of this engine is as follows: As the engine is run on the ground, air is sucked in by the compressor and compressed to several at-

STAT STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

mospheres pressure. The compressed air is then directed into the combustion chamber. The fuel is injected into this chamber. The combustion products rotate a turbine whose shaft is connected with the compressor; the combustion products are then

Fig.29 - Diagram of a Turbojet Engine

a) Diffuser; b) Compressor; c) Turbine; d) Jet nozzle;

e) Kerosene injectors; f) Combustion chamber

ejected through the jet nozzle. In this engine also, the reactive force is the resultant of the forces of the air pressure and the combustion products over the entire inside surface of the engine, and also may be calculated by Stechkin's equation.

At the dawn of the development of ram-jet engines, when they were still of low power, not a turbine but an internal combustion aircraft engine was used for driving the compressor. This type of ram-jet engine was called an engine with motor-compressor drive. This type did not come into wide use, in view of the fact that a gas turbine can develop a much greater power than an internal combustion engine of the same weight.

Except for the pulse jet, all types of ram-jet engines may be run by atomic energy. Let us examine in sequence a number of probable designs of atomic ram-jet engines.

Atomic Ram-Jet Engine (ARJE)

The atomic ram-jet engine (Fig.30) is the simplest type of atomic power plant.

What it amounts to is a "flying reactor" with a diffuser in the nose and a jet nozzle at the rear.

Within the speed range exceeding the speed of sound by a factor of not more than 3 - 4, the ram jet develops increased thrust in proportion to the flying speed. Therefore, this type is used for high-speed aircraft. In flight at supersonic speeds, a shock wave develops ahead of the engine, which results in retardation of the increase in engine thrust as the flying speed increases. Installation ahead of the engine of a cone such as that shown in Fig.30 facilitates reduction in the intensity of the shock wave and thus leads to a reduction in the loss of thrust. The cone can be used for housing electric motors to operate the control rods of the reactor.

One of the major parameters used for rating of jet engines is the specific thrust. If the thrust of an engine is divided by the number of kilograms of air passing through the engine per second, the magnitude of the specific thrust is obtained. The greater the thrust created by each kilogram of air, the more ideal is the engine.

The specific thrust of a ram jet is determined by the altitude and speed of flight, the design of the diffuser and jet nozzle, and the temperature to which the air is heated in the engine. The higher the temperature of the air, the greater the specific thrust. In modern ram-jet engines, the air is heated to approximately 1500°C. It is impossible today to heat the air in an ARJE to this temperature. The structural materials of modern reactors can only withstand temperatures of the order of 1000 - 1100°C, and the temperature of the heated air will be even lower than this. Moreover, the friction losses, as air moves through the channels honeycombing the reactor, will be considerably greater than the losses in the combustion chamber of the ordinary ram-jet engine. The result is that the specific thrust of and ARJE is inferior to that of a conventional type of ram-jet engine.

However, the thrust of an engine is determined not only by its specific thrust

STAT

STAT

but also by the air throughput, i.e., by the quantity of air passing through the engine per second. If the dimensions of an ARJE are larger than those of a conventional ram jet, then a larger amount of air will flow through it, and its thrust

Fig.30 – Schematic Diagram of an Atomic Ram-Jet Engine

a) Nose cone; b) Control rod; c) Reactor; d) Jet nozzle

will be greater. There is no need to worry about the fact that the increase in size of the ARJE will increase the consumption of nuclear fuel. A fuel supply sufficient for the entire possible service life of an ARJE is charged into the reactor at a single time so that there is no need to refuel during the life of the engine.

The maximum flying speed may be increased either by raising the thrust of the engines or by reducing the drag of the aircraft. If the drag is reduced and the thrust remains the same, the maximum speed will increase.

In terms of increasing the maximum speed of the aircraft, the perfection of an aircraft engine is rated by its frontal thrust. The frontal thrust of an engine is the thrust of that engine per square meter of frontal cross-sectional area. The cross-sectional area determines the drag experienced by the engine. The greater the frontal thrust, the smaller the cross-sectional area of the engine has to be to reach a given total thrust, or the greater will be the maximum flying speed attainable. Therefore, it is desirable to have the greatest possible frontal thrust.

At a given rate of airflow, the cross-sectional area of the engine is determined either by the dimensions of the diffuser or by the dimensions of the reactor

or of the jet nozzle. The diameter of the jet nozzle usually is less than that calculated in the original design, so as to prevent the jet nozzle from exceeding the overall dimensions of the engine. This "cutdown" of the jet nozzle causes some reduction in thrust, but at the same time the drag of the engine is decreased to an even greater degree. Therefore, it may be considered that the cross-sectional dimensions of an ARJE are determined either by the diffuser or by the reactor. Calculations show that only at very high flying speeds, approximately three times as high as the speed of sound, will the lateral dimensions be determined by the diffuser. At speeds less than 2.5 times the speed of sound, the diameter of the reactor, will exceed the diameter of the diffuser. This means that, in order to increase the frontal thrust, an effort must be made to reduce the cross-sectional area of the reactor.

If the air throughput of the engine is taken as given, then at a flying constant speed the cross-sectional area of all channels of the reactor will be smaller, the greater the rate of airflow through these ducts.

Heating of the air as it flows through the ducts is accompanied by an increase in its velocity, since the density of air decreases with increasing temperature while the cross-sectional area of the duct remains constant. The air velocity at the reactor outlet is several times greater than at its inlet. At a given air velocity at the inlet, its speed at the outlet of the reactor will equal the speed of sound. A further increase in the air velocity at the reactor inlet and, consequently, free passage of air through the engine is impossible. What happens is "cutoff" of the reactor.

An engine will have its greatest frontal thrust when the velocity of the air at the reactor outlet is equal to the speed of sound. If, in this case, the temperature of the heating surface is increased, the temperature of the air will also rise. This causes the velocity of the air at the reactor outlet to increase somewhat, but as usual it will equal the speed of sound when a temperature of specific magnitude is attained. The velocity of the air at the reactor input decreases and the passage of air through the engine is reduced.

What will be accomplished with such an engine? The specific thrust will increase with increasing air temperature increases, and the rate of flow will decline. The thrust of the engine, equal to the product of the specific thrust and the airflow, will either not change at all or change very little. Calculation results showing the relationship between frontal thrust and speed of sound for two ARJE, in which the temperatures of the heating surface of the reactor are 1100°C and 1600°C, respectively, are presented in Fig.31 in the form of curves. A comparison of these curves shows that it is not always necessary to strive for an extraordinary increase in the air temperature by increasing the temperature of the heating surface of the reactor.

How can the thrust of an ARJE be varied in flight? The thrust of a conventional ram jet is changed by changing the amount of fuel injected into the air. Control of the thrust of an ARJE is even simpler and may be accomplished by means of the regulating (control) rods of the reactor. To reduce the thrust of an ARJE, the rod is pushed into the reactor, thus reducing the amount of heat liberated by the reactor to the desired level. This causes the air temperature at the reactor output to drop and, consequently, reduces the thrust. To increase the thrust, the thermal capacity of the reactor must be increased by withdrawing the control rods. To prevent an excessive rise in temperature of an ARJE reactor, a temperature control has to be provided.

In addition to the above-discussed ARJE design, in which the air is heated directly in the reactor, another design may be conceived, namely one involving heating of the air by means of an intermediate heat-transfer agent. Figure 32 presents a schematic diagram of an ARJE in this category. The air compressed by the velocity head is heated in a heat exchanger. The transfer of heat from the reactor to the air is performed by an intermediate heat-transfer agent, which is circulated by a

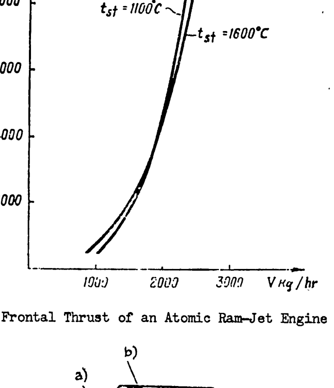

Fig.31 - Ratio of Frontal Thrust of an Atomic Ram-Jet Engine to Flying Speed

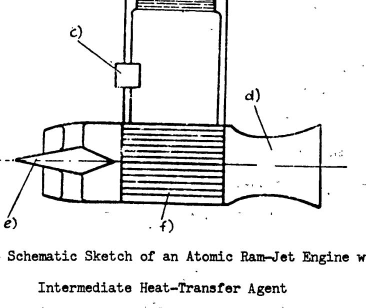

Fig.32 - Schematic Sketch of an Atomic Ram-Jet Engine with Intermediate Heat-Transfer Agent

a) Control rod; b) Reactor; c) Pump; d) Jet nozzle; e) Nose cone; f) Heat exchanger special pump. This ARJE design permits the use of a much smaller reactor. The coefficient of heat transfer from the heating surface of the reactor to the heat-transfer agent is many times larger than to air. Therefore, the heating surface of the heat-transfer agent need be only a fraction of that in the former case, and the dimensions of the reactor may be reduced accordingly.

However, atomic ram-jet engines using intermediate heat-transfer agents are more complex, both in design and in operation. For example, they will have poor pickup. Pickup is the capacity of an engine rapidly to gain thrust at the desire of the pilot, from any operating condition up to maximum thrust. The greater the pickup of the engine, the more maneuverable the aircraft will be. The thrust of an ARJE with direct heating of air in the reactor begins to increase at the instant of pulling out the control rod, whereas the thrust of an ARJE with an intermediate heat-transfer agent begins to increase only after the heat-transfer agent is heated slightly.

A basic drawback of the ram-jet engine is its inability to produce thrust when on the ground and at low flying speeds. This shortcoming makes it impossible to use an ARJE as the sole form of propulsion. It must necessarily be used in combination with other types of engines to permit the aircraft to take off and to accelerate to the speed at which the ARJE produces adequate thrust.

<u>Atomic Turbojet Engines (ATJE)</u>

The turbojet engine is the predominant type used in modern jet aircraft. This is due to the fact that the engine is simpler in design than the turboprop engine, which can compete with it insofar as fuel consumption is concerned. In addition, an aircraft with a turbojet engine can reach significantly greater speeds than one with a turboprop engine, in view of the fact that, at supersonic flying speeds, the efficiency of thrust production by a propeller diminishes.

The ATJE is the simplest of atomic aircraft engines which can be used entirely

alone. Installation of an ATJE on an aircraft permits it to take off independently, to fly with good maneuverability over the entire possible range of speeds and altitudes, and also to make a normal landing. Let us discuss the possible design variants of an ATJE. The simplest is a design that differs from that of the ordinary turbojet engine only in that the combustion chamber is replaced by a reactor. This design is illustrated in Fig.33. Air from the compressor enters the reactor, which is placed between the compressor and the turbine. A portion of the energy of the heated air is consumed in the turbine for rotating the compressor. Another portion is converted into the kinetic energy of the exhaust from the engine, within the jet nozzle.

Proper selection of the compression ratio of the compressor is a major factor

Fig.33 - Schematic Sketch of an Atomic Turbojet Engine

a) Nose cone; b) Compressor; c) Control rods; d) Reactor;

e) Turbine; f) Jet nozzle

in designing a turbojet engine with high specific parameters. In projecting an aircraft engine, the designer knows the speed at which the aircraft and its engine will fly. He selects a compression ratio permitting development of the greatest possible thrust at this calculated flying speed, with the lowest possible fuel consumption and the smallest possible engine weight. It is usually impossible to satisfy all three of these requirements at once. If the compression ratio is so selected that the specific thrust of the engine is at its maximum, the fuel consumption will be high. If minimum possible fuel consumption is desired, the specific thrust will

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

decrease. The designer determines which factor is more important for the aircraft and determines the compression ratio on that basis. Thus, an engine designed for a long-range bomber must have minimum fuel consumption. As a result, the saving in fuel weight during a flight of many hours duration permits an increase in range. On the other hand, interceptor aircraft require maximum frontal thrust. The excess consumption of fuel that is inevitable in this case is not of importance, since the flying time of such an interceptor may be measured in minutes.

How then shall we approach the selection of the compression ratio for an ATJE? The fact that ATJE are used for high-speed aircraft indicates that the compression ratio must be such as to yield maximum frontal thrust. It is desirable, of course, that the engine weigh as little as possible. However, it must not be forgotten that the main portion of the weight of an atomic aircraft engine is the weight of the radiation shielding. Therefore, a reduction in engine weight at the expense of a reduction in frontal thrust will hardly be desirable.

Thus we have come to the conclusion that the compression ratio of the compressor of an atomic engine for aircraft must be such as to give maximum frontal thrust. As in conventional turbojet engines, it is to be expected that, with an increase in the calculated flying speed, the compression within the compressor will be reduced. This is explained by the increase in compression due to the velocity head. For example, for sea-level operation of an engine the optimum compression ratio of a compressor is six. At flying speeds equal to that of sound, the compression of the air due to the velocity head is a little less than two, and in order to attain a total compression ratio of six, the compression in the compressor need be only slightly above three. This is a crude example and does not reflect all the complexities of the phenomena that must be taken into consideration in calculating the optimum degree of compression within a turbojet compressor designed to yield high flying speeds, but it is clear from this that, at increasing flying speed, compression ratio of a turbojet compressor should be reduced.

When the daily press carried the first reports on possible designs of atomic aircraft engines, it was believed that the compression ratio of an ATJE engine would have to be considerably greater than that of a conventional turbojet engine. This was explained by the increase in heat emission from a reactor with increasing pressure of the airflow through this reactor and the attendent possibility of reducing the size of the reactor accordingly. The possibility of designing atomic ram-jet engines was completely denied. It was held that the degree of compression of the air due to the velocity head, even at high flying speeds, would be insufficient to drive the air through the ducts of the reactor. Later, when the required calcula-

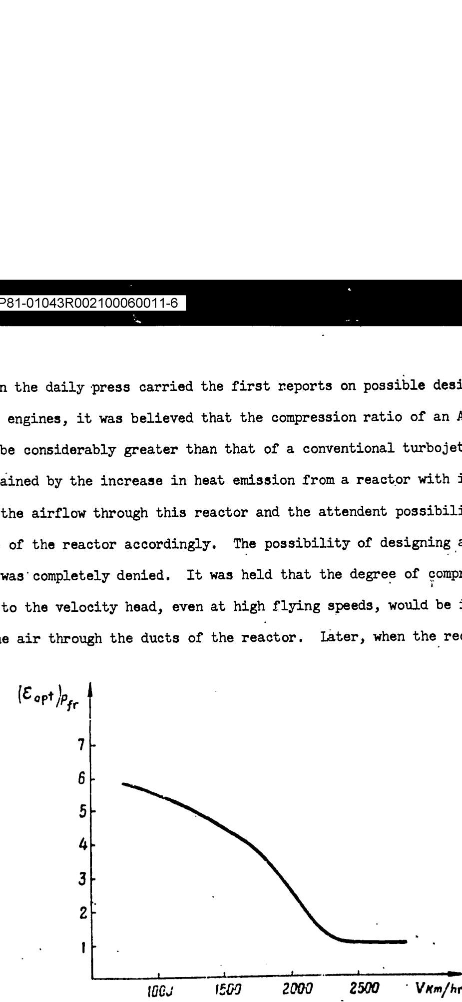

Fig.34 – Optimum Calculated Compression Ratio of an Atomic Turbojet Engine, to Obtain Maximum Frontal Thrust, as a Function of the Flying Speed

tions had been made, it appeared that the optimum compression ratio of an ATJE compressor, calculated to yield a maximum frontal thrust, differs much less from the optimum compression ratio of a conventional turbojet than had previously been assumed. The nature of the relationship of the optimum compression ratio of the compressor of an ATJE and the flying speed is illustrated in Fig.34. This curve per-

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

mits selecting the compression ratio of the ATJE compressor for any desired flying speed. It is obvious that, at high flying speeds of M = 2.5 - 3 or more, the optimum compression ratio is unity, i.e., that at these speeds an atomic ram-jet engine develops greater frontal thrust than does an atomic turbojet engine. This again confirms the desirability of using ARJE for high flying speeds.

As indicated above, an increase in the compression ratio of the compressor for an ATJE results in a better dissipation of heat from the reactor and permits a reduction in its weight. However, at high flying speeds, the total degree of compression of the air due to the velocity head and due to the compressor rises excessively. The temperature of the air past the compressor increases to such a degree that all that is possible within the reactor is a very small rise in the heating of the air

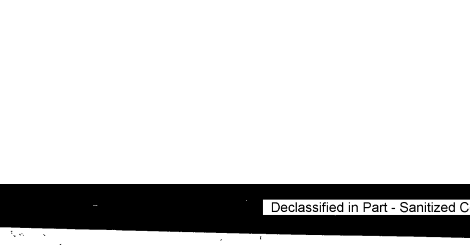

Fig.35 - Atomic Turbojet Engine with Two-Stage Compressor and Intermediate Cooling of Air

a) Nose cone; b) First-stage compressor; c) Cooling-air scoop; d) Second-stage compressor; e) Control rods; f) Two-stage turbine; g) Jet nozzle; h) Reactor; i) Outlet for cooling air; j) Heat exchanger

to that permissible in terms of the thermal strength of the reactor. The thrust of an engine decreases with a reduction in the amount of heat delivered to the air. A

y be avoided if the air is cooled during the compression process.

With this object, the ATJE compressor may be designed as a multistage type, with cooling after each stage. Figure 35 illustrates a two-stage ATJE compressor. The heat exchanger between the compressor stages functions basically as a ram-jet engine when both air intake and ejection are properly laid out, and will create additional thrust.

The simplest design for an ATJE, illustrated in Fig.33, permits obtaining the highest specific parameters. In this case, the air duct becomes a uniflow duct where the airflow through the engine is at all times parallel to the engine axis

Fig.36 - Diagram of an Atomic Turbojet Engine with Reactor Outside the Engine

a) Nose cone; b) Control rod; c) Compressor; d) Reactor; e) Turbine; f) Jet nozzle

in a straight line, so that the hydraulic resistance is at a minimum. The air is heated directly in the reactor without an intermediate heat-transfer agent. This simplifies the design and eliminates excessive heat loss. However, this design, which is simple in principle is exceedingly difficult to realize. The shaft connecting the turbine with the compressor has to pass through the reactor. Cooling the shaft under these conditions becomes a difficult and actually, one might say, the key problem. The point is that the shaft not only becomes heated as a result of heat transfer from the hot reactor parts, but considerable liberation of heat within the shaft itself, due to the scattering and absorption of neutrons and gamma rays by the shaft material. So much heat is liberated in the shaft that cooling of the shaft changes from a simple engineering matter to a complex problem, whose solution will govern the very possibility of developing an ATJE on the basis of this "simplest" design.

