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WHEEL-FLOW GASEOUS-CORE REACTOR CONCEPT

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C.





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SUMMARY

The wheel-flow gaseous-core reactor concept suggested in this report employs a cylindrical or toroidal core of hot fissioning uranium or plutonium fuel. This core is surrounded by a rotating annular region of propellant that enters and leaves the reactor tangentially. If the two flows rotate together as a wheel, no shear will occur at the interface between the propellant and the fuel. Hence, the fuel loss due to the mixing processes associated with shear would be minimized.

Several reactor geometries employing or modifying the wheel-flow concept are suggested. These range from the basic cylindrical shape to toroidal geometries employing rotation about the jet axis to establish a radially outward centrifugal force. The stability problems in the flows and the possible use of magnetic fields and electric currents for damping of instabilities are briefly discussed.

INTRODUCTION

The specific impulse of a conventional nuclear rocket is temperature limited by the fuel-element materials in the reactor to 800 to 1200 seconds. A gaseous-core nuclear rocket in which fissioning gaseous uranium transfers heat to the hydrogen propellant offers the hope that the specific impulse might be raised to 3000 seconds. This limit is established by the cooling capacity of the propellant, which must remove the neutron and gamma ray energy deposited in the temperature limited moderator (ref. 1).

The use of a gaseous uranium or plutonium core through which propellant flows exposes the reactor to loss of fuel. The cost of uranium is sufficiently high so that the weight ratio of hydrogen to uranium in the rocket exhaust should be of order 25 to 50 (ref. 2). Because of the large difference in molecular weight between uranium and

hydrogen, this ratio is difficult to achieve.

One approach is to keep the hydrogen-uranium partial-pressure ratio as high as possible. The limit is set by the practicality of high reactor operating pressures and criticality considerations. At a pressure of 2000 pounds per square inch and a partial-pressure ratio of 80, the reactor weights would typically be 250 000 to 500 000 pounds. The propellant load on a mission would then have to exceed 500 000 to 1 000 000 pounds to capitalize on the increased specific impulse over the graphite-core nuclear rocket.

Even with a partial-pressure ratio of 80 an additional improvement factor of 35 to 70 is still required to achieve a mass-flow ratio of 25 to 50. This improvement must be accomplished by maintaining a high hydrogen-uranium volume flow ratio. If an extremely high volume flow ratio could be achieved, the uranium partial pressure could be raised, and the reactor weight required for criticality could be decreased, to yield a more acceptable reactor system.

Numerous schemes have been suggested to achieve a high hydrogen-uranium weight flow ratio. The vortex reactor (fig. 1) diffuses hydrogen radially inward through a

