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NUCLEAR POWERED AIRCRAFT

By

J. F. BRADY

Convair, Division
General Dynamics Corp.

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Opening Remarks

The phrase "Nuclear Powered Aircraft" has changed over the years, from a phrase that sounded intriguing, intensely interesting, and excitingly romantic - to a phrase ringing of stupid politics, blood and guts engineering, and just plain old hard work.

I have had the pleasure of being a part of the "Nuclear Powered Aircraft" Program for the past 5-1/2 years, with all of its ups and downs - and there have been many downs.

I have watched, and had a part in, the hiring into the large aircraft companies, of the young brilliant nuclear physicist, with the fate of the world resting squarely on his intelligent forehead, only to watch him grow unhappy, disgruntled, and finally quit because of the slow progress, or many program cut-backs.

Today, the program is limping along, licking its wounds, and making slow but steady progress. In this presentation I will give, within the limits of security, some data on the different types of problems encountered and some idea of the types of aircraft being considered.

We will first take a look at schematics of the proposed power plants. Fig. 1 shows an over-simplified schematic diagram of a reactor. It is made up of a central core where the fuel (uranium) is located, and where the heat producing fission process takes place. Heat is removed from this core by a coolant such as air, water or liquid metal. This core is surrounded by a moderator, whose basic function is to moderate (slow down) and reflect the neutrons back into the core at the correct velocity to continue the fission process. Because there is a large leakage of neutrons and gamma rays from the core through the moderator, it is necessary to shield the reactor and moderator. The shielding of gamma rays requires a very dense material, like lead, and therefore it is located close in to save weight. The neutron shielding is lighter (water as an example) and is located farther out.

Fig. 2 shows some of the proposed propulsion cycles for aircraft. In the upper left corner we see the most direct application: that of heating the propulsive air by directing it through the reactor. Air enters the jet engine, is compressed by a compressor in the usual manner, then passes through the reactor where the heat of fission is transferred directly to the air; then expanded through a normal turbine and expelled through the tail pipe producing thrust. This jet engine can have the usual afterburner burning ordinary aviation fuels, if desired.

The turboprop version of this cycle is shown in the lower left hand corner, the only difference being the transfer of power through a gear box and thence to the propeller.

Shielding is difficult for this cycle because of the large air passages required through the shielding.

On the right hand side of the illustration we have another possible cycle, where the reactor heat is transferred to a medium which in turn transfers its heat to the engine air (similar to the radiator in your car). One of the advantages is the use of a dense heat transfer medium resulting in smaller reactor heat transfer surfaces and therefore smaller reactor, and also smaller holes through the shielding. A disadvantage is the plumbing involved and the loss of heat because of two transfers.

Either of these cycles can use normal aviation fuel in addition to or in place of nuclear power as shown in the central figure.

The next few illustrations will indicate some of the problems associated with designing nuclear aircraft. The problem that designers and physicists have been battling for years is the shielding problem. As previously discussed we indicated the necessity for heavy lead and water shielding to capture the neutron and gamma ray radiation. Fig. 3 shows two methods of shielding: on the right the unit shield where all the shielding is at the reactor, resulting in low radiation throughout the aircraft as indicated by the light color. On the left we see the divided shield concept where the shielding is distributed around the reactor and also around the crew. This latter method is lighter (provided the crew is small enough - usually the case in combat type aircraft); however, it has the disadvantage of allowing a higher dose to escape from the reactor and therefore the aircraft structure and components are in a higher radiation field. Also this makes it difficult to handle the airplane.

The curve shows the divided shield being lighter and also the trend of getting more power per unit of shield weight as the power is increased. This, of course, tends toward larger airplanes, but other factors, such as handling, cost, etc., prevent us from taking full advantage of this.

Radiation of the aircraft components and structure also causes damage. Fig. 4 shows some of the more common materials used in airframes and components and their approximate life under normal estimated radiation fields associated with the divided shield type aircraft. It is obvious that no structural problem exists; however, oils, lubricants and rubbers will require some development. Electronic systems are not shown because of the security involved, but many problems exist; however, programs are underway to solve these problems.

Another problem to contend with is the aircraft activation. Neutron bombardment of the airframe components and structure causes them to become radioactive. When the activating source is removed the activated part continues to radiate but there is a reduction of radiation per time. This is indicated by Fig. 5. This illustration shows typical airframe activation per time after reactor shut-down, and with the power plant removed from the airframe. The arrows indicate areas outside of which a man can work under normal laboratory tolerances as set up by AEC. This does not mean there is any danger inside these areas; it only means the men would work a shorter time than the usual 40 hour week and reasonable personnel rotation could handle this problem. It must be remembered that this would vary greatly depending upon the amount of shielding used. A unit shielded airplane could be designed to have no such activation problem.

Having discussed the nuclear power plants and the major nuclear problems in broad general terms, now let us be a little more specific and see what types of aircraft might result. Fig. 6 shows a typical attack type aircraft. It is a delta wing airplane utilizing a direct air cycle type power plant as shown schematically in Fig. 2. This type aircraft requires a highly divided shield resulting in high dose rates throughout the aircraft; however, the crew is housed in the crew shield and is subjected to reasonable dose rates. These dose rates are classified; however, they can be given in allowable pilot nuclear cruise hours per year as indicated. The next illustration will discuss this in more detail.

This airplane is designed to either penetrate at high subsonic speed at sea level or supersonic speed at high altitude. The low altitude mission can be performed on nuclear power only; however, the high altitude supersonic mission requires chemical fuel augmentation. This is reflected in the increased weight when this fuel is added. This brings us to one of the undesirable present day limitations of nuclear power - that is, maximum operating temperature. At present, and for some years to come, reactors have a maximum operating temperature resulting from metallurgical limitations. The turbo jet engines being coupled with the reactors do not have this temperature restriction, and can therefore use chemical fuel to develop higher thrust when desired.

The radius of 8000 n.mi. and 500 n.mi. - as shown - are for broad general range indications only, and could be easily extended with a small increase in dose rate to the crew.