In order to avoid the effect of reactor radiations on the shaft, the reactor could be installed outside the engine and deliver the air to the engine through special ducts. Figure 36 illustrates an engine of this type. The air duct of such an engine can no longer be considered a ram jet. The air passing through the engine and the reactor undergoes several changes in direction. This results in additional

Fig.37 - Schematic Sketch of an Atomic Turbojet Engine with Intermediate Heat-Transfer Agent

a) Nose cone; b) Compressor; c) Pump; d) Control rod; e) Reactor; f) Heat exchanger; g) Turbine; h) Jet nozzle

hydraulic losses, which reduce the specific thrust of the engine. In addition, there are inevitable heat losses through the walls of the ducts as the air moves from the reactor to the turbine, which also impairs the specific parameters of the engine. However, the reactor in this case has been moved far outside the engine, and provision for shielding from radiation therefore becomes significantly simpler.

To realize an ATJE on the basis of this general scheme apparently is easier than on the basis of the design presented in Fig.33. An increase in hydraulic losses can be prevented by using a slightly more complicated design. Figure 37 shows a design for an ATJE using an intermediate heat-transfer agent. The function of the intermediate heat-transfer agent is that of transmitting heat from the reactor to the air. The advantages of this ATJE are the same as those of an atomic ram-jet engine with intermediate heat-transfer agent: a comparatively small reactor, and lower hydraulic losses than those in the engine designed in accordance with Fig.36. The shortcomings lie in the field of greater complexity of design and operation.

Many modern turbojet engines are equipped with boosters. Boosting is an increase in the thrust of an engine above its maximum for a short period by means of some "overloading" of the engine. The majority of turbojet engines with boosters are provided with what is known as afterburner chambers placed between the turbine and the jet nozzle. Considerably more air is delivered to the combustion chamber of a turbojet engine than is required for burning the injected fuel; consequently, the combustion products still contain a considerable amount of oxygen. Additional fuel is injected into the after burner in which this residual oxygen is used for combustion. The temperature of the gases rises, the exhaust velocity increases, and the thrust is augmented. However, the fuel consumption almost doubled in this procedure. The temperature of the engine parts starts to rise sharply. Therefore, boosting is possible only for a brief period of time, not more than a few minutes. Usually, the boosters are turned on when there is need for rapid acceleration or for gaining altitude.

In this connection, the thought arises as to whether it might be possible to reheat the air after it has passed through the turbine of an ATJE? The simplest solution is supplementary heating with an intermediate heat-transfer agent. Figure 38 shows a schematic sketch of an ATJE with supplementary heating of the air downstream of the turbine. The heat-transfer agent moves from the reactor first to the auxiliary heat source and then, having surrendered part of its heat, proceeds to the other section of the heat exchanger where the heat going to the turbine is heated. The temperature of the air upstream of the turbine will be somewhat lower than is the case without supplementary heating; in addition, the dimensions of the turbine have to be increased somewhat so as to keep the power of the turbine at the same level. It is possible that, as far as weight is concerned, it may prove more advantageous to use two independent circulation circuits for the heat-transfer agent: one for heating the air upstream of the turbine and the other for supplementary heating of the air downstream of the turbine.

An objection to the use of an ATJE in which the air is heated directly in the

Fig.38 - Schematic Sketch of an Atomic Turbojet Engine, with the Air Heated Downstream of the Turbine

a) Nose cone; b) Compressor; c) Control rod; d) Pump; e) Reactor; f) Turbine; g) Cone; h) Jet nozzle; i) Auxiliary heat exchanger; j) Heat exchanger

reactor may be raised on the grounds that the air, having passed through the reactor, will become radioactive and will constitute a hazard for the ground crew. Let us define the extent of this possible danger. The bulk of the radioactive radiation

in the air will be argon, which constitutes 0.94% of air. Radioactive radiations may be produced by one of the isotopes of oxygen, by water vapor in the air, and also by dust. The air passing through the engine is constantly intermixed with the ambient atmospheric air, so that the concentration of radioactive argon drops rapidly. In practice, at the point where the temperature in the stream of hot air emitted from the engine drops to the point where a person entering this air stream does not suffer a burn, the radioactivity of the air has also dropped to below the danger point for the human organism. Somewhat more dangerous is the radioactive dust that may have passed through the reactor. This dust, settling on the airfield, may create a significant radiation level of rather long duration. The best methods of counteracting this phenomenon are those used to prevent dust from forming on an airfield: laying of concrete runways, proper dust removal from these strips, wetting with water before aircraft take-offs, etc.

In closing this Section, let us review data for calculation of the ATJE shown in Fig.33. The weight of the engine, including the reactor and reflector surrounding the reactor, will be 15 tons. The length of the engine will be 6.5 m and its diameter 2.3 m. At sea-level operation, the engine will develop a thrust of 32 tons. An aircraft with a flying weight of 130 tons, equipped with two such engines, will be able to develop a maximum flying speed of 2100 km/hr at an altitude of 11,000 m. The aircraft will be able to fly at this speed and altitude more than 1,000,000 km (26 times around the earth) without the need for refueling. A total of 15 kg of uranium^{235} will be consumed in the course of such a flight.

Atomic Turbojet Engine with Motor-Driven Compressor (ATJEMC)

It had been indicated above that supplementary heating of the air past the turbine causes an increase in engine thrust. It is obvious that the same result will be obtained if an auxiliary engine, not utilizing the energy of the air heated in the heat exchanger or the reactor, is used for driving the compressor. A steam or gas turbine may be used for this purpose. Figure 39 shows a schematic sketch of an ATJEMC with a mercury-vapor turbine. The mercury turbine operates on a closed cycle. A pump forces the mercury under high pressure through the reactor. The mercury is heated there and converted into vapor. The mercury vapor enters the turbine, rotates it and, after passing through a condenser, condenses. The liquid mercury is recycled by the pump into the reactor.

The mercury turbine rotates the compressor, which takes in air, compresses it,

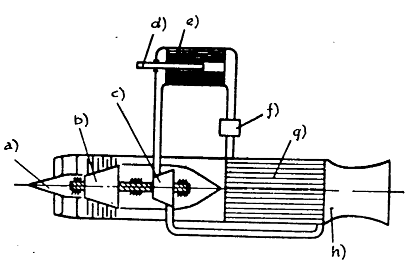

Fig.39 - Schematic Sketch of an Atomic Turbojet Engine, Using a Steam Turbine for Driving the Compressor

a) Nose cone; b) Compressor; c) Mercury turbine; d) Control rod; e) Reactor; f) Mercury pump; g) Condenser; h) Jet nozzle

and drives it to the condenser. In the condenser, the air absorbs the heat of the mercury, becomes heated, and is ejected through the jet nozzle at high velocity. The increase in the velocity of the air passing through the engine is accompanied by the production of reactive thrust, which, as in all ram-jet engines, represents the difference between the pressure of the air at the frontal area of the engine and the air pressure directed to the rear.

A reactor operating on this principle must use fast neutrons, since mercury is an avid absorber of thermal neutrons. However, it will be rather difficult to de-

sign a fast-neutron reactor. The point is that the mercury, passing through the reactor, is converted from liquid to vapor. Its density will differ at various points along its path through the reactor, the absorption of neutrons will be different, and the conditions of heat transfer will vary. All these difficulties indicate that it will be more desirable to heat the mercury in a heat exchanger by means of an intermediate heat-transfer agent.

Another possibility also exists. A gas turbine, e.g., a helium turbine, instead of the mercury turbine can be used. Figure 40 presents the design of an

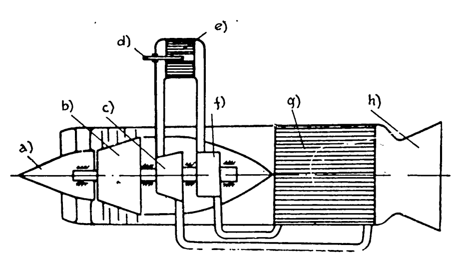

Fig.40 - Diagram of Atomic Turbojet Engine with Gas Turbine Driving Compressor

a) Nose cone; b) Air compressor; c) Gas turbine; d) Control rod; e) Reactor; f) Gas compressor; g) Heat exchanger; h) Jet nozzle

ATJEMC of this type. To supply the same power to an air compressor, the power of a helium turbine must be several times higher than the power of a mercury turbine. This is due to the fact that a colossal power, several tens of times greater than that required for a mercury pump, is needed to drive a helium compresoor. For example, if the power of the helium turbine is 150,000 hp, more than 100,000 hp are consumed in rotating the helium compressor, and less than 50,000 hp remain for the air compressor. To provide the same power for an air compressor, a mercury turbine would need 53,000 - 54,000 hp, i.e., slightly more than a third of the amount required by a helium turbine. However, the power required by the reactor in both cases is approximately the same, since the efficiency of the helium turbine under the conditions existing in an ATJEMC is considerably higher than with a mercury-vapor turbine.

Both the pressure of the helium and the pressure of mercury vapor at the input to the turbine must be several tens of atmospheres. A similar or even somewhat higher pressure is needed in the reactor. This clearly indicates the need for providing a strong and reliable reactor. The thickness of the walls of the steel pressure vessel of the reactor must be several centimeters, and dependable cooling of the pressure vessel must be provided.

In the ATJEMC whose designs are illustrated in Figs.39 and 40, the air is heated by the working medium of the turbine, which is mercury vapor condensing into liquid mercury, or helium. The working medium is delivered from the turbine to a condenser. Only when this happens, as we know from the Second Law of Thermodynamics, will the turbine be able to do work. The condensation of mercury vapor and the cooling of helium in the condenser take place as a result of heat exchange with the air. The air is heated under these conditions. In order to obtain high thrust, the air must be heated to the highest possible temperature. In the best case, the air temperature will be 50 - 100° lower than the temperature of the working medium arriving in the condenser. In addition, the temperature in the turbine decreases by several tens of degrees. Thus, we see that the temperature to which the air is heated in an ATJEMC is 150 - 200° less than the temperature to which the working medium is heated in the reactor. In order to increase the temperature to which the air is heated, it is necessary to insert in its path downstream of the condenser, an additional heat exchanger through which the heat-transfer agent is forced directly from the reactor, bypassing the turbine. Several designs for ATJEMC are possible, using this type of supplementary heating. Two of these are shown in Figs.41 and 42.

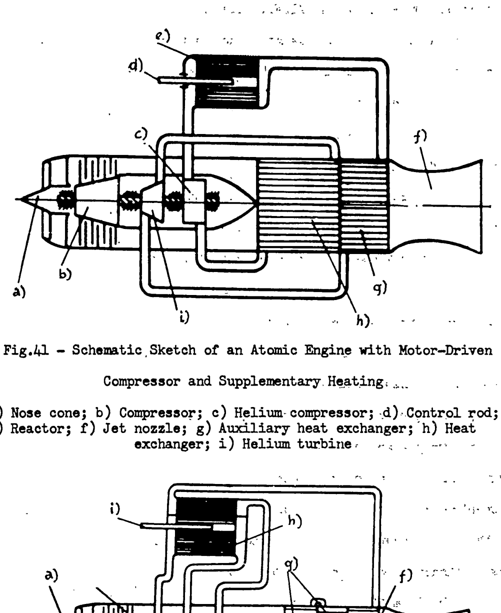

Fig.41 - Schematic Sketch of an Atomic Engine with Motor-Driven Compressor and Supplementary Heating

a) Nose cone; b) Compressor; c) Helium compressor; d) Control rod; e) Reactor; f) Jet nozzle; g) Auxiliary heat exchanger; h) Heat exchanger; i) Helium turbine

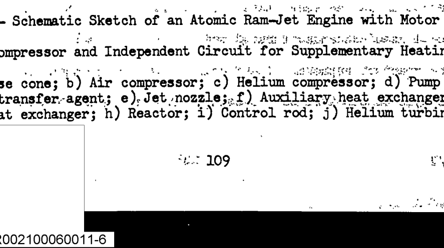

Fig.42 - Schematic Sketch of an Atomic Ram-Jet Engine with Motor Driven Compressor and Independent Circuit for Supplementary Heating

a) Nose cone; b) Air compressor; c) Helium compressor; d) Pump for heat-transfer agent; e) Jet nozzle; f) Auxiliary heat exchanger; g) Heat exchanger; h) Reactor; i) Control rod; j) Helium turbine

Figure 41 gives a sketch of an ATJEMC with one circuit for both working medium and heat-transfer agent. From the reactor, the helium proceeds to the auxiliary heat exchanger, then to the turbine and to the condenser, finally being recycled to the reactor by the compressor.

Figure 42 gives a sketch of an ATJEMC with two separate circuits, and with a reactor divided into two parts. The circuit for the working medium is the same as in the ATJEMC illustrated in Fig.40. The heat-transfer agent of the auxiliary circuit may be either gaseous or a liquid metal. The circulation of the gaseous heat-exchanger may be effected by a compressor, which is rotated by the main gas turbine or by a specially provided turbine. In the latter case, the turbocompressor of the auxiliary circuit may be installed independently of the engine. This results in a simpler design of installation of the entire power plant on the aircraft.

The use of helium as the working medium and as a heat-transfer agent for raising the operating temperature of the reactor opens broad vistas. If special chromium-nickel alloys are used as structural material for the reactor, the heating surface of the reactor may be increased to 1000 - 1100°C. At higher temperatures, the mechanical strength of these alloys is inadequate. The temperature of the heating surface of the reactor may be raised by another 200 - 300°C if molybdenum alloys are used. However, molybdenum combines readily with oxygen. Therefore, molybdenum heated to a high temperature must not be allowed to come into contact with air. If the molybdenum is surrounded by helium and inert gas, it will retain its mechanical strength for a long period at very high temperatures. If the temperature of the heating surface of the reactor is increased, the possibility exists to increase the temperature level of the entire power plant and, as a final result, to raise the temperature to which the air is heated, leading to an increase in engine thrust without the need of increasing its dimensions and weight.

If the temperature level of the entire power plant cannot be raised, then an increase in the temperature of the heating surface of the reactor will provide considerable benefits in terms of size and weight of the reactor required. In designing a reactor for an aircraft power plant, its dimensions are determined on the basis of the required heating surface. This area will be smaller, the greater the temperature differential between the gas being heated and the heating surface. If the temperature of the gas being heated is taken as constant and if the temperature of the heating surface is increased, a reduction in the required heating surface area becomes possible and consequently a reduction in the dimensions of the reactor and its weight. This is exceedingly important for aircraft, since a reduction in flying weight at a power plant of identical capacity, results in improvement of the flight characteristics.

Let us discuss the power fluctuations in the turbine rotating the air compressor, with variations in flying speed. It was stated above that, in order for a gas turbine to operate in a closed cycle, a condenser must be installed between gas turbine and gas compressor. We know that the power of the gas compressor depends on the gas temperature. The lower the gas temperature at the compressor input, the smaller will be the required power of the gas compressor and the greater the excess power of the turbine which drives the air compressor. If the gas temperature at the input to the gas turbine is equal to the temperature of the gas at the turbine exit, the required power of the gas compressor will equal the power of the gas turbine, and no excess power will be available at the air compressor drive. Thus, the condenser is an important link in a gas-turbine system. If the temperature to which the gas is heated in the reactor is regarded as constant, then the excess power of the gas turbine will be determined by the condenser, namely by the amount of heat dissipated from the gas in the condenser. This heat removed from the gas is used for heating the air passing through the ATJEMC. The amount of heat absorbed by the air, if we regard its thermal capacity as constant, depends on the temperature difference of the air and the gas and on the amount of air passing through the condenser.

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

From the theory of ram-jet engines we know that, as the flying speed increases, the air throughput of the engine per second also rises. At the same time, an increase also occurs in the temperature of the air at the engine input and, consequently, in the condenser. The temperature difference of gas and air in the condenser declines. Thus, two opposing factors act upon the amount of heat withdrawn from the gas. The increase in air consumption with increasing flying speed results in a greater dissipation of heat from the gas, while the decrease in temperature differential between air and gas tends to lower the dissipation. At low speeds the first factor predominates. Therefore, at the beginning, as the flying speed increases, the excess power of the gas turbine increases. Later, particularly at supersonic flying speeds, the second factor is predominant, and the excess power of the gas turbine decreases; there is also a drop in the compression ratio of the compressor. At the flying speed at which the temperature of the air at the condenser input becomes equal to the temperature of the gas at the turbine outlet, the turbine yields no excess power. The air compressor ceases to compress air, and the ATJEMC becomes an atomic ram-jet engine. The flying speed at which this "conversion" occurs is exceedingly high, several times that of sound. The resultant ARJE will develop thrust only if supplementary heating of the air is provided, i.e., only when engine designs such as those illustrated in Figs.41 and 42 are used. An aircraft with engines of the type shown in Figs.39 and 40, never attains the speed of "conversion" from ATJEMC to ARJE, due to the fact that at speeds below this level the ATJEMC ceases to develop thrust as a result of various types of losses.

Let us derive data for calculating aircraft power plants built around two ATJEMC serving a single reactor. Each atomic engine develops 20 tons of thrust at sea level. The engine has a helium turbine of 48,500 hp capacity, rotating an air compressor. The circulation of helium in the closed cycle is provided by a helium turbocompressor. The capacity of the turbine of the helium turbocompressor is 94,800 hp at a rated rotational speed of 16,000 rpm. The six-stage axial helium

compressor has a compression ratio of 2.1. The helium pressure at the compressor input is 25 atm and at the reactor input about 52 atm. The air compressor has two supersonic stages. At 5850 rpm, the compression ratio is 2.3. The air is heated by helium in a slot-type heat-exchanger, having 2520 m^2 heating surface. A total of 370 kg air passes through the heat-exchanger of each engine per second at sea-level operation.

The reactor is of the uranium-beryllium type, using intermediate neutrons. Its thermal capacity, under design operating conditions, is 490,000 kw. At this rate, the reactor consumes 21 gm $uranium^{235}$ per hour.