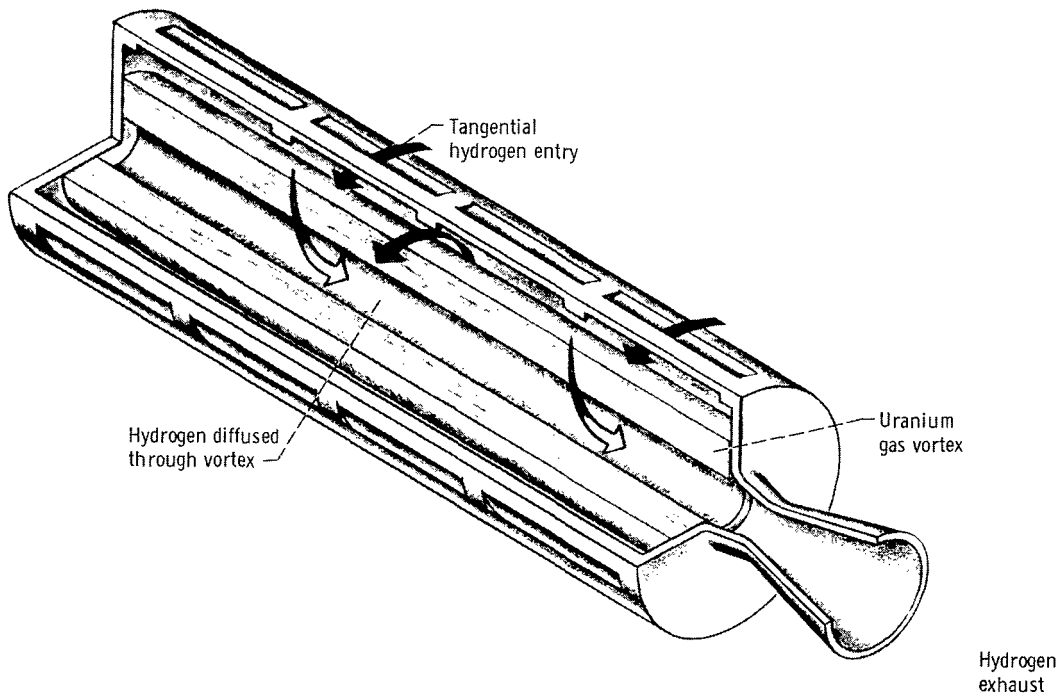


Figure 1. - Vortex-contained diffusion gaseous-core reactor.

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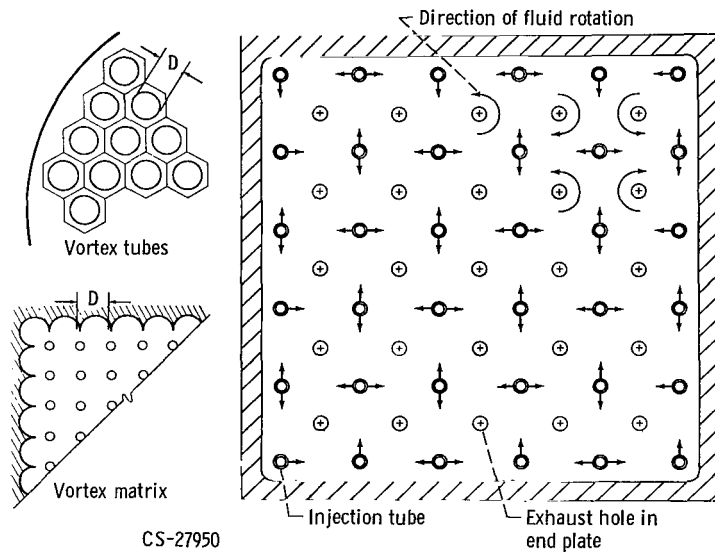


Figure 2. - Multiple vortex tubes and vortex matrices.

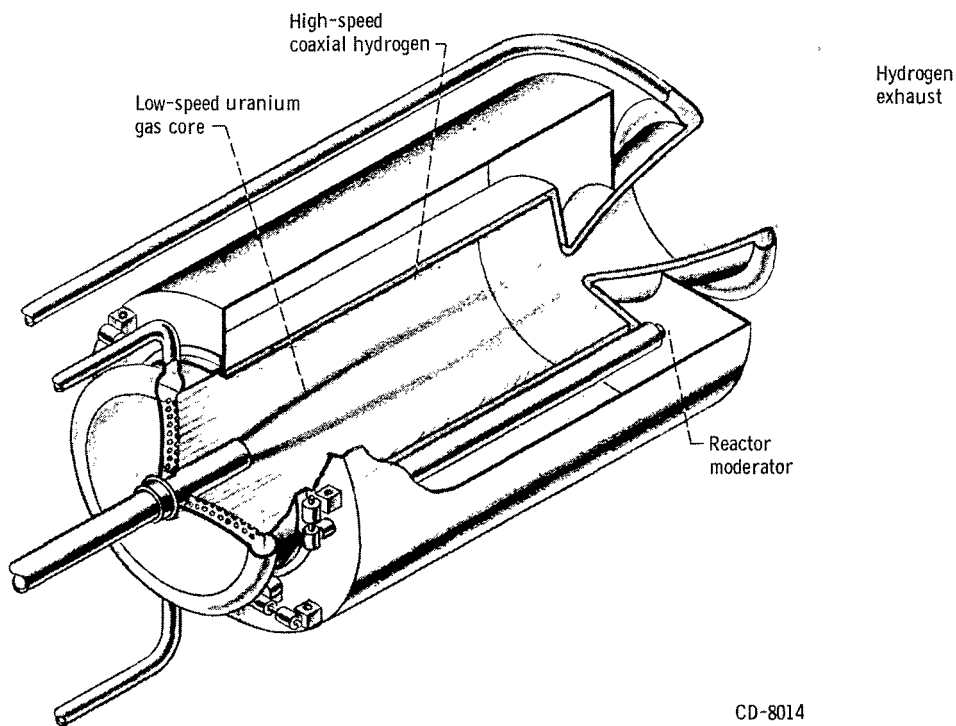


Figure 3. - Coaxial jet reactor.