Fig. 7 indicates the dose to the pilot of the aircraft described on the last illustration. After looking at the career of the average naval aviator we concluded that with this dose limit it is reasonable to stay within National Academy of Sciences and National Bureau of Standards radiation limits. The lower of the two (National Academy of Sciences) is indicated on this illustration. By rotating the pilot's duty between shore duty and active nuclear aircraft operation, total dose for his career will be 90 REM. This leaves at least 10 REM margin for background radiation, X-Rays, etc. It should be noted that the system of duty rotation is not unusual. It is done as a normal procedure.

The number of hours of nuclear flight per year that the pilot would be permitted to fly, with and without augmented shields, is shown in the lower right hand corner of the illustration. The augmented shield would be increased in weight by the amount of payload, for pilot training on nuclear power. These numbers are considered reasonable in light of the fact that present day non-nuclear aircraft of this category rarely exceed 300 hours per year.

The nuclear turbojet powered attack aircraft uses a divided shield - part of the shield material is on the reactor and part around the crew compartment - in order to avoid excessive weight penalties. As a result, the radiation dose rates are quite high outside of the crew compartment during reactor operation.

Fig. 8 shows the estimated service life of various materials at several locations in the hull. Many materials offer no problem, of course, but others may either require further development to increase their resistance to radiation or special effort may be required by the designer to see that the sensitive materials are not used in high dose areas.

You will recall that one of the problems associated with nuclear propulsion is activation and after-shutdown radiation. For the attack aircraft using the direct air cycle turbojet considerable gamma radiation results from fission product decay in the reactor after shut-down. The table on Fig. 9 shows the after-shutdown activity from the airframe only in millirem/hr. Laboratory tolerance is presently established at 300 millirem/week. The power plant has been removed from this aircraft in order to perform service and maintenance within practical time limits. With the engine installed this is impossible. In actual practice some functions such as servicing for rapid turnaround would probably be done by remote procedures while other functions such as periodic inspections would be done with the power plant removed.

Fig. 10 shows a nuclear turboprop powered airplane which might be used for a number of missions such as ASW, AEW, barrier patrol, or stand-off attack. This aircraft has a unit shielded direct air cycle reactor made possible by separating the reactor from the engines. The dose to the crew is low enough that the endurance of the aircraft is limited only by the physical endurance of the crew. Also, there would be no radiation activation or damage resulting from such a low dose.

This aircraft weighs greater than 400,000 lb., but it should be emphasized that it has not been optimized to an optimum power plant. Instead it was designed to use what is considered the earliest nuclear power plant which could be made available. The aircraft could have been considerably smaller with an optimum power plant.

This power plant consists of (4) existing turboprop engines modified for nuclear power by removing the burners and installing scrolls to pipe the engine air from the compressor to the reactor and back to the turbine. The reactor itself is a low temperature adaptation of current state-of-the-art development of the direct air cycle.

This aircraft can also take advantage of reactor development advances and higher temperatures without becoming obsolete. By using higher temperatures, smaller reactors can be used thus increasing the payload.

In summary, two possible programs can be pursued toward development of nuclear powered aircraft. They are:

<u>Turboprop</u>

1. The fastest, easiest program would be a subsonic turboprop aircraft because it would use existing components and technology.

2. Low radiation from the unit shielded reactor would eliminate radiation activation and damage thus minimizing the operating and handling problems.

3. It is also important to note that this would be a logical development program. Advanced data on powerplant operating techniques, servicing and maintenance problems and general operating problems associated with a nuclear reactor can be investigated at low risk to personnel and equipment.

Turbojet

1. The turbojet powerplant is now under development but needs an advance in technology over the turboprop powerplant.

2. The operating and handling procedures necessary to obtain optimum use of the turbojet aircraft need investigation and development which can be accomplished in part with the turboprop aircraft.

If only our politicians, military leaders, and numerous Department of Defense committees would realize that even with our first crude power plants we can show useful nuclear powered aircraft - and if they would only remember the utterly useless Wright Bros. airplane - and if they would only remember the low performance of our first jet powered aircraft - and if they would realize that these embryo beginnings are developing a knowledge of almost unlimited possibilities - then maybe they would get off their broad backsides and help this country to be first with the Nuclear Powered Aircraft.