Atomic Turboprop Engines

Turboprop engines are used today primarily for heavy long-range aircraft flying at speeds close to the speed of sound. At subsonic speeds, turboprop engines are more economical than turbojets. Per kilogram of thrust, the former require consider-

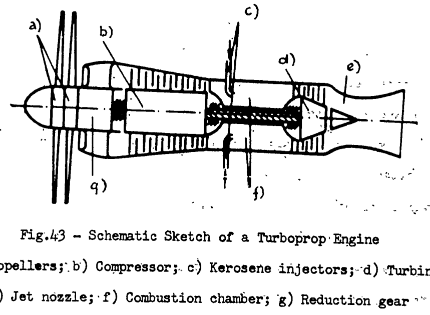

Fig.43 - Schematic Sketch of a Turboprop Engine

a) Propellers; b) Compressor; c) Kerosene injectors; d) Turbine; e) Jet nozzle; f) Combustion chamber; g) Reduction gear

ably less kerosene per hour. Moreover, turboprop engines provide the best flight characteristics for aircraft: the length and time of the take-off run is reduced, and the rate of climb is increased. The design of turboprop engines (Fig.43) similar to that of a turbojet engine. The turbine in a turboprop engine is usually of the multistage type. Such a turbine is considerably more powerful than that of a turbojet having the same thrust. The excess thrust of the turboprop turbine over that used to rotate the compressor is consumed in rotating the propellers. Usually two coaxial propellers are rotated in opposite directions over a reduction gear. The bulk of the thrust is produced by the propellers. Only 10% - 15% is created by the reaction of the stream of gases ejected from the jet nozzle.

The use of atomic turboprop engines offers the simplest solution of the problem of vertical take-off and landing of aircraft. ATJE and ATJEMC engines eject powerful jets of highly heated air. This would require the provision of special exhaust ducts to prevent destruction of the runway surface. The aircraft remains dependent upon properly equipped landing strips. If the power plant of the aircraft consists of atomic turboprop engines, the streams of hot air will be only a fraction as intense and will mix with the cold slipstream of the propeller. This will permit landing on any level field with a hard surface.

However, the main advantage of atomic turboprop engines over atomic turbojet engines and ATJEMC is the fact that the former develop a take-off thrust 20% - 30% greater, with a reactor of identical power.

Atomic turboprop engines can be classified into two groups in terms of design. The first group comprises engines using air turbines and the second group includes engines using steam or gas turbines.

The design of engines in the first group is similar to that of the atomic turbojet engines illustrated in Figs.33, 36, and 37. The difference lies in the fact that in all atomic turboprop engine designs the turbine is not only connected to a compressor but also (over a reduction gear) to propellers. Figure 44 shows the design of a turboprop engine in this category. The air is sucked in by the compressor, compressed, and supplied to the reactor. In the reactor, the air is heated and delivered to the turbine, where it is rotated and then ejected through the jet

nozzle. The turbine rotates the compressor and the attached coaxial propellers.

It is also possible to develop atomic turboprop engines with two independent turbines, one rotating the compressor and the other the propellers. Figure 45 illustrates an atomic turboprop engine with two coaxial turbines. The front two-stage turbine is connected to the compressor by a hollow shaft, while the rear turbine is

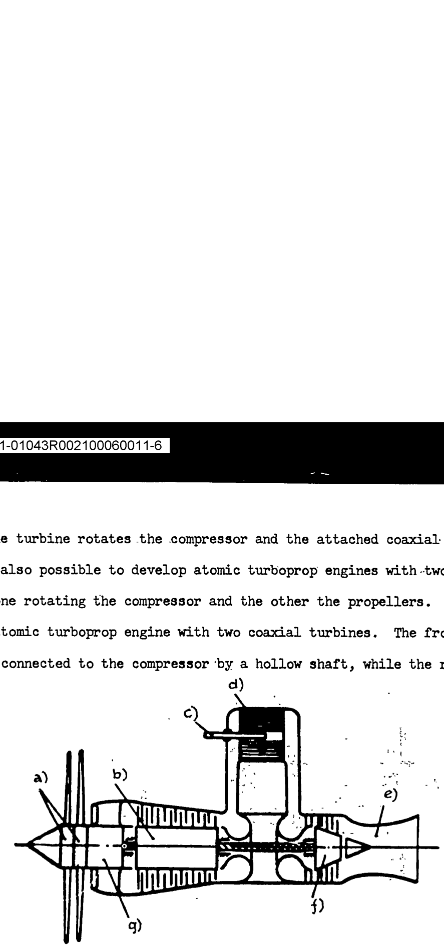

Fig.44 - Schematic Sketch of an Atomic Turboprop Engine with Separately Housed Reactor

a) Propellers; b) Air compressor; c) Control rod; d) Reactor; e) Jet nozzle; f) Air turbine; g) Reduction gear

connected to the reduction gear via a long shaft passing within the turbocompressor shaft. This method of making the turbocompressor a separate assembly should logically facilitate the control of the engine since the operating conditions of the turbocompressor and the propellers will be less interdependent under these circumstances. In the design of an atomic turboprop engine, illustrated in Fig.44, the rotational speed of the propellers and the compressor are interrelated, and any change in the rotational speed of the propellers will cause a change in that of the compressor, in the compression ratio of the air in the compressor, in the air throughput of the engine, and in the power of the turbine; this, in turn, will affect the rotational speed of the propellers.

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

Engines with steam or gas turbines may be categorized as forming a second group of atomic turboprop engines. Their design is similar to that of atomic ram-jet engines with motor-driven compressors, as illustrated in Figs.39 and 40. Figure 46

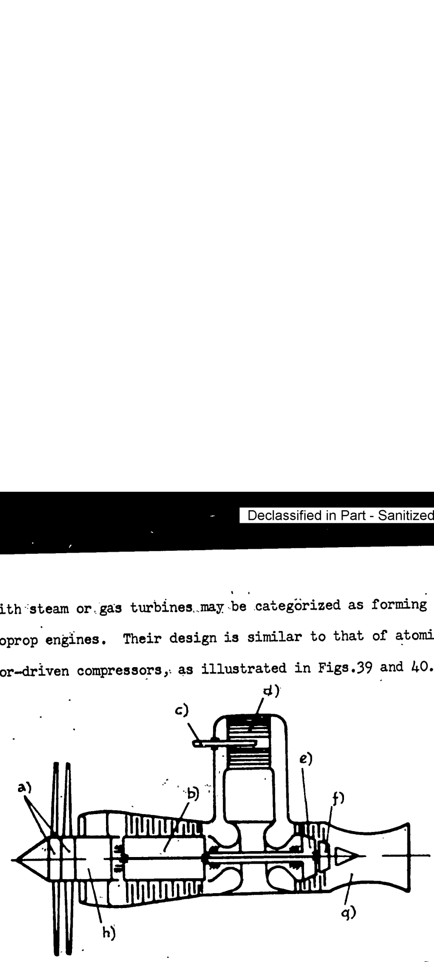

Fig.45 - Schematic Sketch of an Atomic Turboprop Engine with Separate Drives for Compressor and Propellers

a) Propellers; b) Air compressor; c) Control rod; d) Reactor;
e) Air Turbine for compressor; f) Air turbine for propellers;
g) Jet nozzle; h) Reduction gear

presents the design of an atomic turboprop engine with a mercury turbine. The mercury is heated in this engine by means of liquid sodium as the heat-transfer agent, which is circulated by a pump. The mercury vapors, produced in the heat exchanger, are delivered to the turbine. The energy of the mercury vapor is converted to mechanical energy in the turbine and is transmitted to the propellers by means of the reduction gear. The used vapor proceeds to a condenser and is there condensed to liquid mercury, which is recycled by pump to the heat exchanger. Heat is removed from the mercury vapor in the condenser by air forced through the condenser by a fan.

More than 90% of the thrust of an atomic turboprop engine with a steam turbine is created by the propellers. The thrust created by the reaction of the air passing

through the condenser is negligible, since the air is heated to a comparatively limited extent. However, the condenser of an atomic turboprop engine is essentially a ram-jet. Thus, the atomic turboprop engine with a steam turbine actually repre-

Fig.46 - Schematic Sketch of an Atomic Turboprop Engine with Intermediate Heat-Transfer Agent

a) Propellers; b) Fan; c) Jet nozzle; d) Condenser; e) Mercury turbine;
f) Mercury pump; g) Reduction gear; h) Heat exchanger; i) Control rod;
j) Reactor; k) Pump for heat-transfer agent

sents two engines: a turboprop, and a ram-jet. This combination is quite intriguing. Thus, a turboprop engine operates efficiently at low flying speeds, and a ram-jet at highspeeds. The problem is that of making proper and full use of the advantages of both types of engines. At low speeds, the main engine is the turboprop and at high speeds, the ram-jet. In order to make more complete use of a turboprop engine, it is desirable to install an auxiliary heat exchanger in the path of the air downstream of the condenser, similar to that illustrated in Fig.42, and heat the air to the highest possible temperature. As the flying speed increases above a given level, the power of the steam turbine begins to drop due to a decrease in the dissipation of heat in the condenser, and the share of the propellers in the production of thrust begins to decline, while the share of the ram-jet engine starts to increase. At a flying speed only 50% greater than the speed of sound, the condenser and its auxiliary heat exchanger will develop one-half the thrust of the entire power plant, even if special supersonic propellers are used whose efficiency decreases only insignificantly with increasing flying speed. Thus, an atomic turboprop engine with steam turbine is capable of self-regulation. As the flying speed increases, there is a reduction in the power of the propellers accompanied by an increase in thrust of the ram-jet engine.

The above statements on self-regulation are also valid for the atomic turboprop engine using a gas turbine, whose design is presented in Fig.47.

However, as in the case of an ATJEMC, the gas turbine has to be several times as powerful as a steam turbine of equal power. The dimensions of the gas turbocompressor will be considerably greater than those of the mercury turbine and the mercury pump. The advantage of an atomic turboprop engine with gas turbine is the lack of the need for a heat exchanger and an intermediate heat-transfer agent, and the possibility of heating the gas directly in the reactor. This is no small advantage, since the presence of an intermediate heat-transfer agent significantly complicates the operation of an atomic power plant.

In order to increase the economy of modern power plants and engines using chemical fuels, wide use is made of what is known as heat recovery. The principle of heat recovery lies in the fact that a portion of the heat of the combustion product is utilized to heat the air entering the furnace.

Heat recovery may also be used in an atomic turboprop engine with a gas turbine. In addition to economizing nuclear fuel, heat recovery permits a significant reduction in the heat-exchange interface between working medium and air in the condenser.

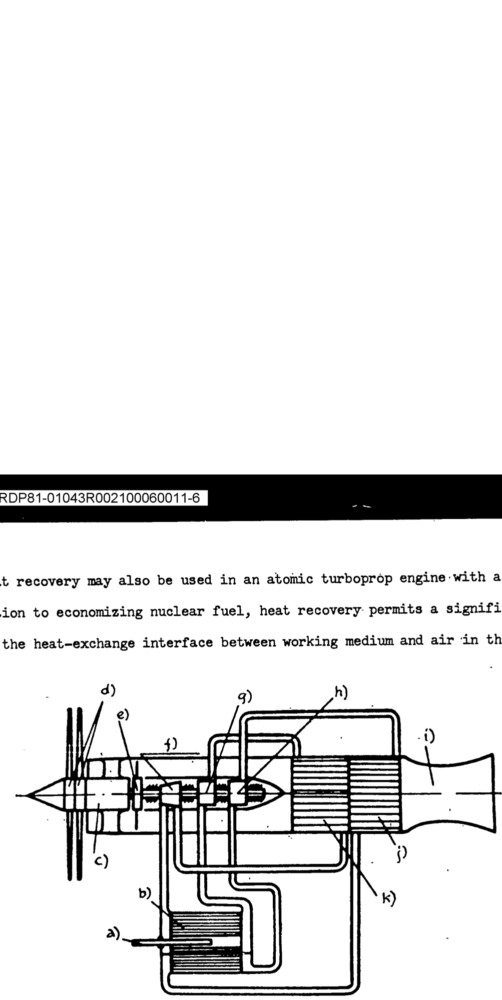

Fig.47 - Schematic Sketch of an Atomic Turboprop Engine with Independent Supplementary Heating Surface

a) Control rod; b) Reactor; c) Reduction gear; d) Propellers; e) Fan; f) Helium turbine; g) Helium compressor; h) Pump for heat-transfer agent; i) Jet nozzle; j) Auxiliary heat exchanger; k) Heat exchanger

Figure 48 gives a schematic sketch of a helium atomic turboprop engine with heat recovery. The helium from the turbine passes through the heat recovery unit, where it surrenders a portion of its heat to the helium, proceeding to the compressor from the reactor, and is then delivered to the condenser. The finally cooled helium is compressed in the compressor and delivered to the reactor. On the way to the reactor it undergoes preliminary heating in the recovery unit. Consequently, the consumption of nuclear fuel decreases, and the weight and size of the reactor may be reduced.

Thanks to the fact that the heat transfer in the recovery unit takes place from helium to helium, the heat-exchanger surface in the recovery unit need only be a fraction of that which would be required to remove the same amount of heat from helium to air. As a result, the size and weight of the recovery unit can be relatively small.

When a recovery unit is present, the quantity of heat removed from helium to air in the condenser will decrease, so that the dimensions and weight of the condenser can also be reduced.

Fig.48 - Schematic Sketch of a Helium-Driven Atomic Turboprop Engine with Heat Recovery

a) Propellers; b) Reduction gear; c) Fan; d) Control rod; e) Reactor; f) Heat recovery unit; g) Helium compressor; h) Heat exchanger; i) Jet nozzle; j) Helium turbine

However, despite the above advantages, the use of heat recovery may be unprofitable. The point is that the temperature to which the air is heated in the condenser is reduced in the presence of a heat recovery unit. Consequently, the role of the condenser as a ram-jet engine is diminished.

Let us describe one more design of an atomic turboprop engine with a steam turbine using water vapor, produced in a "boiling-water" type of reactor. This design

is presented in Fig.49. The "boiling-water" reactor is a large vessel containing ordinary or heavy water, into which uranium rod lattice encased in aluminum or zirconium cans is inserted. If the rods are of natural uranium, heavy water has to be used; if the rod material is enriched uranium, ordinary water may be used. The water in the reactor acts as a moderator and, at the same time, serves to remove the heat from the uranium rods. The power level of the reactor is so regulated that the required amount of steam will be produced each second. The steam from the reactor

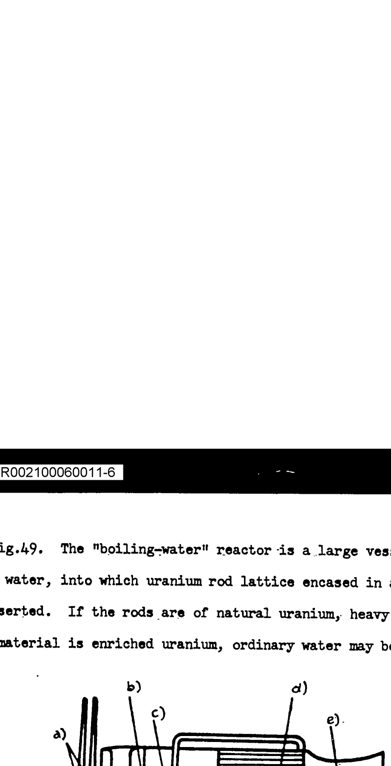

Fig.49 - Schematic Sketch of an Atomic Turboprop Engine with "Boiling-Water" Reactor

a) Propellers; b) Fan; c) Steam turbine; d) Condenser; e) Jet nozzle; f) Reduction gear; g) Water pump; h) Water reactor with steam separator; i) Control rod

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

proceeds to the turbine which it rotates; the steam is then condensed in the condenser and is recycled to the reactor by pump. The power of the pump is about 2% of the power of the turbine. The turbine is connected to coaxial propellers as in the above-described design.

The advantages of this design are simplicity, reliability in operation, and its relatively low cost. A "boiling-water" reactor has a self-protection from explosion in case of breakdown if, for any reason the control rod mechanism fails. At the instant of excessive liberation of heat, the water is converted into steam which latter is discharged into the atmosphere through a safety valve. The reactor now no longer has a moderator, and any nuclear reaction instantly decays. To start the reactor again all that is needed is to refill it with water. It is easy to remove from the water the uranium fission products, which are very strong neutron absorbers. This makes it possible to reduce the reserve reactivity of the reactor and increase the percent "combustion" of nuclear fuel.

The shortcomings of this design are the radioactivity of the water passing through the turbine and the exceedingly low temperature of condensation of the water vapor. The latter prevents efficient use of the condenser as a ram-jet engine.

The reader has no doubt become aware by now that, in all above designs of atomic turboprop engines, a reduction gear is an essential component. The turbines of modern turboprop engines rotate at 6000 - 15,000 rpm. The high rotational speeds are necessary to hold down the dimensions of the high-power turbines. The propeller operates most effictively when it rotates at about 1000 rpm. Thus, the reduction gear serves the purpose of reducing the rpm to the level most advantageous for propeller operation.

If two propellers are mounted on the engine, the reduction gear has the additional function of changing the direction of rotation of one of the propellers so that they will rotate in opposite directions. This also increases the efficiency of the propellers. Difficulties with the reduction gear are among the major causes for

the limited usefulness of turboprop engines in modern aircraft. At present, transmissions with involute teeth are in wide use in reduction gears. There are many shortcomings inherent in this system (low contact strength, sensitivity to lack of precision in manufacture and assembly, high friction losses leading to overheating of the gears, etc.). The lightest and most reliable type of reduction gear is that used in marine power plants. The weight of such reduction gear is about 1 kg per horsepower transmitted. The weight of modern aircraft reduction gears is 7 - 10 times lower. This saving in weight is obtained at the expense of a sharp reduction in the service life of the gear. But even this weight level is excessive for aircraft. Even if only 0.1 kg of reduction gear weight is required per transmitted horsepower, the total weight of the transmission, for a 50,000 hp engine will be 5 tons, and powers of 50,000 - 100,000 hp will be customary for atomic power plants. Designers and scientists of all countries are making every attempt to reduce the weight of the reduction gear. There is reason to hope that, in the very near future, the gearing invented by N.L.Novikov, will provide a means for increasing the power transmitted by reduction gears without increasing their weight.

However, it would be desirable to completely eliminate the use of a reduction gear. Is this possible? Calculations show that a reduction gear may be eliminated completely if a mercury turbine is used. The possibility exists of designing a turbine in which the rotor will rotate in one direction and the housing in another. The rotor will be connected by shaft to the tractor propeller and the housing will be connected to the pusher propeller over a hollow shaft which contains the second shaft. If the rotational speed of the rotor relative to the housing is 4000 rpm, then each propeller will rotate at 2000 rpm. This rpm is satisfactory for specially-designed supersonic propellers. The design difficulties encountered in creating such an engine without reduction gear will, of course, result in an increase in turbine weight, but this increase in weight will be only a fraction of the weight of a reduction gear.