gaseous uranium vortex. Hopefully, the centrifugal forces associated with the heavier uranium molecules would counteract the diffusion drag of the inwardly moving hydrogen. The hydrogen would ultimately turn and move along the axis toward the exhaust nozzle. Unfortunately, the drag produced by the flowing hydrogen is so great that excessive uranium loss would occur except at very low hydrogen flow rates.

Kerrebrock and Meghreblian (ref. 1) have suggested that a multiplicity of vortex tubes, each with a high length-diameter ratio, might be employed to boost the hydrogen throughput. Rosenzweig, Lewellen, and Kerrebrock (ref. 3) propose to establish the vortex patterns by a tailored array of hydrogen injection tubes. These two schemes are shown on figure 2. Both would have the difficult problem among others of cooling the internally contained structure. Other vortex stabilized reactor schemes have been studied in considerable depth by McLafferty and his coworkers at the United Aircraft Corporation (refs. 4 and 5).

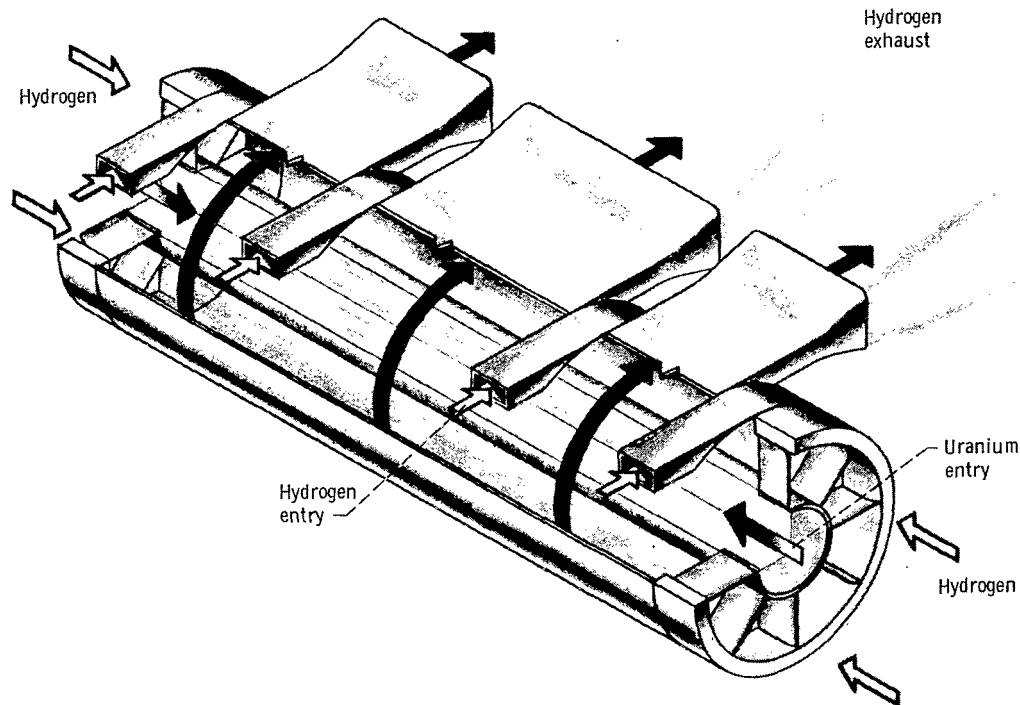
Radiation is the dominant heat transfer mode in cavity reactors. Cold hydrogen is nominally transparent so that seeding with opaque additives, such as solid particles or other gases, will be required to absorb the radiant heat from the core. When a sufficiently high temperature is reached, hydrogen becomes opaque and thus further seeding is unnecessary.