FIG. 1

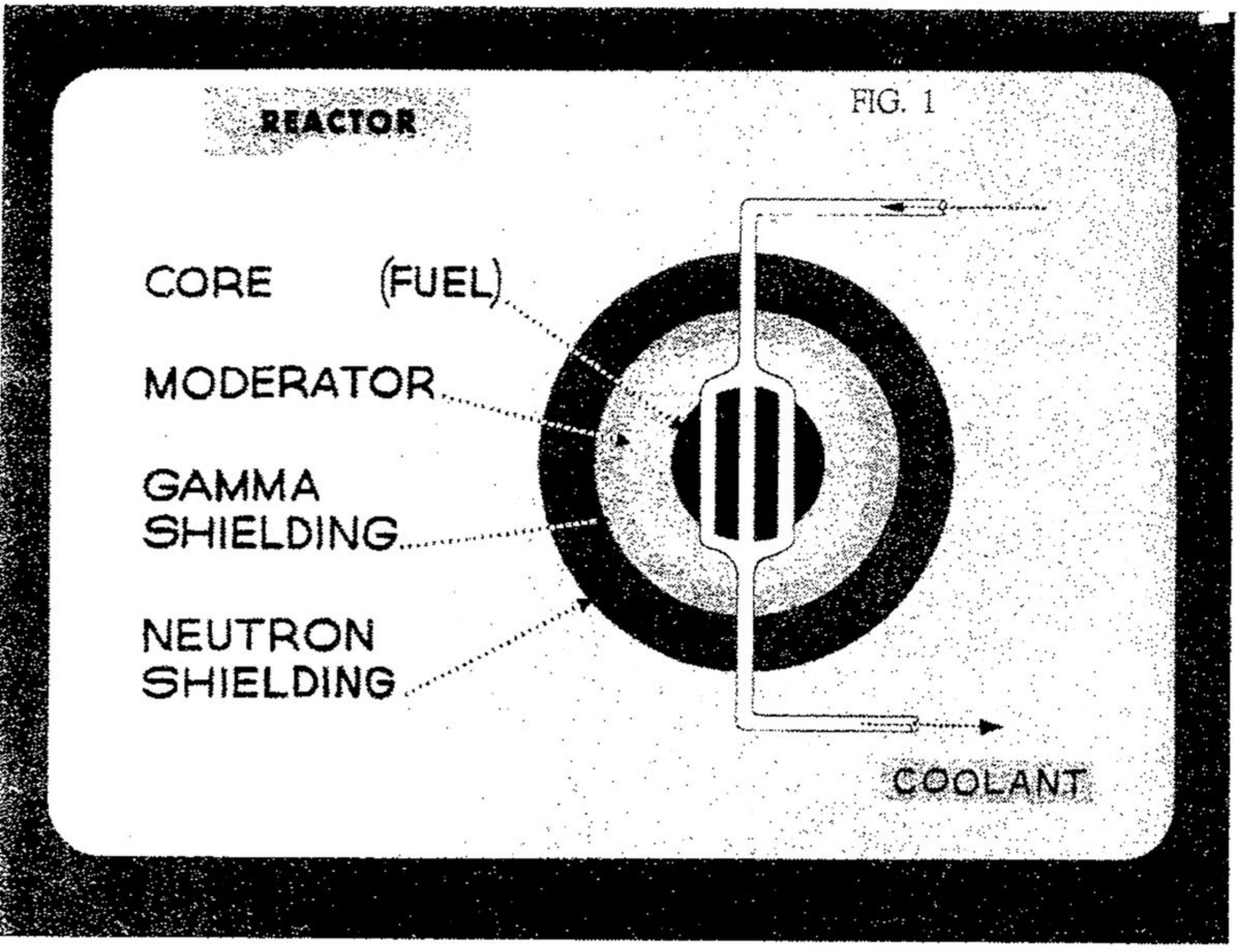


FIG. 2