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

Let us give an example of the project of an atomic aircraft power plant consisting of two atomic turboprop engines without reduction gear and using mercury turbines. Mercury vapor, heated to a temperature of 800°C is delivered to the six-stage turbines of 70,000 hp each, at a pressure of 112 atm. The mercury vapor is produced in a fast-neutron reactor. The power of each turbine is distributed between two coaxial propellers (60,000 hp), with the fan forcing the air through the condenser (9000 hp) and the pump recycling the liquid mercury to the reactor (1000 hp). The weight of the entire power plant will be 20.5 tons. Of this, the weight of the two engines is 11.2 tons, the dry weight of the reactor (without shielding) is 4.5 tons, and the weight of the mercury is 4.3 tons. At a flying weight of 85 tons, an aircraft with this type of atomic power plant will be able to carry 3 tons of useful load and fly at a speed 2.5 times that of sound. The consumption of nuclear fuel under these conditions will be 13 gm/hr.

<u>Combination Power Plants with Nuclear and Chemical Fuels</u>

We have already discussed the difficulties of designing a high-temperature reactor, the difficulties of shielding the aircraft from the reactor radiations, and the lack of a clearly defined method for overcoming these difficulties. The general trend to travel a blazed trail has resulted in the appearance in the press of opinions to the effect that the first atomic power plants will include not only atomic, but also conventional engines, and that after the air is heated in the reactor, it will be heated further by the combustion of kerosene or gasoline in this air.

Underlying some of the suggestions for the development of power plants, including both atomic and conventional engines to function throughout the flight, is the effort to reduce the capacity of the reactor so as to lower the dimensions and weight both of the reactor itself and of the radiation shielding. Other suggestions along these lines are based on the effort to use an atomic engine as the main source of energy and to connect the conventional engine whenever necessary for a brief

period in order to increase the power of the power plant, as for example, during take-off, climb, etc. Let us see what the real possibilities of such proposals might be.

The compound power plant and its radiation shielding can make use of that portion of the total weight of the aircraft which is ordinarily taken up by the conventional power plant and its fuel reserve in present-day aircraft. If a conventional engine is retained in the compound installation, then the atomic engine and its radiation shielding can be installed on the aircraft only at the expense of the fuel reserve, with the provision that a portion of this reserve must be set aside for operating the conventional engines. This portion is so small that the possible operating time of the conventional engine may be calculated in minutes. If this fuel residue is divided by the entire period of flight, the thrust of the conventional engines would have to be so small that no noticeable improvement in the flight characteristics of the aircraft could be expected from this operation. Thus, a compound power plant, consisting of atomic and conventional engines, can hardly be considered realizable and is obviously not rational.

However, it is possible to combine the use of nuclear and chemical energy in a single engine. Figure 50 illustrates an engine of this type. This is an atomic turbojet engine in which the air is heated in a separately housed reactor. Then kerosene is injected into the air and, on combustion, heats the air further. If this engine would use a turbine with cooled blades, the temperature of the air upstream of the turbine could be raised to 1500°C. This will result in increasing the specific and frontal thrust and in reducing the engine weight. If the engine is limited to standard temperatures ahead of the turbine (of the order of 800°C), then in an engine built according to the design shown in Fig. 50, the temperature of the heating surface of the reactor can be reduced compared to that of the heating surface of the reactor in a regular atomic turbojet engine. It will be easier to design this type of reactor. This is the point generally emphasized in statements to the effect that combination systems will be developed before purely atomic systems. However, it is quite doubtful whether the range of flight with such a combination engine will exceed the range of an aircraft with conventional engines of today. They may, however, serve as experimental installations for gathering experience in the operation of power plants with nuclear reactors.

It is much more probable that atomic jet engines with kerosene afterburners

Fig.50 - Schematic Sketch of a Combination Turbojet Engine Using Nuclear and Chemical Fuels

a) Nose cone; b) Compressor; c) Control rod; d) Reactor; e) Kerosene injectors; f) Combustion chamber; g) Turbine; h) Jet nozzle

will come into practical use. Such engines will have a standard afterburner chamber between the turbine and the jet nozzle. In this chamber the air will undergo supplementary heating by combustion of kerosene. The afterburner chamber will be turned on for brief periods: on take-off, in climb, during acceleration, and for brief boosts of maximum flying speed. Atomic turbojet engines with afterburners will first be used in military aircraft so as to provide air superiority in tactical flight characteristics. In passenger and transport aircraft, it might be more desirable to save the weight of kerosene required for such boosters, in favor of increasing the payload, the number of passengers to be carried, etc.; in addition,

the possibility of improving the tactical flight characteristics of a given aircraft by increasing the power of the atomic power plant itself should not be forgotten. If a more powerful atomic turbojet engine were installed on an aircraft, whose weight would equal that of an atomic jet engine with booster and supplementary fuel, it could well be that the thrust would be no less than that of the atomic jet engine with its booster operating. If this proves to be the case, it is obvious that there will be no gain by using an atomic turbojet engine and booster.

From the above statements on combination power plants, it would follow that their application, if at all, will be only for experimental purposes.

Probable Designs of Atomic Power Plants for Aircraft

The basic shortcoming of all atomic ram-jet engines is the very method of heating air in the engine by heat-transfer from the heating surface of the reactor or the heat exchanger. In the first place, this method of heating results in increased friction losses. In the second place, the heating of the air by heat transfer requires a temperature of the heating surface at least 50° - 100°C higher than the temperature of the already hot air. When kerosene is burned in conventional engines, the liberation of heat occurs throughout the entire volume of the combustion chamber, and the temperature of the combustion products is usually considerably higher than the temperature of the combustion-chamber walls, cooled by forced currents of cold air.

We know that the mechanical strength of metals is reduced at increasing temperatures. If the structural materials of the reactor and the combustion chamber can withstand equally high temperatures, the temperature to which the air has to be heated in an atomic engine will be less than in a conventional engine, which along with the increased friction losses, will result in a reduction in the specific thrust of the engine, and in an increase in its specific weight. Thus, the very principle of transferring heat to air by heat liberation in atomic engines faces the problem of lower specific parameters than those in conventional jet engines. Now, if we could only cause the heating to take place throughout the entire volume of the air instead of only in a thin layer adjacent to the heating surface!

Let us examine a design of an atomic ram-jet engine, as illustrated in Fig.51. A gaseous, liquid, or powdered nuclear fuel is injected into the air, compressed by the velocity head. On entering the reactor chamber, this nuclear fuel is subjected to the effects of a neutron flux, with a result that a portion of the nuclei under-

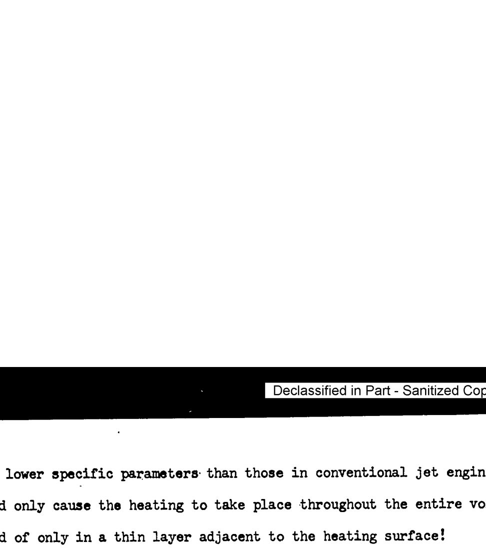

Fig.51 - Schematic Sketch of an Atomic Ram-Jet Engine with Gaseous Nuclear Fuel

a) Nose cone; b) Reactor; c) Jet nozzle; d) Reactor cooling; e) Gaseous nuclear fuel

goes fission. In this case, the liberation of heat occurs throughout the entire volume of air, with the result that the contact area between air and reactor can be reduced by hundreds of times. This leads to a significant reduction in friction losses. Heated air, as before, enters the jet nozzle, and is ejected at high velocity.

The function of the reactor in this design is different from that in all atomic engine designs we have discussed up to now. There the reactor was a source of heat, here the reactor is used as a neutron source. However, the production of neutrons

during the nuclear reaction is accompanied by the liberation of large quantities of heat. A heat-transfer agent must be circulated through the reactor in order to dissipate this heat. The heat removed from the reactor may be used for operating a steam or gas turbine of another engine or for heating air in an atomic turbojet engine heat exchanger, used in combination with the atomic ram-jets discussed above.

An analysis of the practicability of the engine illustrated in Fig.51, shows that the decisive factor is the high concentration of nuclear fuel injected into the air, i.e., in the final analysis, a large rate of consumption of this fuel. Moreover, in order to increase the probability that neutrons will collide with fuel nuclei, the density of the neutron flux must be considerably increased. To attain the necessary rates of consumption of the injected nuclear fuel, it is necessary, as we learn from calculations, to increase the density of the neutron flux of the reactor by thousands and hundreds of thousands of times, relative to the maximum attained to this date in stationary systems. An increase in the density of the neutron flux will, in turn, lead to an increase in heat liberation in the reactor itself which will require a higher rate of heat dissipation, etc. All of this makes realization of the design in Fig.51 improbable.

If it is impossible at present to solve the problem of attaining a high density of neutron flux, might it not be possible to provide for trapping the powdered nuclear fuel? An atomic turbojet engine operating on this principle is illustrated in Fig.52. Into air compressed by the compressor, a mixture of powdered atomic fuel and air is injected (or taken in by suction). The nuclear fuel is more or less uniformly mixed with the air and enters the channels honeycombing the reactor. It is here that the nuclear reaction occurs and the air is heated, from where it enters the turbine which in turn rotates the compressor. From the turbine the air emerges in a spiral stream, rotating about the axis of the engine. The heavy particles of nuclear fuel are hurled toward the outer surface and are sucked out along with a small quantity of air, again to be mixed with the air at the reactor input.

STAT STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

Certain authors propose a complete elimination of a reactor in the conventional meaning of the term. They propose that atomized nuclear fuel be introduced at the compressor input. In the air compressed by the compressor, the concentration of nuclear fuel increases; as soon as this air enters a duct surrounded by a neutron reflector, a nuclear reaction is initiated and the air is heated. Downstream of the

Fig.52 - Schematic Sketch of an Atomic Turbojet Engine with Atomized Nuclear Fuel

a) Nose cone; b) Compressor; c) Reactor; d) Reactor cooling; e) Turbine; f) Jet nozzle; g) Duct for recycling the atomized nuclear fuel

turbine, the nuclear fuel is trapped, as in the engine (Fig.52). The cooling of the reflector is much easier for the cooling of the reactor. However, the realizability of such a design is rather dubious. The dimensions of the duct in the reflector must be quite large in order for a nondecaying nuclear reaction to occur in the nuclear fuel, atomized in the air. As the concentration of nuclear fuel in the air increases, the dimensions of the channel may be reduced. However, this would lead to a decrease in engine thrust, due to the fact that an excessively large share of the air will be tapped downstream of the turbine, along with the nuclear fuel. An increase in concentration by increasing the compression ratio of the compressor is not possible above a fixed level since, in the course of compression, the air be-

comes heated and may reach the maximum temperature permissible for strength considerations. Thereafter, further heating becomes impossible, so that the turbine will be unable to rotate the compressor, not to mention the fact that the engine will develop no thrust.

There have been proposals to heat the air in the engine by an electric arc. However, this method of air heating has its drawbacks. For example, it is difficult to develop a reliable electric arc of such extraordinary power, that will function for the relatively long period during which the engine is expected to operate without interruption. In addition, the system for producing electric energy will be bulky and heavy and most likely will cancel the gain obtained by the absence of a heat exchanger.

Vast perspectives will open before the aircraft designer when science is able to control thermonuclear reactions. The rapid development of nuclear physics in recent years testifies to the fact that the major difficulties in creating a controlled thermonuclear reaction will be overcome and a thermonuclear engine will be developed. The application of thermonuclear engines to aviation will result in further advancement in aircraft design, and will make aircraft less earth-bound, enabling it to fly in the upper layers of the atmosphere at colossal speeds.

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

CHAPTER IV

AIRCRAFT WITH ATOMIC ENGINES

The Problem of Radiation Shielding

The development of aircraft with atomic engines involves the necessity of overcoming the radiation hazards due to the emission of various types of radiation having a detrimental effect upon the human organism.

The first concepts as to radiation hazards and the difficulties of shielding human beings from the radiations of atomic engines appeared simultaneously with the first ideas on atomic aircraft. As far back as the beginning of 1935, the Soviet scientist, O.Petrovskiy, advanced the idea of an atomic train of stratoships (Figure 53), in which the protection of the passengers from the effects of radiation would be attained by housing the crew and passengers at a considerable distance from the atomic, or subatomic, engine. These ideas, advanced more than twenty years ago, are still of interest today. Therefore, we will quote an excerpt from O.Petrovskiy's article* in which he discusses an atomic train of stratoliners: "This train will consist of two units. The first travels, as a rule, without human beings aboard and is equipped with subatomic engines. This unit will tow a second aircraft by means of cables approximately 1000 m in length. The second aircraft will be designed, more or less, along the lines of a glider without engines. Con-

* The article "An Isotope Gun" was published in the journal Tekhnika Molodezhi (Technics for Youth), No.1, January 1935.

trol will be exerted from this second aircraft.

"The reason for the separation of this stratoplane train into two separate machines is chiefly the fact that the powerful radioactive decay in the engine is ac-

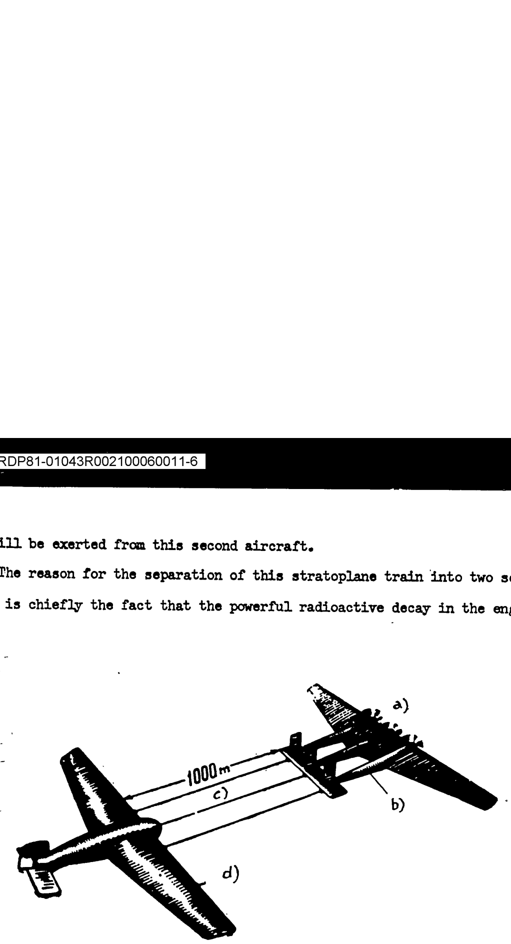

Fig.53 - Schematic Sketch of an Atomic Train of Stratoplanes from the Journal "Tekhnika Molodezhi", No.1, 1935

The train of stratoplanes with subatomic engines will consist of two units. The subatomic engines will be installed on the first, while crew and control mechanism will be carried on the second.

a) Engine stratoplane (no crew); b) Fuselage with groups of isotope guns; c) Towing cables of 1000 m length; d) Engineless stratoglider with crew (towed by cable)

companied by a no less powerful radiation.

"For protection from this radiation, which is extremely harmful to the human organism, no means other than removal to a considerable distance exist at present."

Today, the problem of protection from radiation by other means, for example shields, is no longer as hopeless as it had been then; however, even now this is

CHAPTER IV

AIRCRAFT WITH ATOMIC ENGINES

The Problem of Radiation Shielding

The development of aircraft with atomic engines involves the necessity of overcoming the radiation hazards due to the emission of various types of radiation having a detrimental effect upon the human organism.

The first concepts as to radiation hazards and the difficulties of shielding human beings from the radiations of atomic engines appeared simultaneously with the first ideas on atomic aircraft. As far back as the beginning of 1935, the Soviet scientist, O.Petrovskiy, advanced the idea of an atomic train of stratoships (Figure 53), in which the protection of the passengers from the effects of radiation would be attained by housing the crew and passengers at a considerable distance from the atomic, or subatomic, engine. These ideas, advanced more than twenty years ago, are still of interest today. Therefore, we will quote an excerpt from O.Petrovskiy's article* in which he discusses an atomic train of stratoliners: "This train will consist of two units. The first travels, as a rule, without human beings aboard and is equipped with subatomic engines. This unit will tow a second aircraft by means of cables approximately 1000 m in length. The second aircraft will be designed, more or less, along the lines of a glider without engines. Control will be exerted from this second aircraft.

* The article "An Isotope Gun" was published in the journal Tekhnika Molodezhi (Technics for Youth), No.1, January 1935.

"The reason for the separation of this stratoplane train into two separate machines is chiefly the fact that the powerful radioactive decay in the engine is accompanied by a no less powerful radiation.

Fig.53 - Schematic Sketch of an Atomic Train of Stratoplanes from the Journal "Tekhnika Molodezhi", No.1, 1935

The train of stratoplanes with subatomic engines will consist of two units. The subatomic engines will be installed on the first, while crew and control mechanism will be carried on the second.

a) Engine stratoplane (no crew); b) Fuselage with groups of isotope guns; c) Towing cables of 1000 m length; d) Engineless stratoglider with crew (towed by cable)

"For protection from this radiation, which is extremely harmful to the human organism, no means other than removal to a considerable distance exist at present."

Today, the problem of protection from radiation by other means, for example shields, is no longer as hopeless as it had been then; however, even now this is

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

one of the most complex problems in the development of atomic aircraft equipped to carry human beings. During the last 10 - 15 years, scientists have made a careful study of the properties of various types of radiation produced in the operation of atomic power plants, and have discovered the most effective materials for shields. They have also developed the basic principles for shielding systems. Let us briefly treat these problems:

The radiation emitted during the operation of atomic power plants include the following that are harmful to the human organism: alpha rays, beta rays, gamma rays, and neutrons.