Rom and Ragsdale (ref. 2) have no vortex in their coaxial jet reactor illustrated on figure 3. The central core of uranium gas would be injected at a much slower speed than the coaxially flowing hydrogen. Hopefully, the mixing processes can be tailored by selection of upstream geometry and initial velocity profiles to minimize the uranium loss rate. A hydrogen buffer layer with an intermediate velocity profile between the uranium central core and the outer concentric hydrogen might further this purpose.

In the modified vortex reactors and in the coaxial jet, the uranium loss rate would be strongly affected by the laminar or turbulent mixing processes in the shear region generated by the difference in bulk velocity between the uranium core and the coaxially flowing hydrogen. The question may be posed as to whether a geometry can be found that will minimize the velocity differences and shear between the hydrogen and uranium at the interface but at the same time will permit large hydrogen flow rates through the reactor. The wheel-flow reactor described in this report might approach this aim. The concept is presented in order to stimulate thoughtful discussions among those interested in gaseous-core reactors. The ideas were initially disclosed to members of the Lewis Research Center Staff at an inhouse Gas Core Reactor Conference April 29, 1963.

DISCUSSION OF WHEEL-FLOW REACTOR CONCEPT

The wheel-flow reactor concept may be visualized with the aid of figure 4. The cy-



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Figure 4. - Wheel-flow reactor.

Cylindrical geometry permits the hydrogen propellant to enter and leave the reactor tangentially along the outer periphery after circulating around the inner cylindrical core of hot reacting uranium gas. The local velocity of the uranium core may be matched exactly at the interface with the outer hydrogen flow. Hence, the shear mixing associated with a bulk velocity difference between the uranium and the hydrogen layers can be eliminated in this concept.

Also, if the concentric gaseous cylinders of uranium and hydrogen are rotated together as a solid body, there will be no shear to produce stream turbulence. Thus, barring instabilities, the uranium loss rate might conceivably be reduced to that of molecular diffusion if it were not for stream turbulence from other sources.

The hydrogen gas which enters on the periphery of the reactor will be heated and expanded as it moves around the circumference. If this expansion were radial, conservation of angular momentum would tend to promote vortex shear flow. Hence, axial and circumferential expansion only are contemplated. Thus, the fluid would exhaust at about the same radial distance from the axis as it enters.

The lost uranium would be replenished along the axis at the two end walls. These

walls are visualized as rotating to maintain the wheel flow and to minimize the mixing associated with secondary flows. The small axial velocity component generated by the uranium replenishment may be matched by flowing additional hydrogen through the spokes of the wheel-like rotating end walls.

Unfortunately, the equilibrium wheel flow of a heavy gas core and a lighter outer gas annulus is unstable. If a glob of core gas containing uranium were displaced into the lighter hydrogen region, a radial outward buoyancy force of magnitude

$$dF = r\omega^2 dm \left(1 - \frac{\rho_H}{\rho_U} \right) \quad (1)$$

would be generated. The quantities ρ_H and ρ_U are the densities of outer and inner gas regions, respectively. The quantity dm is the mass of the glob at the radial position r in a gaseous rotating wheel flow of angular velocity ω (or in other kinds of flow with local angular velocity ω). This buoyancy force can be minimized by decreasing the density difference or by decreasing the angular velocity.

The uranium core would actually contain considerable hydrogen. Also, ionization of the uranium further reduces the density of the core region. When these effects are combined with the possibility of a higher core temperature than that of the outer hydrogen flow, density ratios close to unity may be feasible. A more sophisticated analysis than that represented by equation (1) would of course be required to determine stability limits and the growth rates of disturbances which might lead to the loss of uranium fuel. A first approach toward the stability problem is included in reference 6.

There is also the possibility of using propellants of higher molecular weight than hydrogen. If the latter approach permitted lighter reactors, it might be worthwhile even at the expense of the correspondingly reduced specific impulse.

Another approach would be to use an axial magnetic field to stabilize the flows. The uranium gas would presumably be more ionized than the hydrogen because of both its higher temperature and its lower ionization potential of about 6 electron volts compared to 13.5 electron volts. If no circulating currents were generated in the plasma, this magnetic field would produce no drag, but the diffusion of ionized uranium gas would presumably be inhibited.