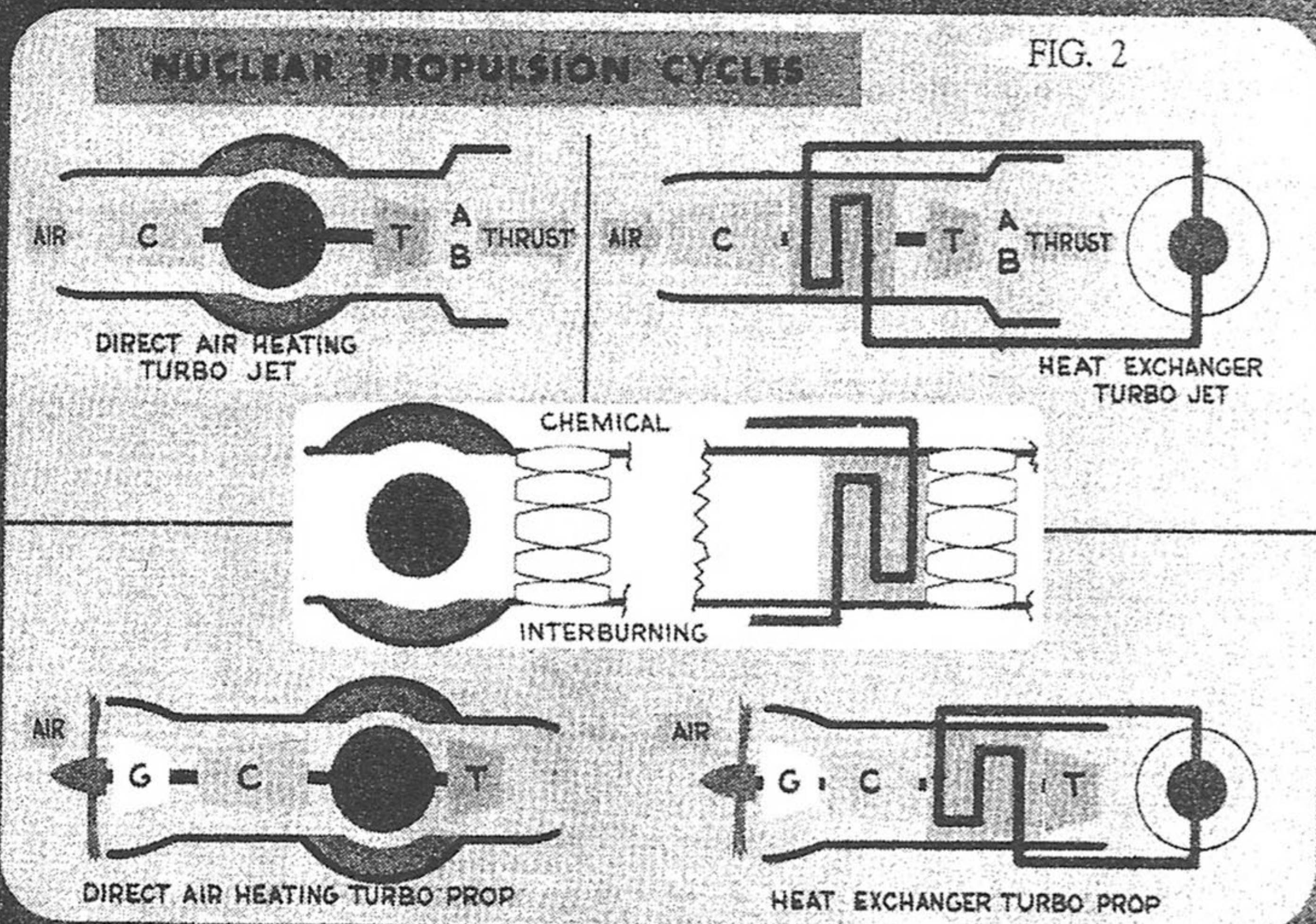
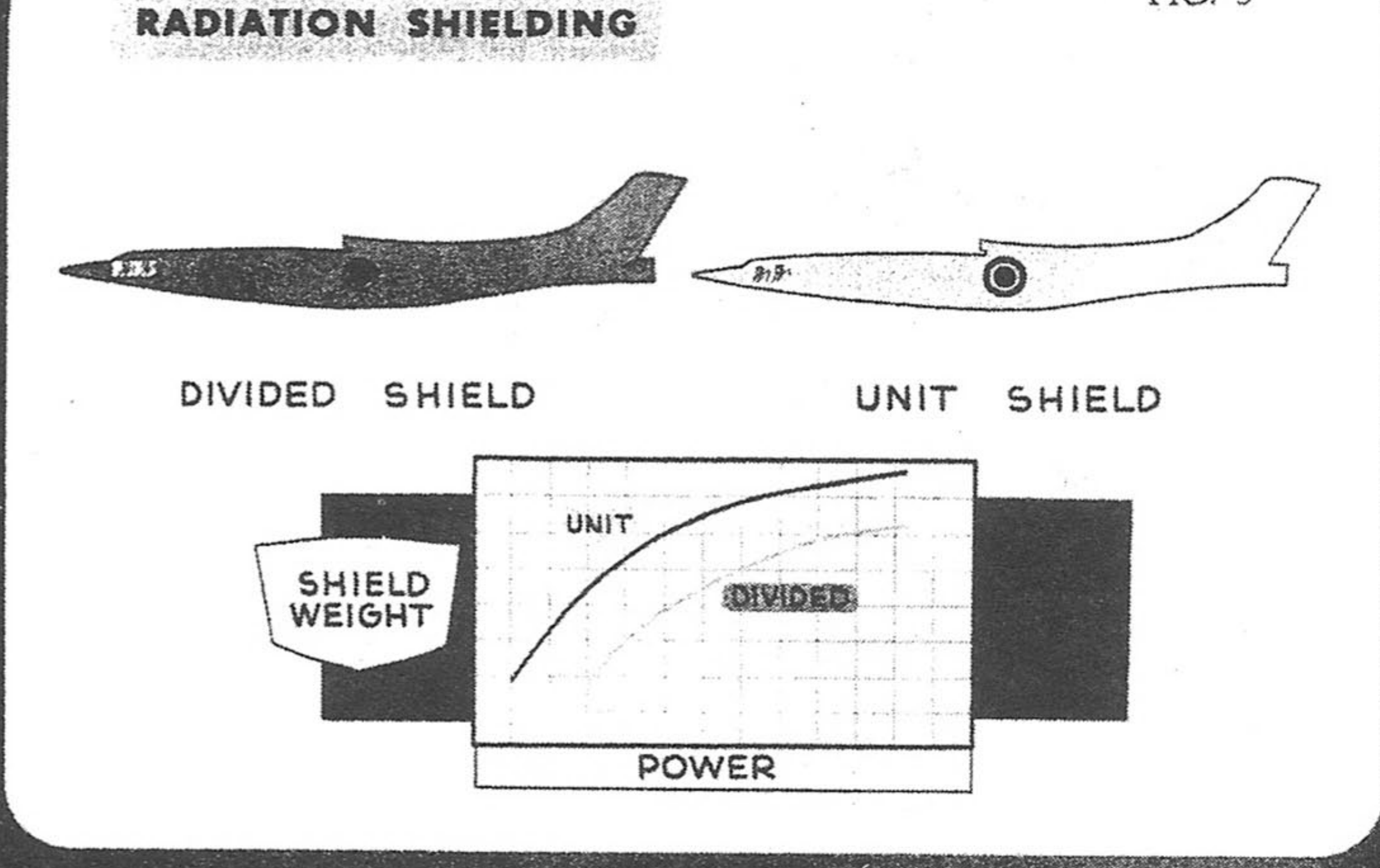