Alpha Rays represent a stream of positively charged particles: helium nuclei. Their penetrating power is quite insignificant. In air, for example, they travel no more than 10 cm from the radiation source and in metals only hundredths of a millimeter. Virtually the sole source of alpha particles in an atomic power plant is the nuclear fuel (uranium and plutonium), which is naturally radioactive. Alpha particles are completely absorbed in the metal cans in which nuclear fuel is usually encased and, therefore, require no further consideration on our part.

Beta Rays represent a stream of electrons. The major source of beta radiation are the fission "fragments" of the fuel nuclei. Emission of beta rays also results from the absorption of neutrons by nuclei of most of the chemical elements comprising the moderator, the heat-transfer agents, the structural materials, other materials used. The penetrating power of beta rays is greater than that of alpha rays, but still comparatively small; in air, beta particles can travel up to 20 m and in metals a few millimeters.

Gamma Rays are an electromagnetic radiation similar to x-rays but of shorter wavelength. About 95% of the total flux of gamma rays emitted by a reactor is due to fission of the fuel nuclei. In addition, such rays are generated on absorption of neutrons by the nuclei of certain chemical elements that go into the makeup of a nuclear reactor.

Neutrons are particles of neutral charge, representing a constituent of atomic nuclei. These are emitted on fission of the fuel nuclei. The absence of an electric charge explains their high penetrating power. Fast neutrons have an exceptionally high penetrating power. The absorption of neutrons by nuclei usually results in artificial or induced radioactivity. In other words the nuclei of a majority of elements themselves become sources of radioactive radiation as they absorb neutrons.

The above types of radiation cause a specific disease in man: radiation sickness. The degree of damage to the organism depends upon the quantity of radiant energy absorbed or, as it is called, the radiation dose. The magnitude of the dose received is greater, the greater the intensity of radiation and the longer the time during which the human being is exposed. A special unit called the roentgen is used for measuring the size of the dose.

A single irradiation at a dose of up to 50 roentgens produces no observable changes in the human organism, and the subjective feeling of well-being is no way impaired. A dose of 50 - 100 roentgens induces insignificant changes in the blood, which rapidly disappear without leaving a trace.

If irradiation is repeated periodically, then even at a small daily dose radiation sickness may occur since the effect of radiation is cumulative. At present, it is believed that the maximum dose for a human being daily exposed to irradiation over a period of years should not exceed 0.3 roentgen.

The main source of radiation in an atomic aircraft is the nuclear reactor. The intensity of radiation is greater, the greater the power of the reactor. When the reactor is turned off, the intensity of radiation diminishes greatly, but a rather significant radiation continues for a long period, since certain artificially radioactive substances formed during operation of the reactor decay very slowly.

Special shelters and shields are only necessary for biological protection from gamma radiation and neutrons. In view of the small penetrating power of beta rays,

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

these will be absorbed completely in the shields.

In view of the fact that gamma rays react primarily with electrons, the best shielding material is a substance with a large number of electrons per atom. Iron, steel, lead, and bismuth find practical application as materials capable of weakening the flow of gamma rays. As a rule, the greater the density of the substance, the smaller will be the thickness of the layer of substance required for obtaining a given reduction in the intensity of gamma radiation. For example, in order to reduce the intensity of gamma radiation by one-half, a layer of steel of about 2 cm thickness is required. The thickness of a layer of lead for the same purpose is 1.3 cm.

The neutron flux of a reactor includes neutrons of widely varying energies: from thermal to fast neutrons. Since high-energy neutrons are weakly absorbed by various materials, one of the main functions of neutron shielding is to retard these neutrons. In practice, protection from neutrons may take the form either of single-layer or double-layer shields. When using a two-layer shield, the first shield facing away from the reactor is made of a good moderator, and the second of a good absorber of neutrons. Minimum shield thickness is obtained when ordinary water is used as the moderator. However, the use of water for shielding an aircraft reactor is hardly within the realm of possibilities. In terms of operational realities, the best moderator for neutron protection aboard an aircraft is graphite. Graphite, however, has a drawback of its own: The thickness and weight of the protective shield is greater than for water.

If the shield is of a single layer, its structural material must simultaneously be able to moderate and absorb neutrons. To accomplish this end, the reactors of stationary power plants are surrounded by thick layers of ordinary water and concrete, with graphite or boron added. To improve the shielding qualities of the concrete, the water content in the cement mix is sometimes increased and added cadmium or boron is used, or graphite with added boron, or even pure boron. If

pure boron is used, the shield is thinner and lighter than a concrete shield or a shield in which graphite is used.

The difficulties in developing an atomic aircraft, with respect to radiation hazards, lie in the fact that even if the best materials presently known are used for shielding purposes, the weight and dimensions of the shield are quite considerable. The distances to which the crew and passenger quarters can be removed from the reactor in an aircraft is comparatively small and, for practical purposes, not more than 20 - 30 m. In this connection, a considerable portion of the required degree of moderation of the reactor radiation is taken up by the protective shields. When an aircraft reactor is operating at maximum output, the shields must reduce the intensity of radiation by a factor of 10 million. To reduce the intensity of gamma radiation by a factor of 10 million we need a lead shield of approximately 35 cm thickness. The weight of one square meter of such a shield is four tons.

The American scientist, R.Murray (Bibl.14), in an investigation of several possibilities of application of atomic energy in aviation, gave, as a typical example, the calculation of a shield for the B-47 bomber if that aircraft were to be equipped with atomic engines. The purpose of the calculation was to show the relationship between the weight of the shield and the payload of the aircraft for a given condition of flight: altitude 11 km, speed 800 km/hr. The initial weight data of the aircraft were as follows: empty weight, 62.5 tons; weight with conventional fuel plus payload, 92.5 tons. In order to attain these flight characteristics, the engine has to develop a total thrust of about 6.4 tons which, at a speed of 800 km/hr, corresponds to an engine power of about 18,000 hp. If it is considered that the total efficiency of an atomic power plant is 15%, then the thermal power of the nuclear reactor required would be approximately 90,000 kw, or 120,000 hp. Protection from gamma radiation and neutrons, as suggested by the author, would take the form of two spherical shields: the first of lead and the second of water. The diameter of the nuclear reactor, spherical in shape, would be

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

0.9 m. When the reactor is removed 15 m from the crew quarters, the necessary thickness of the lead shield will be 35 cm and that of the water shield 1.67 m. The total weight of such a shield (total weight of lead and water) was calculated as 172.5 tons, i.e., greater than the total flying weight of the aircraft.

In the next stage of his calculations, the author no longer used a closed spherical shell as basis. He now proposed a shield in the form of a sector of a sphere, placed between the reactor and the cockpit, and weighing only one fifth as much as a complete sphere, i.e., 34.5 tons. Using a reactor weight of 7 tons as basis, the author arrives at a flying weight of the aircraft of 104 tons, i.e., 12% greater than the normal flying weight of a B-47. If the flying weight is increased, the required conditions of flight, necessitate an increase in engine thrust and thus in reactor power. This, in turn, involves an increase in the weight of the shielding. On the basis of these calculations, the author draws the conclusion that "A vicious circle is thus created: The increased weight of the shielding requires an increase in engine power, and an increase in power requires an increase in weight of the shielding, and so forth".

We are not in agreement with this disoriented kind of conclusion. If the author had carried his calculations slightly further, he would have become convinced that in reality no "vicious circle" exists at all. An increase in flying weight by 12% certainly does require an increase in the reactor power and consequently an increase in the weight of the shielding. However, Murray's own calculations show that the weight of the neutron-radiation shielding increases by approximately one ton, i.e., by about 3% relative to its previous weight. Let us assume that we have increased the weight of the shielding by one ton. Then the flying weight of the aircraft will increase by that same sum. However, this increase is now only 1% and requires (in view of a certain increase in the necessary reactor power) an increase in the weight of the neutron shielding by only two or three tenths of a percent. Analogous results are obtained by calculation of

shields for gamma radiation.

The simplest calculations will show that, at any required condition of flight, the relative weight of the shielding system decreases with increasing flying weight. Reliable shielding from radiation in atomic aircraft, not inferior in speed and ceiling to the best modern aircraft using chemical fuel engines, is completely realizable. It is true that, for the present methods of radiation shielding, this will hold only for the heaviest types of aircraft, whose all-up weight is not less than 100 - 120 tons.

It would be advantageous if it were possible to design a shielding system as suggested by Murray, i.e., to place both shields only on one side of the reactor. In reality, the matter is somewhat more complicated. In order to reduce the neutron radiation, the reactor must be encased in shields on all sides. Otherwise, the structural materials of the aircraft, adjacent to the unshielded portions of the reactor, will be permeated by a powerful neutron flux. The degree of induced radioactivity will be so great that it will be impossible to approach the aircraft for long periods, even after the reactor has been removed. True, the weight of the shell on the sides of the reactor not directly facing the crew quarters can be reduced by making this portion of the shell thinner.

The shell, while reducing the intensity of neutron radiation to a nondangerous level, will not reduce the gamma-ray flux to the required degree. For protection from gamma radiation, a supplementary steel or lead shield is required. To do this in the form of a closed shell around the reactor is not believed possible because of the excessive weight that would result. Protection from gamma radiation can only be a partial or, as it is sometimes termed, shadow protection. The protective shield is mounted only on the side of the reactor directly facing the cockpit. Since the gamma rays will for the most part, move in straight lines, the location of the crew and passengers on an atomic aircraft will be within the shell, as it were. Except for a small spherical sector, all the remaining space around the re-

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

actor will be permeated by a gamma-ray flux of high intensity. Presence of human beings near an atomic aircraft while the nuclear reactor is operating and for a long

Fig.54 - Schematic Sketch of "Shell" Shielding of Passengers and Crew of an Atomic Aircraft

a) Neutron shield; b) Safe zone; c) Gamma-ray shields; d) Reactor

time thereafter will be impossible.

Figure 54 gives a schematic sketch of one of the variants of reactor shielding within the fuselage of an aircraft. The region of very high-intensity radiation is shown by solid lines, while the broken lines indicate the region with somewhat reduced intensity due to the first shield; however, only past the second shield do we find a danger-free zone for human beings during the entire flight.

It should be noted that the need for heavy shields is eliminated for the case of single pilotless devices, to be used only once i.e., long-range rockets, flying bombs, and radio-controlled bombers. The tendency to convert to pilotless means of aerial warfare exists today, independent of the introduction of atomic aircraft engines. Once atomic engines are produced, this tendency will become even stronger, since the problem of protection from radiation in unmanned devices consists primarily in a protection of ground personnel, so that the specific weight of an atomic

power plant relative to the total weight of the object can be considerably reduced.

Recently, proposals with calculations appeared, for transport or passenger aircraft with atomic engines: aircraft to be used for peaceful purposes. It is true that the design of biological shielding for passenger-carrying atomic aircraft is an even more difficult problem than for military aircraft. The weight of the shielding would be excessive, on the basis of the first approximate calculations. For example, for a passenger aircraft with a 15-ton payload, approximate calculations show that shielding of about 100 tons weight is needed to protect the passengers and crew from radiation. Shielding of this weight, quite obviously, will tip the scales against atomic aircraft. At one time, the thought was advanced that an atomic aircraft would become possible only when the total weight of the engine and the reactor plus the shielding would be less or equal to the weight of conventional aircraft engines plus the full load of chemical fuel (kerosene or gasoline).

This type of ratio is attainable only for the heaviest types of aircraft with an all-up weight of 120 - 200 tons, in which the weight of the engines and fuel would be 60 - 140 tons. It is already possible today to think of a combined weight of reactor, power plant, and shielding that would be in this weight category. In addition it should be remembered that, in view of the enormous advantage of atomic aircraft in terms of range of flight, a minor impairment in flying characteristics of the first atomic aircraft compared to conventional aircraft is entirely permissible. Even at reduced speed and ceiling and tolerating a certain excessive weight of the atomic power plant, the atomic aircraft will have certain indisputable advantages over conventional aircraft with respect to range of flight.

Special Design Features of Aircraft with Atomic Engines

To describe a design of atomic aircraft actually in existence is impossible since no such aircraft exists. But both in the press of our and other countries, a series of proposals as to design and general layout of a passenger-carrying

STAT

atomic aircraft has already been published. The major concern has been that of reliable protection of crew and passengers.

In the first place, considering that the intensity of direct gamma radiation from the reactor declines in inverse proportion to the square of the distance therefrom, the tendency is to move the reactor as far as possible from the passenger com-

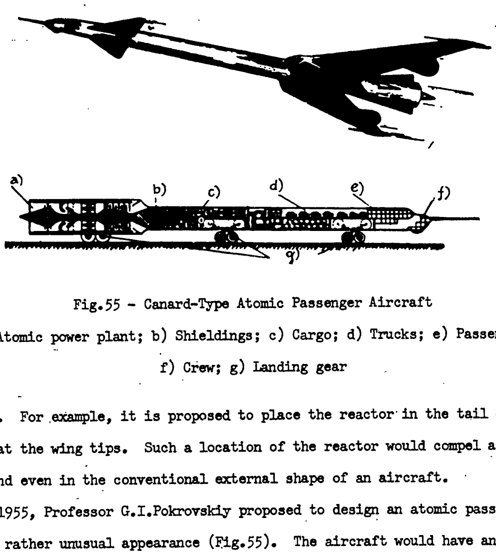

Fig.55 - Canard-Type Atomic Passenger Aircraft

a) Atomic power plant; b) Shieldings; c) Cargo; d) Trucks; e) Passengers; f) Crew; g) Landing gear

partment. For example, it is proposed to place the reactor in the tail of the fuselage or at the wing tips. Such a location of the reactor would compel a change in design and even in the conventional external shape of an aircraft.

In 1955, Professor G.I.Pokrovskiy proposed to design an atomic passenger aircraft of rather unusual appearance (Fig.55). The aircraft would have an exceptionally long fuselage whose tail section would contain the atomic engine, while the passenger compartment would be carried far forward. The abandonment of the conventional design with rearward location of the empennage is due to the fact that an atomic power plant represents a highly concentrated weight which should be as close

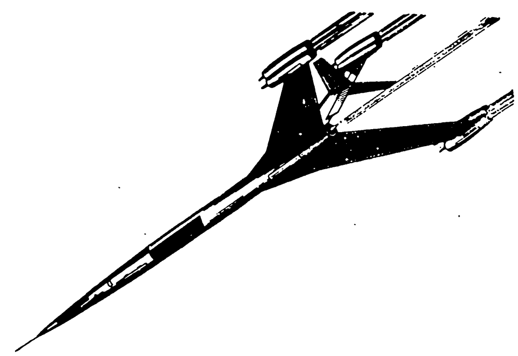

Fig.56 - Possible Variant of Atomic Transport Aircraft

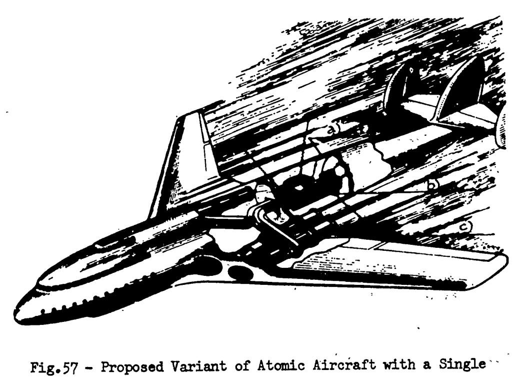

Fig.57 - Proposed Variant of Atomic Aircraft with a Single Reactor and Spherical Radiation Protection

a) Shielding; b) Reactor; c) Engines

STAT

to the center of the fuselage as possible. When shifted to the rear, this concentrated weight disrupts the aerodynamic balance, and the aircraft, with the center of gravity shifted to the rear, will tend to point its nose upward or, as the phrase goes, will pitch. Moreover the tail assembly of such an aircraft would be close to the center of gravity, the cables by which the aerodynamic forces of the controls are applied would be short, and the controls would have little effect. In order to eliminate these undesirable phenomena, G.I.Pokrovskiy proposed instead to use the canard design of aircraft, i.e., one in which the control surfaces are forward of the wing, since he believed this design best suited to the proposed purpose.

Interest in this type of design of an atomic aircraft has been displayed both here and abroad. However, certain doubts have been raised. The canard design was used in the early days of aircraft and was abandoned because of difficulties with the controls: an aircraft with its control surfaces forward of the wing has inadequate stability and is difficult to control on take-off and landing. The possibility is not excluded that, as time passes, the difficulties will be overcome and some atomic aircraft will adopt the canard design. There has been a story in the press to the effect that a canard-type aircraft has already been planned in England.

Another variant of atomic passenger aircraft design (Fig.56) envisages the placement of the engines in the wing tips and vertical tail surfaces. In this case, the general design is very similar to that of conventional aircraft, except that the engines are also carried far back, at the greatest possible distance from the passenger cabin. The stability of such an aircraft may be better, but the removal of heavy atomic engines from the center of gravity and placing them on long thin wing cantilevers and on the control surfaces raises doubt as to the reliability of the entire design.

The question as to which arrangement of the power plant is the more desirable has not yet been answered. Some designers believe that it is best to have one single reactor for all engines and to place it as close as possible to the center of

gravity of the aircraft, as illustrated in Fig.57. In this variant, it is easier to provide shielding for both passengers and ground personnel. In addition, the major concentrated load (reactor plus shielding) is in a more desirable location as far as stability and controllability are concerned. The shortcoming of this variant is the large weight of the all-around shielding of the reactor.

The weight factor in an atomic aircraft would be improved if the gamma-ray were designed not as a single shield but as a number of separate shields (Fig.58).

Fig.58 - Method for Incorporating the Shielding System in the Stress Pattern of the Aircraft

a) Compartments; b) Shielding; c) Engines; d) Reactor

It would be desirable to arrange the shielding material so as to be of greatest benefit to the design, permitting optimum balance of the aircraft and minimum stress on the stressed members of the glider. This would make it possible to use lighter shielding while providing adequate protection to the crew, to avoid excessive point loads, and to compel the shielding material to function in conjunction with the other stressed elements of the aircraft structure. It is true that, in this case, lead would not be as suitable for gamma shielding material, and would have to be replaced by stronger materials such as aircraft structural steel.

STAT

In this case, however, there would be no significant gain as far as the weight of the shield is concerned. Calculations show that the weight of a steel shield is not more than 5% greater than that of a lead one, and that a steel shield may be designed as part of the structure of the aircraft, which in the long run would result in a reduction of the weight of an aircraft with steel shields by comparison to that of an aircraft with lead shields.