On the other hand, the rotating plasma might serve as the armature of a homopolar generator. If the conductivity to the reactor case were sufficient, the electric circuit would be completed. Clearly, the plasma would no longer be shear free. Under such circumstances an experimental approach might be the simplest method to determine the influence of the axial magnetic field on the uranium containment problem.

Axial currents can also be employed to develop confining magnetic forces on the

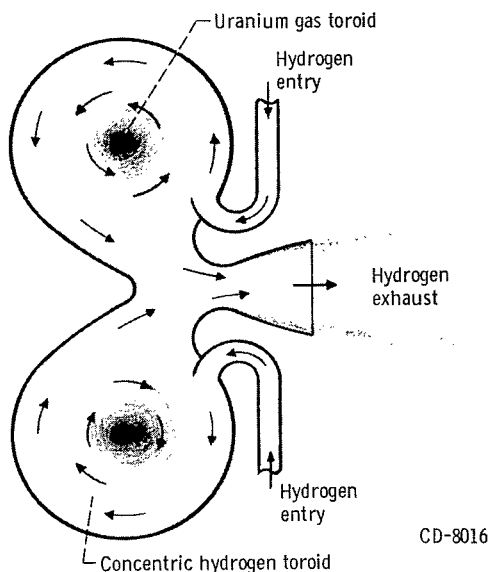


Figure 5. - Toroidal geometry wheel-flow reactor.

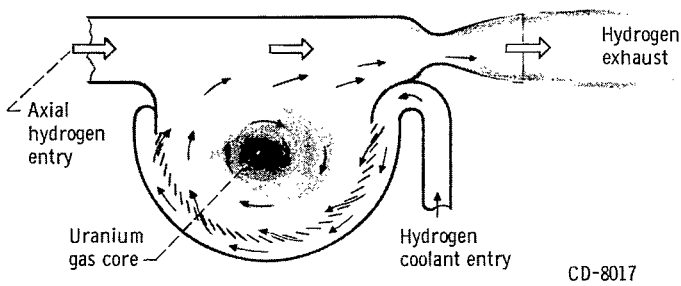
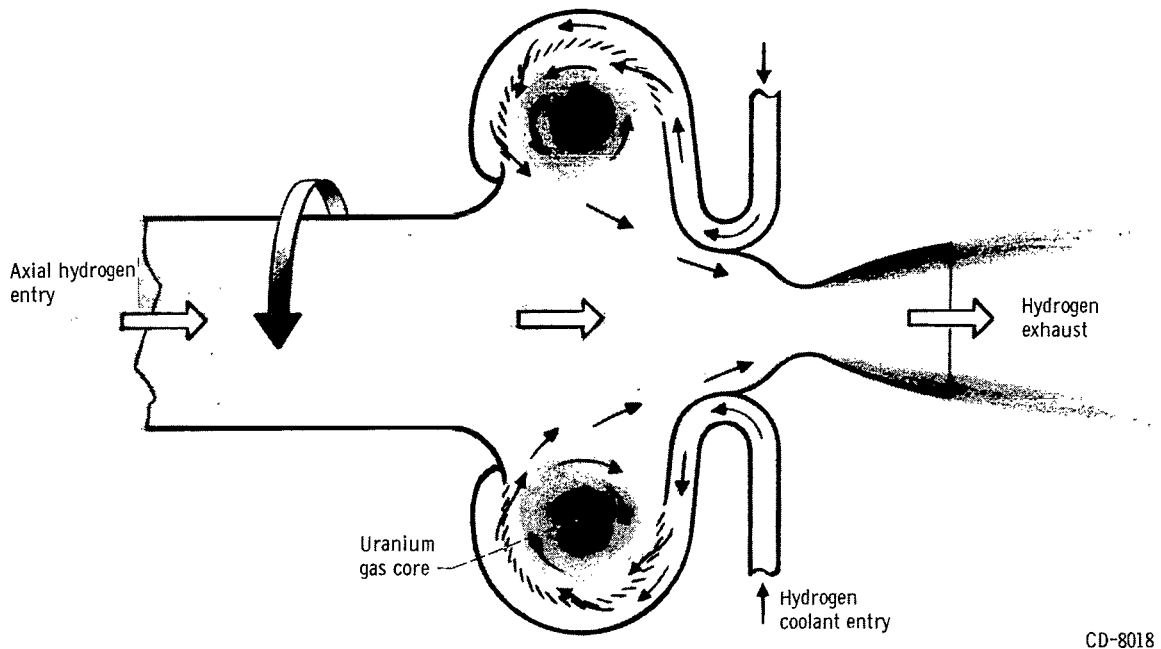


Figure 6. - Offset wheel-flow reactor.

ionized plasma. The required currents are likely to be larger, however, than a practical system would support.