NUCLEAR PROPULSION CYCLES
AIR
C
T
A
B
THRUST
DIRECT AIR HEATING
TURBO JET
AIR
C
T
A
B
THRUST
HEAT EXCHANGER
TURBO JET
CHEMICAL
INTERBURNING
AIR
G
C
T
DIRECT AIR HEATING TURBO PROP
AIR
G
C
T
HEAT EXCHANGER TURBO PROP

FIG. 3


RADIATION SHIELDING
DIVIDED SHIELD
UNIT SHIELD
UNIT
DIVIDED
SHIELD
WEIGHT
POWER

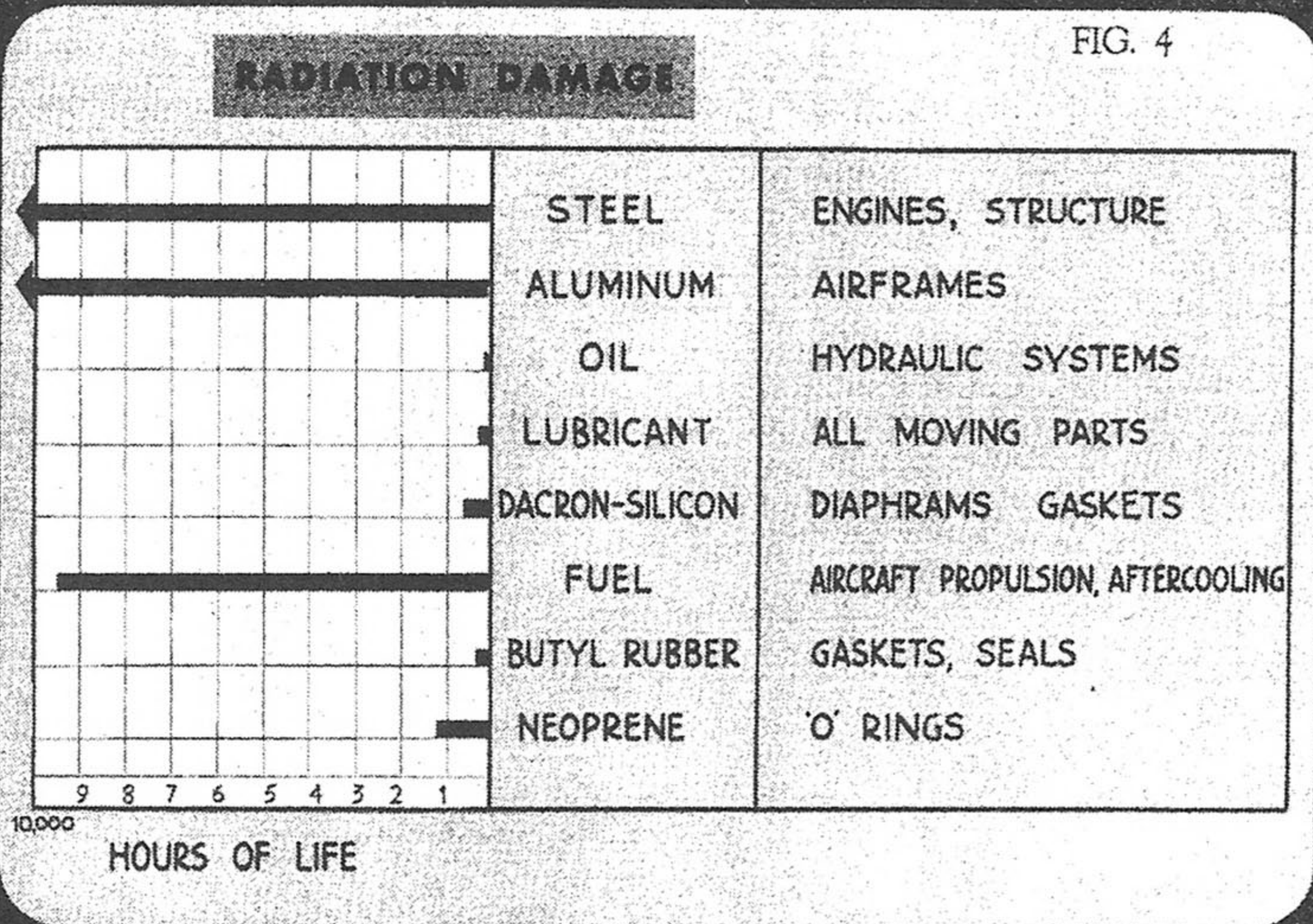

RADIATION DAMAGE
STEEL
ENGINES, STRUCTURE
ALUMINUM
AIRFRAMES
OIL
HYDRAULIC SYSTEMS
LUBRICANT
ALL MOVING PARTS
DACRON-SILICON
DIAPHRAMS GASKETS
FUEL
AIRCRAFT PROPULSION, AFTERCOOLING
BUTYL RUBBER
GASKETS, SEALS
NEOPRENE
'O' RINGS
9 8 7 6 5 4 3 2 1
10,000
HOURS OF LIFE