At present, persistent efforts are being made to find means of reducing the weight of the shielding. The foreign press carries reports to the effect that in the United States and Britain, shielding materials have been discovered permitting the weight of the shielding to be reduced by a factor of 5 - 6 and that a plan for an atomic aircraft with a flying weight of only 42 tons has already been drawn. No confirmation of these reports has been received and it is not possible to vouch for their veracity.

At the same time, there are many interesting and in some cases quite shrewd and bold proposals to reduce the weight of the shielding and to create suitable conditions for passengers and service personnel of an atomic aircraft. One thing, however, is certain: the problem of biological protection has not been solved.

Abroad, many specialists believe that the first aircraft to be built will be an atomic bomber, in view of the fact that it is easier to provide radiation shielding since a crew of only 3 - 5 members will have to be protected. A transport modification of the atomic aircraft will follow some years later. Nevertheless, preliminary calculations of the cost of an atomic passenger aircraft and the cost of its operation were made in other countries as early as 1953 - 1954. As examples for this purpose, a plan was studied for an atomic aircraft with a 15-ton payload, designed to carry 180 passengers at 1600 km/hr for an unlimited distance. The cost of an aircraft with these characteristics was estimated at 9 billion francs, while the cost of the large Comet-3 passenger aircraft was only 700,000,000 francs. However, if the reduction in operating cost, the savings in

cost of chemical fuel, and similar factors are taken into consideration it is felt that a saving of 5 billion francs would be made annually for each atomic aircraft. This permits the hope that atomic aircraft will rapidly amortize their manufacturing cost.

Special Take-Off and Landing Features of Aircraft with Atomic Engines

The difficulties involved in using atomic power plants in aviation also include the fact that while today's heavy aircraft lose almost 50% in weight before landing due to the fuel consumption in flight which improves their landing characteristics, nothing of the kind can be expected of atomic aircraft which means that landing must be made at the same weight as that for take-off. This will, of course, increase the landing speed, the length of the landing run, and in general will complicate landing, making it more difficult and dangerous. The high landing speed of atomic aircraft will compel a lengthening of the runways, construction of stronger landing gear, etc.

However, a careful examination of this problem of the hazards connected with landing an atomic aircraft shows that they are not as insurmountable as might seem. The designers of modern high-speed aircraft were always faced with the task of reducing impermissibly high landing speeds and excessive landing runs. The landing speed and, consequently, the length of the landing run of an atomic aircraft may be reduced by the same means applied or being developed today for modern high-speed aircraft. These include, primarily, an efficient active mechanization of the wing and fuselage for take-off and landing: slots, flaps, and other devices for increasing the lift of the aircraft at low speed. At present, special devices are being developed to control the boundary layer of the air flowing round the wings.

In landing, special pumps are used for removal of the boundary layer by suction from the upper surface of the wing. It would be even better if this air could then be used to "blow away" the eddies forming at the wing at high landing angles.

STAT

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

of attack. Moreover, there are interesting proposals to develop special "air flaps" for increasing the coefficient of lift of a wing on take-off and landing. Measures of this type would make it possible to increase the lift of the wing of an atomic aircraft during landing by several times, meaning that the landing could take place at speeds so low as to be safe. The length of the landing run can be reduced to a minimum by using brake parachutes, by reversing the thrust of the engine (i.e., by creating thrust in the opposite direction) and by a number of other measures, such as "braking" devices on the runway.

In view of the problem of landing difficulties, it seems desirable first to plan and build large atomic hydroplanes which will take off and land at sea, where the landing strip is of whatever length required. In the United States, such a plan has been under development since 1955, and at present the first variant of an atomic hydroplane is under construction. The advantages claimed for this variant are the presence of water, which prevents radioactive contamination of the locality during landing and take-off and the absence of restrictions as far as take-off and landing distances are concerned. The first test flights may be performed over the ocean wastes. This also simplifies the problem of shielding.

The landing and take-off characteristics of atomic aircraft assume a completely different aspect if vertical take-off aircraft are considered (Figs. 59a, 59b). This type of aircraft has been given particular attention during recent years. An aircraft with vertical take-off and landing combines the highly desirable properties of high flying speed and possibility of basing not only on airfields but also on relatively small natural fields. The difficulties in creating an atomic vertical take-off aircraft are great, since this requires the development of a power plant that will be able to produce a sea-level thrust 30 - 40% greater than the weight of the aircraft. Such thrusts and capacities are within the realm of possibilities, but here a lightweight and advanced shielding is particularly necessary, so as to obtain the necessary ratio of shielding weight to aircraft weight,

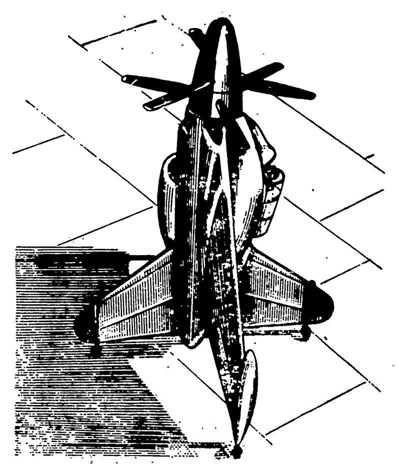

Fig.59a - Vertical Take-Off Aircraft

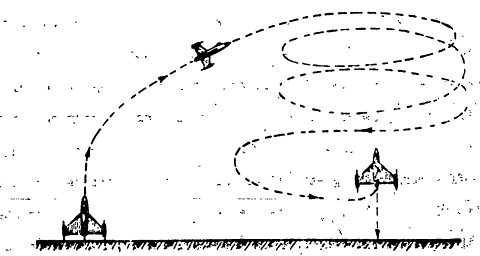

Fig.59b - Schematic Sketch of Vertical Take-Off and Vertical Landing of Aircraft with Turboprop Engine

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

in view of the enormous reactor power required.

More within reach at present may be the creation of an atomic helicopter of large carrying capacity (Fig.60). In this design, vertical take-off and landing

Fig.60 - Probable Aspect of a Heavy Helicopter with an Atomic Power Plant

could be ensured with a reactor of considerably less power than in a regular aircraft with vertical take-off. The rotors of a helicopter, rotating at low speed, develop a sea-level thrust exceeding the weight of the helicopter with engines of a power below that of the rapidly rotating propellers of regular aircraft with vertical take-off. It is true that the extremely large lifting rotor interferes with high speeds in horizontal flight. When the rotating rotor is in the streamline flow of the ambient air around the rotating rotor in horizontal flight, the considerable difference in the speeds of the blade which, at the given moment, is moving against the airflow (forward) and that of the blade moving with the flow (rearward) causes a helicopter to begin losing stability at a speed of about 300 km/hr and creates the risk of nose-over and crash. The speed at which stability is lost is known as the critical speed of a helicopter; at present, it is impossible to exceed this speed.

Despite the comparatively low horizontal flying speeds and the limited critical speeds, helicopters built in the USSR have been widely applied thanks to their advantages on take-off and landing. The ceiling and range of modern helicopters with chemical fuels are small. The development of a helicopter with an atomic power plant will permit a significant increase in range and to extend the area of usefulness of helicopters in general. Heavy atomic helicopters will make it possible to carry freight and passengers over enormous distances, without need to refuel at airfields and, for that matter, without the need for airfields at all.

Even more attractive is the concept of an atomic convertiplane (Fig.61). This is a combined type of aircraft capable of taking off and landing vertically on small areas. In flight, the engines are able to rotate from the vertical to the horizontal position, and the convertiplane is able to develop significantly greater speeds in horizontal flight than the customary type of helicopter. The installation of atomic turboprop engines will make it possible for a convertiplane to fly any desired distance and to land at any point on the surface of the earth. It would be within the power of such an aircraft to carry an expedition from Moscow to the Antarctic or any other distant point on the surface of the earth within a single day, to fly around the world within 24 hours, and rapidly to transport passengers, emergency freight, mail, etc. to any desired distance. Moreover, this will require no intermediate landing fields, bases, or fuel depots, nor will the vast expenditures for the construction of intermediate landing fields be necessary or the cost of delivering hundreds and thousands of tons of chemical fuels to such airfields.

Special Features of Ground Servicing of Atomic Aircraft

The difficulties encountered in designing atomic aircraft are exceedingly great, and some have not been overcome to this day. However, in addition to the difficulties in designing the aircraft themselves, there are difficulties in oper-

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

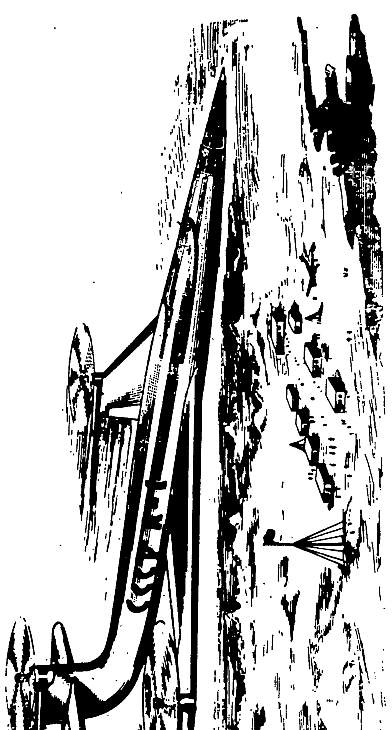

Fig.61 - An Atomic Convertiplane of the Future in the Antarctic

ation and servicing such ships.

The special features of operating atomic aircraft are due primarily to the radiation hazard which complicates the work done in flight, and also inspection, adjustment, and repair work both to the atomic power plant and to the atomic aircraft as a whole. A number of operations will be performable only by means of automatic, remote-controlled equipment which will have to be available at the time at which the first atomic aircraft is built and, as a matter of fact, somewhat earlier.

The organization of flight servicing aboard atomic aircraft will have to be at an absolutely strict and even higher level than the organization of the operation of conventional aircraft.

The servicing of an aircraft in flight will primarily have to provide for constant and precise control of the radiation level aboard the aircraft and at the parking apron on the ground. Each member of the service crew will have to have exact knowledge of his responsibilities both during normal work and in case of emergency. The skill of the engineering and technical personnel of the group will have to be beyond reproach so that each member will be able to make a conscious and accurate evaluation of every step he takes, will know the possible consequences, and will be able to take the necessary precautionary measures in this connection. As far as possible, every step must be reversible. This means that any device, once started, must have been provided in advance with means for stopping it (if necessary, very rapidly).

The above statements prove that an atomic engine and aircraft must be designed with consideration not only of its flying characteristics but also of its major operating characteristics, in order to provide convenience and safety for service in flight and on the ground. Calculations show that, in an atomic aircraft capable of flying at supersonic speeds, "shadow" shielding will provide normal conditions of work only for the crew compartment; outside this zone, the safe distance in the case of a reactor operating at full power will be not less than 1000 - 1500 m or

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

100 - 200 m after the reactor has been turned off. Consequently, to provide for safety of ground servicing, the atomic power plant must be so designed that the re-

Fig.62 - One of the Proposed Variants of an Atomic Aircraft and Inside Design of a Service Hangar

1) Location of reactor; 2) Reactor; 3) Television camera; 4) Well; 5) Shielding walls; 6) Bomb bays; 7) Radiation counters; 8) Lead glass window; 9) Television antenna; 10) Periscope; 11) Control room; 12) Television control panel; 13) Cockpit shielding; 14) Tunnel for crew; 15) Rail trolley for moving aircraft; 16) Reactor cover; 17) Immersed reactor; 18) Well into which reactor is immersed

actor can be readily removed from the aircraft after landing. Moreover, when using an atomic engine with a liquid heat-transfer agent, special measures must be provided for dumping this agent after the flight, since it will also be radioactive. When using an atomic turbojet engine with direct heating of the air in the reactor, of the type illustrated in Fig.33, the entire engine will be radioactive, which means that the entire engine nacelle will have to be readily dismountable.

These specific features of design and operation of aircraft with atomic power plants dictate the necessity for special equipment at landing areas, airfields, and hangars for atomic aircraft, particularly for the first experimental models. The airfield must have special storage provisions and underground laboratories for reactors, for the heat-transfer agents, and other radioactive materials and assemblies. A foreign journal carried a drawing (Fig.62) showing a proposed design variant for an atomic aircraft hangar.

In addition to developing special hangars it is also necessary to provide complete mechanization and automation of all work involving reactors, radioactive heat-transfer agents, and in some cases the engine as a whole. Experience with stationary reactors has shown that modern technology, in addition to the simplest types of manipulation, has also made possible complex, laborious, and very precise operations, by means of sensitive instruments and so-called "mechanical hands". For modern science and engineering, the development of ground equipment for transport of highly active reactors, for installation and removal of reactors by remote control, for connecting and filling the cooling systems with liquid or gaseous heat-transfer agents presents no great difficulty.

In addition to the mechanization means, airfields for atomic aircraft with "shadow" shielding must be equipped with shelters and comfortable air terminals with underground installations for passengers and service personnel. In the first atomic aircraft, it may well be that such special devices will also be required for entering the aircraft and particularly for leaving it after landing, before the reactor has been removed.

The need for much of this ground equipment will naturally be eliminated as soon as a reliable integral radiation shielding for aircraft reactors will have been developed. When this is the case, ground servicing will become simpler and safe; however, for the time being this is a matter for the future (Fig.63).

The preparations for starting and the actual startup of an atomic power plant

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

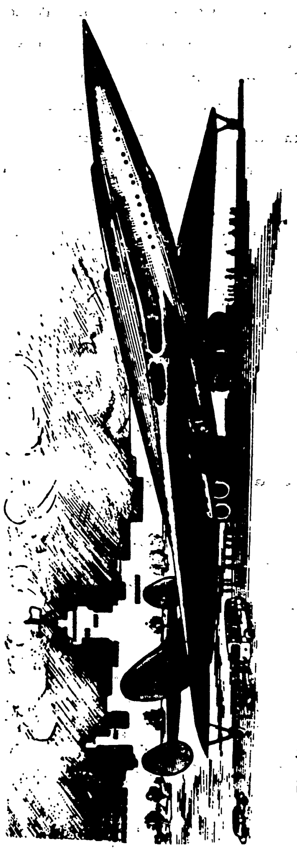

Fig.63 - Variant of Atomic Aircraft with Effective Omnilateral Radiation Protection

on an aircraft will involve certain difficulties with respect to preliminary heating of the heat-transfer agent and initiation of its circulation in the system, for agents which are in a solid or viscous state at ambient temperatures. From this point of view, and in order to reduce the radiation hazard on take-off and landing, certain designers consider it desirable to use compound power plants with both nuclear and chemical fuel. The chemical fuel can be used for starting, heating the engine, and for take-off and climb. In flight, when the heat-transfer agents have been preheated and circulation is in progress, the transition to nuclear fuel would take place, i.e., the reactor would be turned on. However as already stated, the use of combination engines of this type involves considerable difficulties and leads to an increase in the design weight, at the same time requiring a large reserve of chemical fuel aboard the aircraft which is of course unprofitable.

The problems of operating atomic aircraft include another unavoidable phenomenon. For some time after being

turned off, the reactor will continue to emit fairly large quantities of heat due to the radioactive decay of fissioned particles. During this period, circulation of the heat-transfer agent must be maintained by means of special installations at the airfield, or the reactor must be immersed in a tank containing a coolant. Therefore it is advisable, in selecting the landing means, to consider the necessity of removal of the "residual" heat. During the landing approach, it would be necessary to reduce the power of the reactor to a minimum and to turn it off completely after landing. This will permit a rapid cooling of the reactor, even with comparatively small airfield installations.

The special features inherent in the operation of the first atomic aircraft again emphasize the complexities and difficulties involved in the development and the initial use of such aircraft. It is only thanks to the high level of development of modern science and engineering that it will be possible to overcome all these difficulties. An especially important role in this connection will be played by such branches of science and engineering as automation, telemechanics, television, etc. As time passes, the complex and expensive equipment will be perfected, simplified, better thought out, made cheaper, and simpler in shape. The air fleet will receive powerful atomic aircraft which will be greatly superior to the aircraft of today in qualities and properties.

CHAPTER V

ATOMIC ENERGY AND INTERPLANETARY FLIGHT

The use of atomic energy opens broad perspectives for the solution of the exceedingly difficult problems involved in performing cosmic flights and mastering the universe.

What are the objects of cosmic flight? Is there any sense in working to achieve these objects?

These questions may be answered first by mentioning the advantages to science as a result of mastering interplanetary space. Even the launching of the first rockets - first artificial earth satellites - will make possible the creation of extraterrestrial laboratories for physical, chemical, and biological research under conditions of "weightlessness", low temperatures, and high electric discharges. It will be possible to create extraterrestrial weather stations, rebroadcasting stations for short-wave radio and television transmission, astronomical observatories with visibility undistorted by the atmosphere. All this will have a tremendous scientific and practical value. The development of artificial earth satellites and, later, of space ships for flights to other planets will be a new and important step along the road of knowledge of and conquest of nature by man.

As early as the beginning of the Twentieth Century, scientists were able to determine mathematically the conditions required for the performance of interplanetary flights. The studies of the late Russian scientist, K.E.Tsiolkovskiy are of fundamental importance in this connection. He laid the foundation for the science

of interplanetary communications, called astronautics. K.E.Tsiolkovskiy was the first to formulate clearly the concept that the only flying machine suitable for cosmic flight is the rocket, and the only motor able to operate in airless space is the rocket engine and, in particular, the liquid-fuel rocket (LFR) which was first proposed by Tsiolkovskiy. Tsiolkovskiy understood clearly how much labor, preliminary investigations and experiment would be required on the part of engineers and designers before an aerial interplanetary vehicle could be developed that would be able to overcome the gravitational field of the earth and fly into cosmic space.

What are the major engineering difficulties in cosmic flight and what are the practical possibilities existing today for the development of an interplanetary rocket?

When the horizontal flying speed is low, a rocket will (as is known) ultimately return to earth. In order for the rocket not to fall but to continue moving at the same altitude around the earth, thus changing to an artificial satellite, it must attain a given horizontal flying speed, which is known as orbital or first cosmic speed. This speed is not constant. Near the surface of the earth, it is 7900 m/sec and decreases with increasing altitude. At an altitude of 200 km, the orbital velocity of a satellite rocket must be approximately 7800 m/sec (28,000 km/hr), while at an altitude of 800 km this speed will be 7400 m/sec. A sputnik, 35,800 km distant from the earth and moving in the plane of the equator from West to East at a velocity of about 3000 m/sec, will be termed "stationary" since it will make one revolution every twenty-four hours together with the earth.