Since extremely high temperatures are involved in gaseous-core reactors, one might imagine that molecular velocities could dominate the situation. The thermal velocities of the uranium atoms are perhaps an order of magnitude larger than the wheel-flow velocities. On the other hand, the mean free path of the individual atoms is perhaps of order 10^{-6} meter or less. Random collisions equalize the effects of the high thermal velocities so that the mean positional shift of each individual atom is essentially that of the wheel flow. A corresponding situation is experienced in the normal sea-level atmosphere. The mean speed of the molecules is of order 500 meters per second, but the mean free path is only about 10^{-7} meter. There is no problem in the detection and measurement of mean air motions (breezes) of a few meters per second. In a corresponding manner, only the gross motions of continuous flow need be considered in the gaseous-core reactors.

The end walls on the wheel-flow reactor may be eliminated by shaping the gaseous cavity into a toroid. An artist's sketch of such a reactor is shown on figure 5. The toroidal shape would eliminate the end walls and the problem of cooling them (ref. 7), but would complicate the uranium injection system. Magnetic field windings and current conductors, if desired, might also be more difficult to install. It should be noted that the toroidal shape bears some resemblance to a reactor concept suggested by C. C. Chang during summer studies in 1958 at Los Alamos. Studies of these flow types are being continued by Dr. Chang at the Catholic University of America.



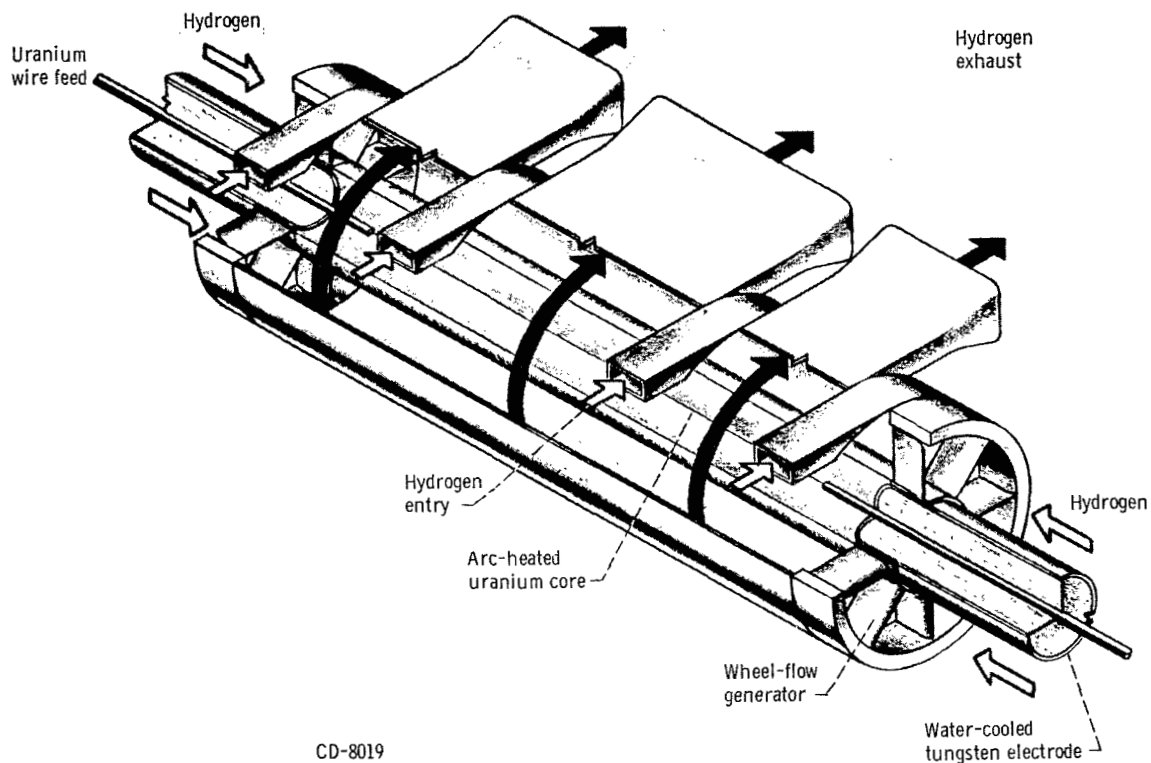
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Figure 7. - Spinning toroidal wheel-flow reactor with axial propellant flow.