FIG. 4

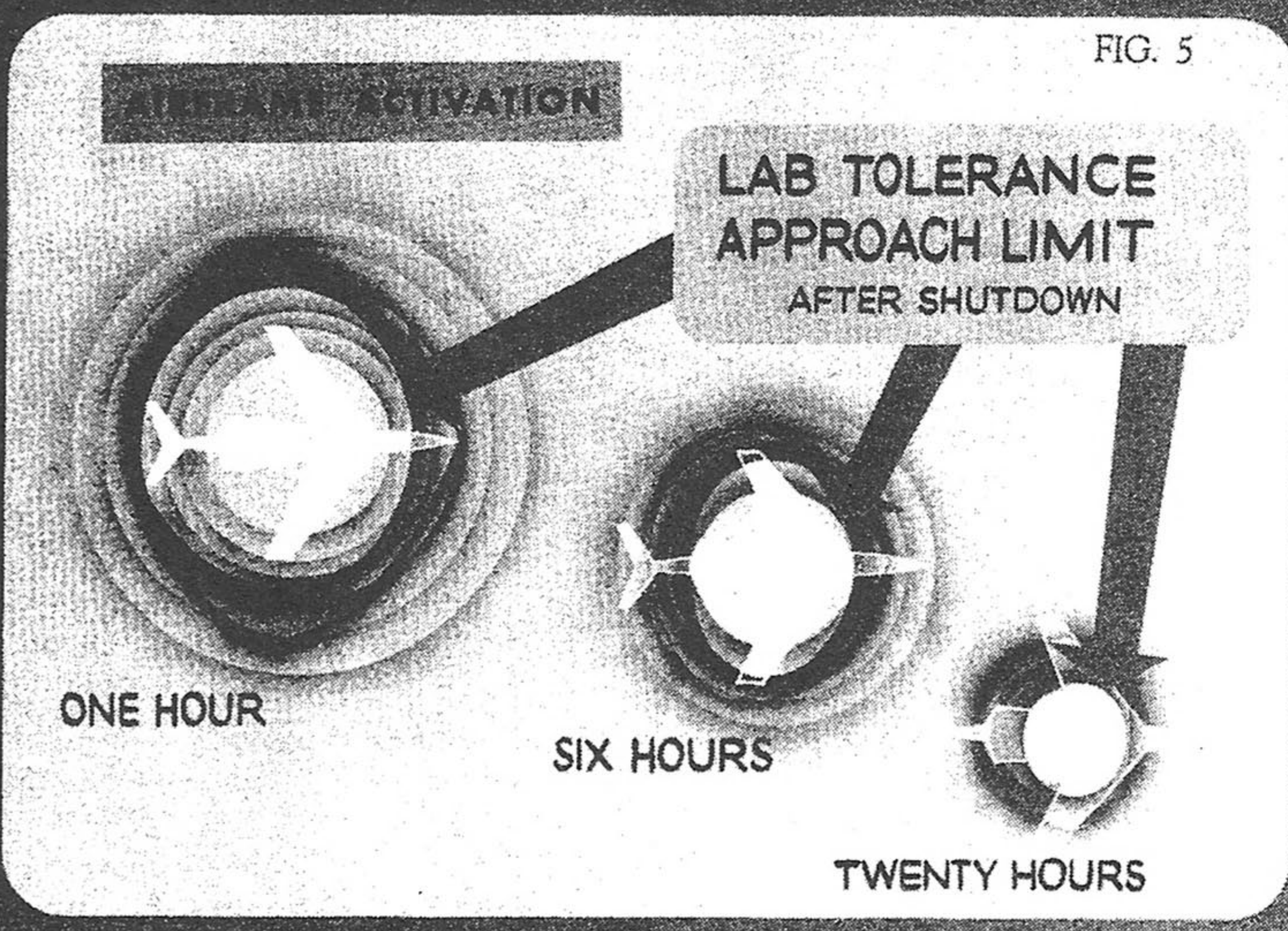
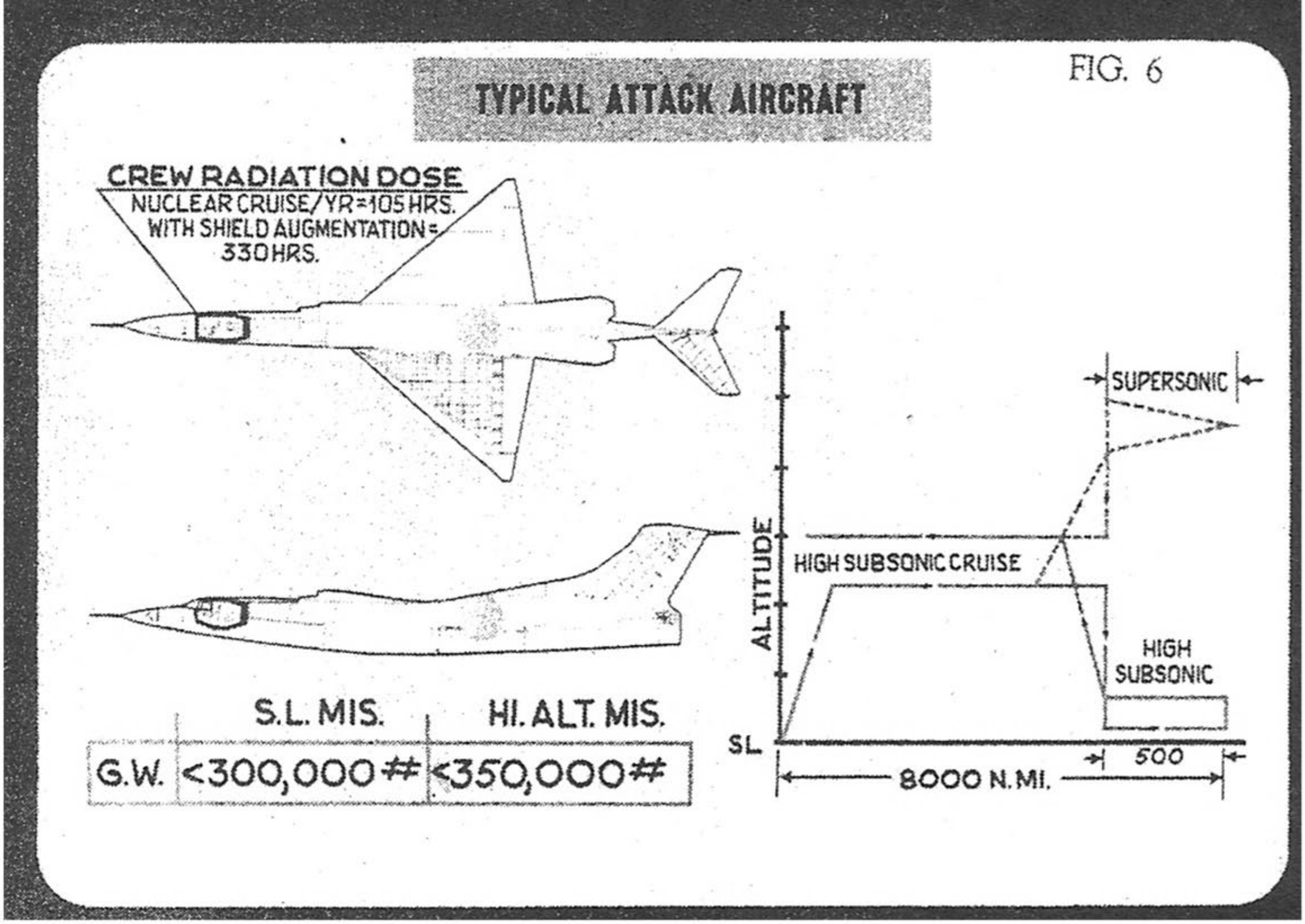

AIRFRAME ACTIVATION
LAB TOLERANCE
APPROACH LIMIT
AFTER SHUTDOWN
ONE HOUR
SIX HOURS
TWENTY HOURS

FIG. 5


TYPICAL ATTACK AIRCRAFT
CREW RADIATION DOSE
NUCLEAR CRUISE/YR = 105 HRS.
WITH SHIELD AUGMENTATION = 330 HRS.
S.L. MIS.
HI. ALT. MIS.
G.W.
<300,000#
<350,000#
SUPERSONIC
ALTITUDE
HIGH SUBSONIC CRUISE
HIGH SUBSONIC
SL.
500
8000 N.MI.
FIG. 6