If the force of terrestrial gravity did not exist, then every body given a horizontal impetus would move by inertia in a straight line and at uniform speed and would travel into cosmic space at a tangent to a circular path, whose center would be at the center of the earth. But the effect of gravity compels a body to deviate from this path relative to the earth. At low velocities, a body falls back toward the earth. At orbital velocity, the body is able to fall only as far as is

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

necessary for it to attain an orbital path. The force of gravity constantly changes the direction of motion of a body, holding it in that path.

Today, after the development by the USSR of the world's first artificial satellite, it will be possible to proceed to the next stage in mastering cosmic space - the dispatch of a controlled rocket to the moon. In order for the rocket to overcome the force of terrestrial magnetism and fly to the moon, it has to attain the second cosmic speed of 11,200 m/sec (more than 40,000 km/hr).

What means are required to reach such high flying speeds?

In order to attain cosmic speeds, an engine which, while small in size and light in weight, will develop a colossal power in airless space will be required. Today, only the rocket engine can meet this requirement. Today, any planetary vehicle or Sputnik is designed as a rocket equipped with a liquid-fuel engine.

Figure 64 gives the design and operating principle of a modern rocket, equipped with a liquid-fuel engine. The sketch shows the principal parts and assembly of the rocket: control and payload section (A), oxidizer tanks (O), fuel tanks (G), turbopump assembly (TPA) for delivery of fuel components to the engine chamber, stabilizer (C), gas control vanes (P), and finally the engine (D) which latter illustrated on a larger scale at the right side of the drawing. The combustion chamber (1) and the jet nozzle (2) serve to convert the chemical energy of the fuel into thermal energy and subsequently into the kinetic energy of the escaping stream of hot gases. The fuel and oxidizer are injected through nozzles into the combustion chamber by the turbopump assembly at a pressure of 5 - 6 atm in the chamber. The oxidizer or the fuel (most often the fuel), prior to injection into the combustion chamber, is circulated through the tube (3) in the space outside the engine jacket to cool the walls of the jet nozzle and the combustion chamber.

The major requirement to be met by a rocket engine is minimum specific fuel consumption or, what amounts to the same thing, high specific thrust. The specific thrust depends on the exhaust velocity from the jet nozzle and, in modern liquid-

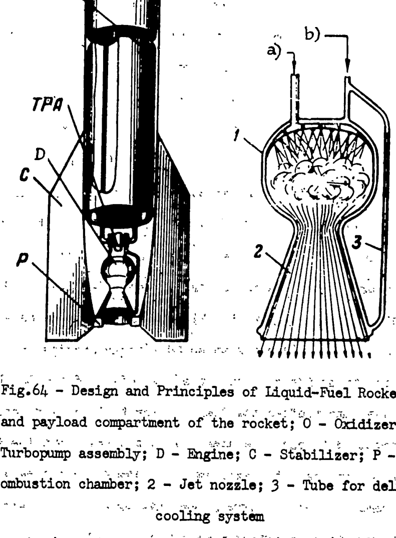

Fig.64 - Design and Principles of Liquid-Fuel Rockets

A - Control and payload compartment of the rocket; O - Oxidizer tank; G - Fuel tank; TPA - Turbopump assembly; D - Engine; C - Stabilizer; P - Gas control vanes; 1 - Combustion chamber; 2 - Jet nozzle; 3 - Tube for delivering fuel to cooling system

a) Fuel; b) Oxidizer

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

fuel engines, is 200 - 300 kg-sec/kg (200 - 300 kg of thrust per combustion of one kilogram of fuel mixture per second). The exhaust velocity, in turn, depends on the temperature and pressure of the gases in the combustion chamber and also on the molecular weight of the combustion products. In modern liquid-fuel engines, the temperature in the chamber reaches 2500 - 3000°C, and the exhaust velocity from the jet nozzle ranges from 2000 to 3300 m/sec. When using fuel components of optimum efficiency, e.g., a mixture of hydrogen and fluorine, the exhaust velocity of the gases may be brought to 4000 m/sec.

Speeds and Altitudes Attained

Rocket engineering, in the past 10 - 20 years, has undergone considerable development. After World War II, rockets equipped with liquid-fuel engines have come into wide use, both for military purposes and for scientific studies of the upper layers of the atmosphere. There is constant improvement at the engineering end with respect to velocity, altitude, and range of rocket flight. Single-stage military and meteorological rockets today rise to altitudes up to 300 km and develop a maximum speed of over 6000 km/hr, corresponding to 5 - 6 times the speed of sound. The range of single-stage rockets exceeds 400 km.

It is no longer possible to expect further significant gain in speed and range merely by increasing the dimensions of a single-stage rocket. Therefore the majority of powerful new rockets is designed as multistage rockets (Fig.65). A step rocket is able to rise to more than 1000 km and fly thousands of kilometers. Such rockets have been given the name of strategic intercontinental ballistic missiles and are now beginning to gain major military significance. In a number of countries, an extensive program for the development of intercontinental rockets has been under way for several years. Abroad, the development of a three-stage rocket is under way. This rocket is to develop a speed of 15 times the speed of sound (18,000 km/hr). The final stage of this rocket is to rise to an altitude of 915 km

and to have a horizontal range of about 8000 km. The development of a multistage intercontinental rocket with a range in excess of 8000 km and traveling at 20 times

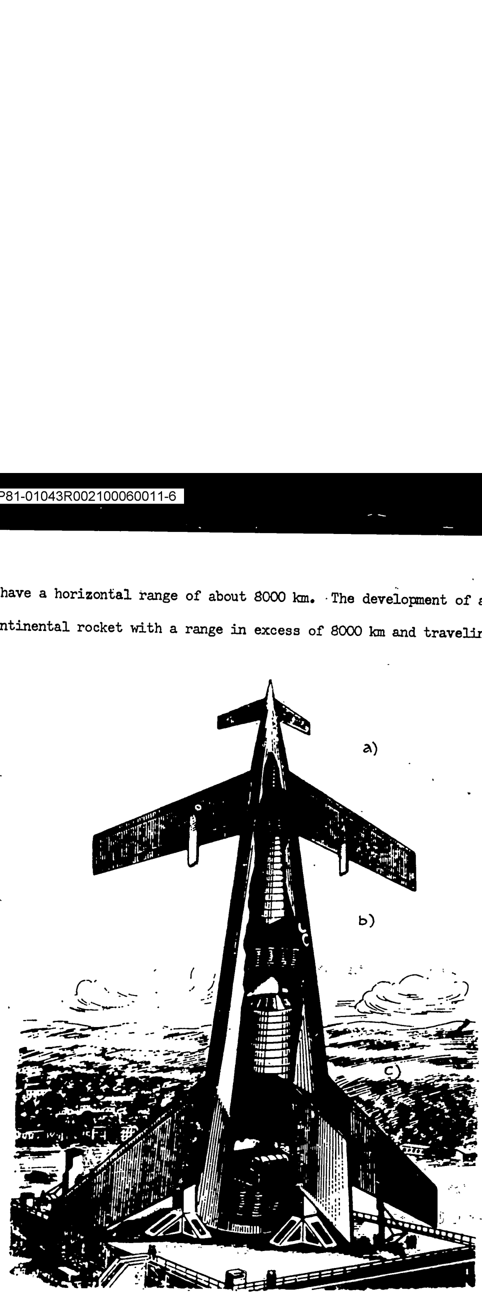

Fig.65 - One Design of a Multistage Rocket

a) Third stage; b) Second stage; c) First stage

the speed of sound is projected as a subsequent step. The highest point in the trajectory of the rocket is 1280 km, and the terminal velocity at the end of the

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

powered portion of the flight will be 6700 m/sec (24,100 km/hr).

Our scientists and inventors have always given much attention to the development and perfection of various types of rocket armament. During World War II no army on earth had rocket armament as effective as those of the glorious Guard Mortar men of the Soviet Army. At present, the Soviet Armed Forces are equipped with every variety of the most modern jet and rocket equipment, including rockets of long and superlong range (intercontinental, multistage ballistic rockets).

In reviewing the truly grandiose success of rocket engineering in our day, we would like to draw the attention of the reader to the fact that the development of rocket engineering paves the way for further rapid progress in special branches of science and engineering, industry, and transport. The development of rocket engineering has served as a helpful preparatory stage for reaching cosmic velocities, for the further development in the very next few years of artificial earth satellites and, in the not-too-distant future, of interplanetary flights. The development, testing, and perfection of giant rockets, equipped witn powerful liquid-fuel engines, has already considerably reduced the distance between the theoretical work of Tsiolkovskiy and the practical realization of the first cosmic trip.

Two Means of Attaining Cosmic Velocities

From K.E.Tsiolkovskiy's equation for the terminal velocity of the powered section of a rocket flight, $V = 2.3 \cdot W \cdot \log\left(\frac{G_{in}}{G_{fin}}\right)$. Obviously, the velocity V, reached by a rocket when all its fuel has been consumed, depends on the exhaust velocity W of the gases from the jet and on the ratio of initial to terminal weight of the rocket $\frac{G_{in}}{G_{fin}}$. Tsiolkovskiy's equation may be understood on the basis of the simplest physical reasoning. Other conditions being equal, the thrust and economy of a rocket engine is determined by the exhaust velocity of the gases. The higher the exhaust velocity, the higher will be the thrust created by each kilogram of gas derived from the fuel mixture and the more efficiently the fuel stored in a

rocket be utilized. At present, very high exhaust velocities have been attained; loud whistling and roar accompany the blinding flash of ignited gases that may be described not so much as a discharge but as an eruptive ejection from the nozzle of liquid-fuel engines of medium thrust. This is even more striking for engines of high thrust. It is absolutely unsafe for an unprotected person to be near the launching pad during the take-off of a large high-altitude rocket (Fig.66).

Fig.66 - Take-Off of Powerful High-Altitude Rocket

However, the exhaust velocities reached at present are inadequate for interplanetary flights.

Reaching exhaust velocities in excess of 4000 m/sec by chemical fuels is exceedingly difficult. Further increase in the speed of rocket flight has to proceed entirely by improvement in design, i.e., by increasing the ratio of the fuel weight to the weight of the empty rocket. It follows from Tsiolkovskiy's formula that even at exhaust velocities of 4000 m/sec, it would be necessary, in order to reach the second cosmic speed of 11,200 m/sec, to produce a rocket whose airframe together with engine, tank, and equipment would weigh only $\frac{1}{16}$ of the initial fuel capacity. In addition, the above Tsiolkovskiy equation was derived without consideration of atmospheric resistance and the effect of terrestrial magnetism. If these factors are taken into consideration and if the exhaust velocities actually attained are entered into the calculation, we find that for each kilogram of airframe, equipment, and payload a rocket must carry at least 25 - 30 kg of fuel. The development of a rocket with such load data today encounters insurmountable engineering difficulties; for this reason, systems of step rockets or "rocket trains", as K.E.Tsiolkovskiy called them in his day, must be used.

Much has already been accomplished by engineers and designers to develop advanced rocket designs. By using the lightest and strongest structural materials and by developing rational layouts, it has become possible to have the modern rocket carry a fuel supply 5 - 6 times as great as its structural weight. Further improvement in rockets with respect to weight will encounter ever greater difficulties, and it will again be necessary to return to the problem of increasing the exhaust velocity, of increasing the energy supply per unit weight, and particularly of increasing the unit volume of rocket fuel.

Nuclear or Chemical Fuel?

The concept of applying atomic energy for attaining cosmic speeds and performing interplanetary flights was originated a long time ago. As early as 1926, K.E.Tsiolkovskiy directed attention to making use of the enormous sources of energy within radioactive elements, and posed the question of using radium as fuel for a rocket engine.

At present, thanks to the progress made in nuclear physics, to the development of a rapidly progressing science of atomic power, and to the creation of an atomic industry, we have come close to the solution of the problem of making use of atomic energy in rocket engineering.

However, even today, many scientists believe that the first interplanetary trip by man will not be made with nuclear but with conventional chemical fuel. Another, and in fact, much larger group of contemporaries hold that interplanetary flights are impossible with conventional chemical fuel and that a more powerful

source of energy such as nuclear energy would have to be used, or else that new discoveries or methods for circumventing this problem will have to appear. One such method was proposed in 1956 by Professor G.A.Chebotarev who showed by calculation the possibility that a rocket ship could fly around the moon and return to earth without using fuel. All that is needed is for the rocket to attain an initial velocity of 11.2 km/sec to overcome gravity. All the rest of the flight will be made by ingenious use of the interlocking gravitational fields of the moon, earth, and sun.

Let us attempt, at least, a qualitative description of the problem of using nuclear fuel for interplanetary rocket engines.

Advantages of an Atomic Rocket Engine

The first advantage of nuclear fuel for rockets usually suggested is the colossal energy or thermal capacity it provided. However, in order for a rocket to move forward at high speed, what is needed is not only energy but also a mass to be expelled backward (a liquid or gas) which, escaping from the engine at enormous velocity, will create reactive thrust. The fact that, in the chamber of an atomic liquid-fuel rocket, heat for heating the gases is not produced by the chemical reaction of combustion but by nuclear reaction, does not mean at all that we have provided thrust for the rocket. The energy is available and enough of it can be generated by fission of nuclear fuel, but application of this energy in the form of heat is of little use since there is not enough mass to be ejected for the creation of thrust. Consequently, a rocket with an atomic liquid-fuel engine, like an ordinary rocket, must carry enormous quantities of its working medium aboard, together with an inertial mass which is able to convert the thermal energy of the nuclear reactor into kinetic energy of a continuous gas jet.

The second advantage of nuclear fuel results from the first and consists in the fact that this fuel may be used to attain, theoretically, any temperature no

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

matter how high in the chamber of the rocket engine. It is known that temperature is one of the main decisive factors in obtaining high exhaust velocities and specific thrusts in a rocket engine. Here, however, an obstacle is encountered. At the temperatures in conventional liquid-fuel engines with chemical fuels (up to 3000°C and more), considerable difficulties are already encountered in the selection of structural materials and the provision of dependable cooling for the combustion-chamber walls and the jet nozzle of an engine. At the slightest difficulties in the cooling system, the walls of a high-temperature liquid-fuel engine will fuse and burn as rapidly as lead foil over a gas burner.

Nuclear reactions make it theoretically possible to reach temperatures of 5000 - 10,000°C and more in the chamber of a liquid-fuel engine. This permits enormous exhaust velocities, several times greater than those of modern liquid-fuel rockets. However, this second advantage of nuclear fuel cannot be utilized until structural materials able to withstand such high temperatures are available. Moreover, nuclear reactors for a rocket engine, using the most refractory of the materials known today, even in theory, will not permit working gas temperatures above those reached by ordinary liquid-fuel rockets with chemical fuels.

Why is this the case?

In order to understand this point, it is sufficient to recall our discussion of the fact that, for reaching the same temperature in the working gases, the temperature of the structural materials of an atomic engine must not only be higher than the temperature of the structural materials of a conventional engine but must be higher than the temperature of the working gas in the engine.

The literature contains a number of proposals on creating high-temperature reactors for rocket engines. An example of such a reactor is that of the atomic liquid-fuel rocket shown in schematic outline in Fig.16. The graphite reactor core has a porous structure and is provided with longitudinal conical channels. Fused uranium (the reactor is designed to operate at 3150°C) is contained in fine honey-

combs within the graphite, which still retain a certain strength at this temperature. Through the ducts in this porous mass hydrogen is propelled by pumps, and this hydrogen, heated in the reactor, should, in the opinion of the inventor of this design, escape from the jet nozzle at a velocity of 7300 m/sec.

Unfortunately, there are many reasons for doubting the possibility of developing such a reactor, particularly its mechanical strength and dependability under the effect of variable temperatures and powerful streams of hydrogen.

The third advantage of nuclear fuel for a rocket engine lies in the fact that an atomic liquid-fuel rocket does not require, as its working medium, two specially selected components (fuel and oxidizer) as in ordinary liquid-fuel rockets, but only one (the inertial mass). Ordinary distilled water, which not only can be converted in the reactor into superheated steam but can also be decomposed into its constituent elements (oxygen and hydrogen) which will escape from the engine nozzle and create reactive thrust, is one possibility as an inertial mass. Water actually is the cheapest inertial mass for an atomic rocket, but it is not the best in terms of maximum exhaust velocity and high specific thrust. The selection of the inertial mass must be based on calculations for obtaining maximum exhaust velocity of the gas stream. This desirable property is exhibited by chemical elements of low molecular weight and therefore, maximum exhaust velocity can be obtained with atomic hydrogen and, as the next best, with ordinary hydrogen. A stream of hydrogen, heated to a temperature of 4000 - 6000°C, should give an exhaust velocity of the order of 8000 - 10,000 m/sec.

A major shortcoming of hydrogen is its low specific gravity. Even in the liquid state, one liter of hydrogen weighs only seventy grams, i.e., less than $\frac{1}{14}$ of one liter of water. This drawback of hydrogen, when considered in the light of its positive properties, has been the cause of a scientific debate conducted for many years among distinguished scientists and specialists in the field of rocket engineering. Thus, refuting the contentions of Professor N.G.Chernyshev (Bibl.25), V.P.Glushko, Member of the Academy, has repeatedly asserted that hydrogen is a fuel without a future as far as rockets are concerned, because of its low density and because of the difficulty in storing enough of it aboard a rocket. A rocket, using hydrogen as fuel, would ordinarily have enormous dimensions and thus high drag as it moves through the dense layers of the atmosphere.

This shortcoming of hydrogen is particularly disturbing to scientists concerned with the problems of astronautics. Thus, today, the way out of the situation is to use chemical compounds of hydrogen of high specific gravity, in the liquid state, which yield high quantities of atomic hydrogen when decomposed at high temperatures. Substances of this kind known today include ammonia (NH_3) and ordinary water (H_2O), which may be regarded as a possible inertial mass for atomic liquid-fuel rockets, along with hydrogen.

Projected Atomic Space Rockets

Confirmation of the above-described advantages and disadvantages of nuclear fuels is found in virtually all designs of atomic space rockets now suggested.

The maximum possible theoretically attainable exhaust velocity is equal to the speed of light (300,000 km/sec). On this basis, it has been suggested that the actually obtained exhaust velocities be compared with the velocity of light and that rockets be categorized accordingly as gas, atomic, and photon rockets.