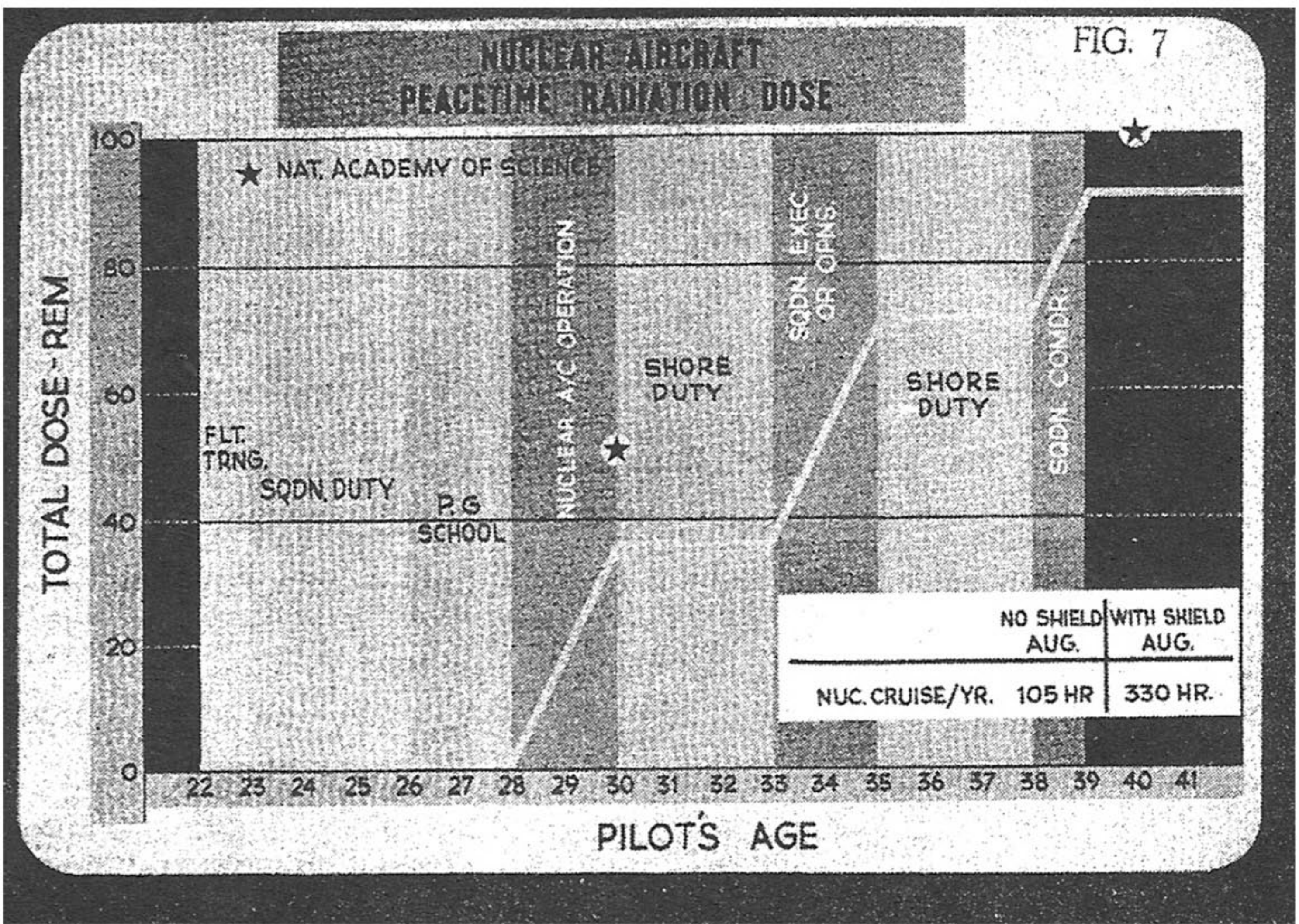
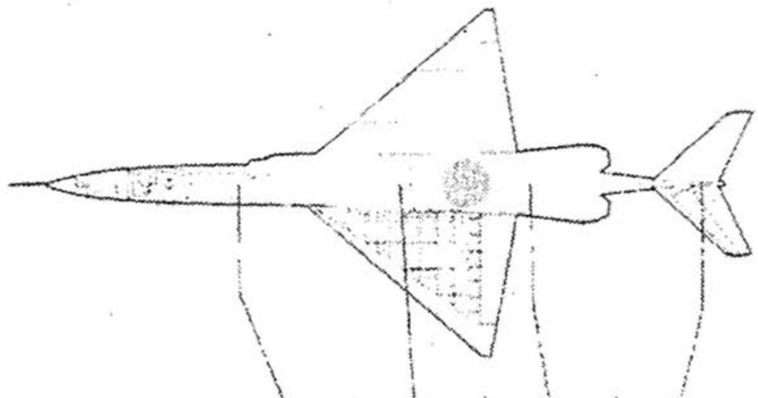

NUCLEAR AIRCRAFT
PEACETIME RADIATION DOSE
★ NAT. ACADEMY OF SCIENCE
TOTAL DOSE - REM
100
80
60
40
20
0
FLT. TRNG.
SQDN. DUTY
P.G SCHOOL
NUCLEAR A/C OPERATION
SHORE DUTY
SQDN. EXEC OR OPNS.
SHORE DUTY
SQDN. COMDR.
NO SHIELD AUG.
WITH SHIELD AUG.
NUC. CRUISE/YR.
105 HR
330 HR.
22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41
PILOT'S AGE
FIG. 7

FIG. 8

ANP ATTACK AIRCRAFT RADIATION DAMAGE

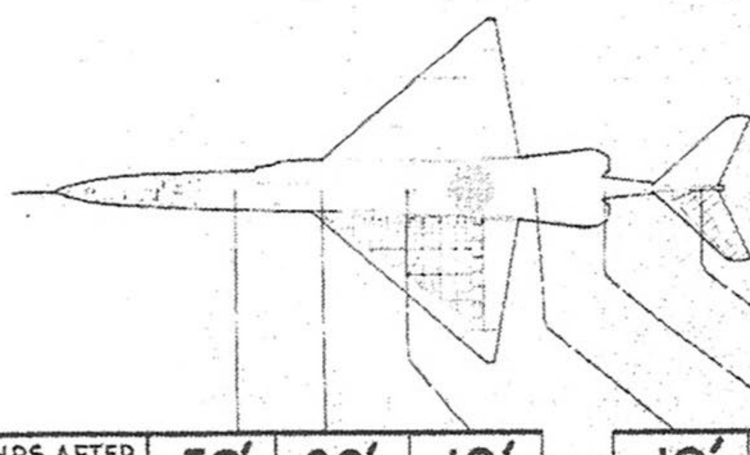


MATERIAL	50' FWD	10' FWD	10' AFT	50' AFT
TEFLON	75	1	0.2	2
TYPICAL LUBRICANT	1670	25	5	50
NEOPRENE 'O' RING	14,000	210	42	420
GREASE	33,300	500	100	1000