Today only gas rockets are in existence (rockets using gas as the ejected mass). In turn, these are subdivided into solid-fuel (powder) rockets, liquid-fuel, and thermo-atomic rockets. Powder and liquid rockets have already produced exhaust velocities somewhat greater than 0.00001% of the velocity of light. Thermo-atomic rockets, i.e., rockets using the heat of a nuclear reactor, are today in the design stage and will, in the course of time, be able to produce exhaust velocities 0.0003% - 0.0001% of the velocity of light. Pure atomic rockets, which will be able to create thrust directly by ejecting the nuclear reaction products, and photon

rockets whose thrust is created by the irradiation of powerful light beams, are as yet purely hypothetical.

At present, of the various types of atomic rockets, only thermal rockets seem realizable in practice. These rockets use the thermal energy of a nuclear reactor to create high temperatures in the combustion chamber of liquid-fuel rockets.

Ten years ago, the first sketch of a rocket satellite, using an atomic liquid-fuel rocket, was published in the foreign press. The author of this project proposed that an atomic liquid-fuel engine be mounted in a single-stage rocket with the object of reaching an orbital velocity of 8270 m/sec. In the combustion chamber of the engine, it was proposed to house a radium and graphite reactor weighing 32 tons and using thermal neutrons. On the basis of the calculations, 3160 kg of hydrogen would have to pass through this reactor per second. (The fuel flow through the well-known German V-2 rocket was only 125 kg/sec.) It is believed that the thrust, when hydrogen is heated in a reactor to 3150°C and the exhaust velocity is 7300 m/sec, will be as high as 2350 tons, which is approximately 100 times as high as the thrust of the V-2 (25 - 26 tons). In order for a rocket with this type of atomic liquid-fuel engine to reach a speed of 8270 m/sec, the engine has to consume 1130 tons of liquid hydrogen in the 358 sec of operation during powered flight. The total take-off weight of the rocket would be 1410 tons.

Obviously, the scale of this project is more in the category of a science-fiction novel than realizable from an engineering viewpoint. Therefore, the next variant of the calculation was one that constituted a closer approximation to reality: weight of the reactor 14.8 tons, hydrogen consumption 1520 kg/sec, engine thrust 1140 tons at a take-off weight of 685 tons for the rocket as a whole.

The major difficulties encountered in the use of a reactor in a liquid-fuel rocket chamber are those of providing high temperatures and reliable conditions of heat liberation. We know that uranium fuses at a temperature of 1130°C, while graphite vaporizes at a temperature of about 3700°C. Therefore, certain authors propose another means of applying nuclear energy in a rocket engine: injecting the nuclear fuel into the liquid-fuel engine in the form of a solution or suspension.

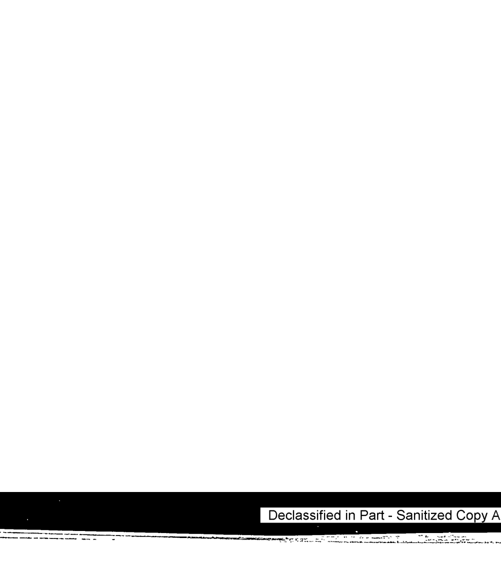

Fig.67 - Schematic Sketch of an Atomic Liquid-Fuel Rocket with "Subcritical" Reactor

a) Supply of nuclear fuel in suspension; b) Shell; c) Control rod; d) Reactor; e) Porous reflector; f) Porous interior wall; g) Supply of liquid hydrogen or water; h) Zone of high-temperature nuclear reaction

Application of nuclear fuel in this manner will provide for adequate temperatures and good conditions for heat liberation in the eddy flow of gases. However, the trouble is that the dimensions of the chamber of such an engine would have to be excessively large. The critical state of the homogeneous gas mixture in which the nuclear reaction would have to occur, is determined by the product of the pressure in the chamber and its radius. According to certain calculations, a mixture of hydrogen and atomized nuclear fuel at a temperature of 5000°C and at 100 atm pressure would require a chamber of at least 240 m diameter. To produce a chamber of this kind is something that obviously no one has undertaken, but the logical

thought arises of combining the first and second principles to make use of the advantages and diminish the shortcomings of both.

The device in the chamber of this engine (Fig.67) is not a solid but a porous annular reactor, made of refractory uranium carbide and graphite and enclosed in a porous graphite reflector. Before the engine is started, the reactor is subcritical and does not operate. On manipulating the control rods, the activity of the reactor increases and, after hydrogen and a small amount of uranium powder have been injected into the chamber, the system becomes critical and begins to generate heat which heats the hydrogen in the high-temperature flow zone of the chamber to 3500 - 4000°C. In this case, the temperature of the reflector and even of the reactor, where significant quantities of heat are also liberated, will not be above 1500 - 1600°C, due to the stream of pure liquid hydrogen which dissipates heat from the structural material of the reactor into the high-temperature zone. The walls of the jet nozzle are of a heat-resistant porous material and therefore start sweating, as it were, when the engine is in operation. Hydrogen, seeping through the pores, forms a dense film of gas which continually being washed away and just as continually renewed, protects the walls of the jet from the effects of the incandescent flow of gas.

If the average temperature to which hydrogen is heated in the chamber of such an engine is assumed as 3700°C, an exhaust velocity of 8100 m/sec would result. At a consumption of liquid hydrogen of 30 kg/sec (i.e., only $\frac{1}{4}$ as large as in the V-2), a thrust of 25 tons is attainable.

Unfortunately, this variant of the atomic liquid-fuel rocket also has its disadvantages. To begin with, the probability of fission of the nuclei of injected fuel is negligible during the period of time an individual nucleus is in the area of the annular reactor. In all probability, the nucleus of the injected fuel will travel through the chamber of the engine intact and undamaged, without being fissioned. Obtaining any significant number of nuclear fissions would require a neutron flux of a density impossible to realize in the reactor serving as the neutron source and simultaneously containing the fuel nucleus.

Selection of a Program for Attaining Cosmic Speeds

At the beginning of its flight, a rocket must pass through the dense layers of the atmosphere. Atmospheric air creates significant resistance, and the bulk of the

Fig.68 - Atomic Launching Aircraft for Artificial Earth Satellites

Fig.69 - Schematic Sketch of Two-Stage Rocket for Launching an Artificial Earth Satellite

a) Instrument compartment of satellite; b) Parachute for instrument compartment; c) Liquid-hydrogen tanks; d) Atomic liquid-fuel rocket for second stage; e) Conventional liquid-fuel rocket for first stage; f) Parachute for first stage; g) Tanks for chemical fuel

fuel will have to be used to overcome this resistance. In developing high velocities, even in the comparatively dense layers of the atmosphere, a rocket may be subject to excessive heating due to friction with the air, which is also an undesirable factor.

This raises the question of using, during the first segment of the flight of a cosmic rocket, atmospheric air as the working medium for the atomic engines. It is in this segment, during the first stage of ascent and acceleration of the cosmic rocket, that the advantages of nuclear fuel, with its high energy content, must be utilized to the fullest.

By way of example, we may suggest the following schedule for releasing a whole series of experimental earth satellites: An atomic carrier or launching aircraft (Fig.68) with a payload of 20 - 30 tons would be built. There can be no doubt as to the feasibility of constructing such an aircraft. Aircraft designers agree that the design and development of aircraft with up to 100 tons payload and more represents a problem entirely soluble from the engineering point of view, even today.

The carrier aircraft carries a two-stage rocket (Fig.69) weighing 20 tons to an altitude of 20 km and accelerates it to 600 m/sec in the direction of the earth's rotation from West to East. The density and resistance of the air at 20 km is about $\frac{1}{14}$ that at the earth's surface, so that the danger of excessive heating of the rocket during further acceleration is significantly reduced.

When the carrier aircraft reaches the Sputnik launching area, the operator connects the first stage of the rocket engine. In order to protect the crew of the launching aircraft from the radiations of the atomic liquid-fuel engine, an ordinary liquid-fuel engine, using liquid oxygen and hydrogen, is used for the first stage of the rocket. The characteristics of the rocket, as projected, are entirely attainable at the present time: 35 tons thrust, fuel consumption 104 kg/sec, exhaust velocity 3300 m/sec. After consuming 4500 kg fuel in 43 - 44 sec, the first stage accelerates the rocket to a velocity of 900 m/sec, is separated at an altitude of 34 km, decelerated, and returned by a cargo chute. On separation of the first stage, the main Sputnik engine goes into operation - an atomic liquid-fuel rocket of the type illustrated in Fig.67. With an engine thrust of 28 tons, the rocket will, in 280 sec of final acceleration, reach an orbital velocity of 7840 m/sec at an altitude of 294 km.

The characteristics of the selected two-stage rocket are shown in Table 3, and its approximate dimensions in Fig.69.

Table 3

Rocket Characteristics	Unit	First Stage	Second Stage
Initial weight	Tons	20	14
Weight of fuel	Tons	4.5	9.5
Fuel consumption	kg/sec	104	34
Time of operation	Sec	43	180
Engine thrust	Tons	35	28
Speed at combustion cutoff	m/sec	900	7840
Altitude	km	34	294

The calculations and drawing reveal clearly an undesirable feature of the hydrogen rocket. The volume occupied by 9.5 tons of liquid hydrogen is 135 m^3 which means that the rocket has to be extremely large, because of the hydrogen tanks. If it would be possible in some way to increase the density of the hydrogen, let us say by 14 times, i.e., to bring it to the density of water, the volume of the inertial mass would be less than 10 m^3, and the rocket would be compact with good aerodynamic qualities.

This program for launching satellite rockets has a number of advantages. The launching aircraft, as the first stage of the rocket, may be used repeatedly. The hull and tanks of the second stage do not have to be jettisoned, which will give the Sputnik greater dimensions and reflectivity, making it easier to observe from the earth. When, as result of the small amount of friction in the highly rarefied upper layers of the atmosphere, the satellite gradually starts losing speed and altitude, the hull and tanks of the second stage can be automatically converted into a kind of air brake for decelerating the instrument compartment before the main parachute opens to save the equipment and instruments. The experience in the operation of such satellites and the experimental data obtained will later make it possible to proceed with confidence to explorations of higher levels of cosmic space.

The more nearly we approach practical steps in the field of astronautics, the more frequently the question arises as to the cost of a satellite rocket, its equipment, launching platforms, and other auxiliary installations. In October 1957 the world's first artificial earth satellite was launched in the USSR. The launching of the first artificial satellite in the United States is planned for 1958. Considerably greater difficulties will be encountered in the development of the first cosmic ship carrying a crew, but this problem also will be solved in the not too distant future.

In view of the facilities that the Party and State have created for fruitful work by our scientists, Soviet science today occupies the leading position in a number of fields. Our scientists are beginning to penetrate the secrets of controllable thermonuclear reactions.

When these reactions are mastered, they will produce several times more energy than the fission reaction. As soon as it is possible to create a controlled thermonuclear reaction within the chamber of a rocket engine, we will have arrived at what is known as a photon rocket, where the thrust will be produced by powerful light irradiation.

Problems of photon rockets have been treated for several years at a small institute of rocket-engine physics, headed by Dr.E.Saenger in the German Federal Republic. It is held, in this institute, that photon rockets will be the final stage

STAT

Declassified in Part - Sanitized Copy Approved for Release @ 50-Yr 2013/07/01 : CIA-RDP81-01043R002100060011-6

in the development of engines both for aircraft and for interplanetary and cosmic travel. Photon rockets will be able to fly at speeds approximating the velocity of light. Sources of energy for photon rockets can be discovered even today, but the question arises as to what can be done as to the materials to be used for the walls of photon engines, and where to find materials able to withstand such enormous temperatures and pressures.

It can hardly be expected that anyone bothers with these problems today. Apparently, materials of this kind will have to be synthesized. In addition, it will be necessary to develop completely new and efficient methods of cooling and protecting the structural materials from excessively high temperatures.

Many questions having to do with problems of the practical realization of interplanetary flights have not yet been investigated, and their solution will take time, tremendous efforts, and enormous expenditures of materials. However, the rapid development of modern aviation in rocket engineering permits us to believe that the day when the first flights into cosmic space become reality is not far distant. The World Astronautical Federation already embraces twenty-three countries. The Interdepartmental Commission for the Coordination and Performance of Interplanetary Communications of the USSR Academy of Sciences is a member of that Federation. Rocket and interplanetary societies, whose members include specialists, enthusiasts, and simply persons interested in astronautics, have been organized in many countries to attract attention to and stimulate support of cosmic flights.

In the Soviet Union, an astronautics section has been established at the Chkalov Central Aviation Club of the USSR in Moscow. Sections and circles are being organized in other cities on this pattern. Today, interplanetary flight enthusiasts are taking active part in the International Geophysical Year, which will last from 1 July 1957 to 31 December 1958. In the course of this year, the launching of a number of experimental rockets into the upper layers of the atmosphere, and of the first chemical-fuel earth satellites, is projected. The launching in

the USSR, in August 1957, of a superlong-range ballistic rocket and, in October 1957, of the world's first artificial satellite, marked a significant step in the development of science and engineering in our country, and in the strengthening of the defense capability of the USSR.

The perspectives before science are limitless. There can be no doubt of the fact that, with the passage of time, these complex problems will be solved, and man will master interplanetary flight exactly as he has mastered flight in the atmosphere surrounding the earth.

Conclusions

The question as to the necessity and possibility of applying atomic energy in aviation has already been given a positive answer and solution. This is primarily demonstrated in the directives of the Twentieth Congress of the Communist Party of the Soviet Union, which indicate the need to develop atomic engines for transport purposes.

The development of atomic aircraft engines is also moving forward on a broad front in other countries. Each day the press carries new data on the development of projects of atomic aircraft, on the development of the first atomic aircraft engines using nuclear fuel, etc. The majority of foreign scientists believe that the first flights by atomic aircraft may be expected in 1959 - 1960. Time will show how accurate these prophecies are.

Much has already been done in the field of applying atomic energy to military, industrial, and transport purposes. But considerably more remains to be done.

The solution of the problem of applying atomic energy in aircraft power plants will require extensive scientific studies, engineering and technical developments, and experiments. The designing of atomic engines and aircraft, experimental work on aircraft reactors on the ground and in the air, the search for new structural materials, methods and means of radiation shielding - these are the main trends along which this work will proceed.

Successful solution of the problems of producing atomic engines for aviation will constitute a new giant step forward in the progress of aircraft science and engineering.

BIBLIOGRAPHY

1. - Reactor Design and Reactor Theory. Izdat. Akad. Nauk SSSR (1955)
2. Vlasov,N.A. - Neutrons. Gostekhizdat (1955)
3. - Problems of Utilization of Atomic Energy. Collection of Papers, Military Publishing House of the USSR Defense Ministry, (1956)
4. Stechkin,B.C., Kazandzhan,P.K., Alekseyev,L.P., Govorov,A.N., Nechayev,Y.N., and Fedorov,R.N. - Theory of Reaction Engines. Oborongiz (1956)
5. Skubachevskiy,G.C. - Jet Engines for Aircraft. Oborongiz (1955)
6. Lozhkin,A.N., and Kanayev,A.A. - Binary Devices. Mashgiz (1946)
7. Yastrzhembskiy,A.S. - Engineering Thermodynamics. Gosenergoizdat (1953)
8. Mikheyev,N.A. - Fundamentals of Heat Transfer. Gosenergoizdat (1956)
9. Kichigin,N.A. and Kostenko,G.N. - Heat-Exchange Equipment and Vaporizing Systems. Gosenergoizdat (1955)
10. - Atomic Power. Gosenergoizdat (1956)
11. - Metallurgy of Nuclear Energy and the Effect of Radiation on Materials. Metallurgizdat (1956)
12. - Scientific and Engineering Fundamentals of Nuclear Power. Ed. by Goodman,K., Publishing House for Foreign Literature, Vol.I, (1948), Vol.II (1950)
13. Glasstone,S., and Edlund,N. - Fundamentals of Nuclear Reactor Theory. Publishing House for Foreign Literature (1954)
14. Murray,R. - Introduction to Nuclear Engineering. Publishing House for Foreign Literature (1955)

15. Namias,M. - Nuclear Energy. Publishing House for Foreign Literature (1955)

16. Lapp,R. - Atoms and People. Publishing House for Foreign Literature (1954)

17. Stefenson,R. - Introduction to Nuclear Engineering. Publishing House for Foreign Literature (1956)

18. - Nuclear Reactors, Part III: Materials for Nuclear Reactors. Publishing House for Foreign Literature (1956)

19. Romadin,V.P. - Application of Atomic Energy to Power Generation. Publ. "Znaniye" (1955)

20. Balabanov,E.M. - Nuclear Reactors. Publ. "Znaniye" (1955)

21. Mezentsev,V.A. - The Atom and Atomic Energy. Voyenizdat (1957)

22. Mikhaylov,V.A., and Mkrtychev,M.G. - Atomic Energy and Perspectives for Its Use. Publ. "Znaniye" (1955)

23. - An Atlas of the Neutron Cross Sections of the Elements. Izdat. Akad. Nauk SSSR (1955)

24. Tsiolkovskiy, K.E. - Papers on Rocketry. Oborongiz (1947)

25. Chernyshev,N.G. - The Chemistry of Rocket Fuels. Gosenergoizdat (1948)

26. Bolgarskiy,A.V., and Shchukin,V.K. - Working Processes in Liquid-Fuel Reaction Engines. Oborongiz (1953)

27. Sinyarev,G.V., and Dobrovol'skiy,M.V. - Liquid-Fuel Rockets. Oborongiz (1955)

28. Sutton,D. - Rocket Engines. Publishing House for Foreign Literature (1952)

29. Gutland,K.U. - Development of Controlled Missiles. Publishing House for Foreign Literature (1956)

30. Merkulov,I.A. - Space Rockets. Publ. "Znaniye" (1955)

31. Karpenko,A.G. - Problems of Cosmic Flight. Publ."Znaniye" (1955)

32. Gil'zin,K.A. - From Rocket to Space Ship. Oborongiz (1954)

33. Shternfel'd,A.A. - Interplanetary Flights. Gostekhizdat (1955)

TABLE OF CONTENTS

STAT

Page

STAT