ESTIMATED SERVICE LIFE IN HOURS

FIG. 9

ANP ATTACK AIRCRAFT RADIATION AFTER SHUTDOWN



AIRFRAME	HRS AFTER SHUTDOWN	50'	30'	10'	10'	30'	50'
ACTIVITY	1	30	100	420	420	100	30
ONLY	6	10	31	130	130	31	10
MR/HR	20		6	24	24	6	

FIG. 10

NUCLEAR TURBOPROP AIRCRAFT

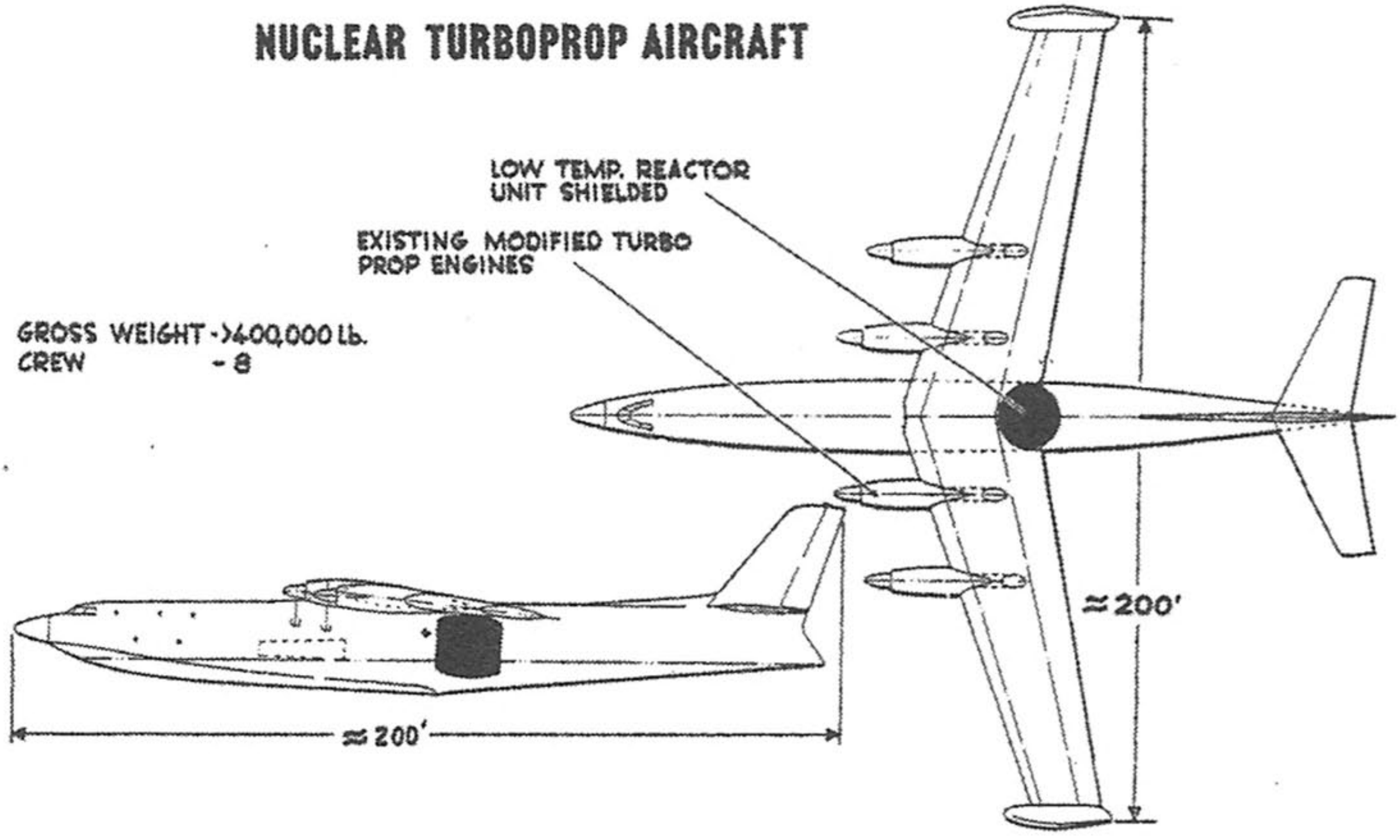
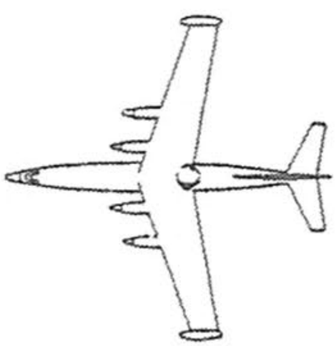
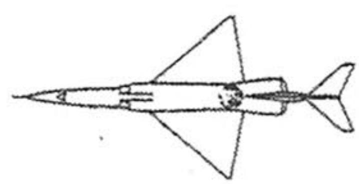


FIG. 11

SUMMARY

TWO POSSIBLE PROGRAMS





TURBOPROP	TURBOJET
1. FASTEST, EASIEST PROGRAM–USES EXISTING COMPONENTS & TECH.	1. POWER PLANT NOW IN DEVELOPMENT BUT NEEDS ADVANCE TECH.
2. LOW RADIATION–MIN. OPERATING AND HANDLING PROBLEMS.	2. USEFUL A/C FOR DETERRENT FORCE BUT NEEDS ADVANCED OPERATING AND HANDLING PROCEDURES.
3. GOOD DEV. PROGRAM–IS USEFUL A/C AND DEV. ADVANCED DATA.	