Other shapes are of course feasible. In a gravitational field, the heavier core gas might try to settle toward the bottom of the cylinder. The partial wheel-flow geometry shown on figure 6 might counteract this tendency. The uranium gas core rotates in a wall cavity. The hydrogen gas passes tangentially across the top of the cavity. The walls would of course be film cooled with hydrogen.

In a zero-gravity environment the wall cavity might assume the toroidal shape shown on figure 7. A radially outward artificial gravity is generated by rotation of the rocket about the jet axis. The centrifugal force so generated would tend to keep the uranium inside the cavity. The flow marked hydrogen coolant entry could also be doped with higher molecular weight materials to improve the stability.

An electric analog (fig. 8) can be imagined to simulate some of the features of the wheel-flow reactor. Water-cooled tungsten electrodes could serve as the terminals for a high-pressure arc along the axis. These electrodes might have hollow centers so that uranium wire could be fed into the arc. Thus, a hot radiating uranium gas core could be generated that would simulate fission heating. Seeded hydrogen gas could enter and leave the simulated reactor tangentially. Thus, many of the fluid mechanic and heat transfer problems might be studied without the requirement of fission.



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Figure 8. - Arc-heated gaseous-core reactor.

The discussion throughout has concentrated on wheel flow because this fluid motion eliminates shear. However, much of what has been said also applies to any type of flow found in a cylindrical cavity with tangential propellant entry. If some radial flow were included, a vortex flow might be generated. Because such a modification would alter the stability characteristics, the possibility of other flows should not be overlooked.

Actually the objective of the various geometries proposed is to increase the residence time of uranium atoms relative to propellant atoms in the reactor. Residence-time ratios greater than 35 are desired but perhaps 10 could be tolerated. The normal fluid mechanic techniques that may be employed to increase residence time include centrifugal containment (vortex reactors), velocity gradients (coaxial-jet reactor), minimization of shear mixing, and recirculation of uranium (wheel-flow reactor). These principles may be combined to produce numerous feasible gaseous-core reactor geometries; for example, the occurrence of recirculating "dead water" regions, such as cavity or base flows, wake regions, etc., is well known in fluid mechanics. Two schematic reactors based on such flows are shown in figures 9 and 10. Questions re-

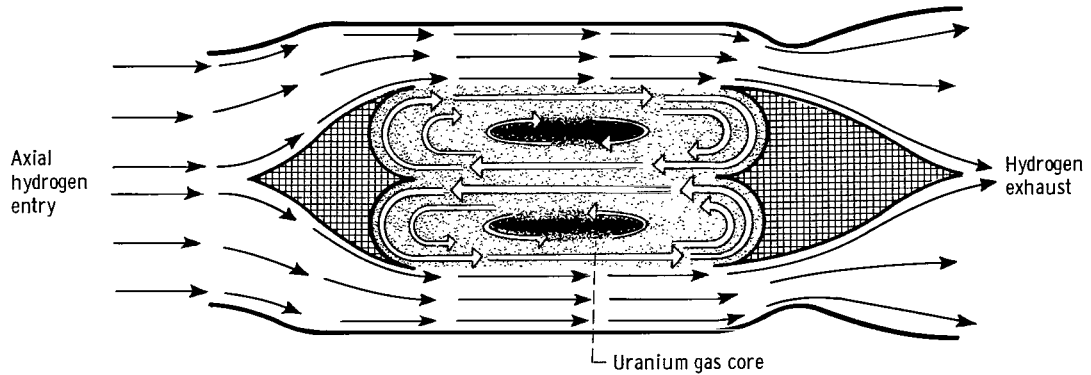


Figure 9. - "Deadwater" trapped vortex reactor.

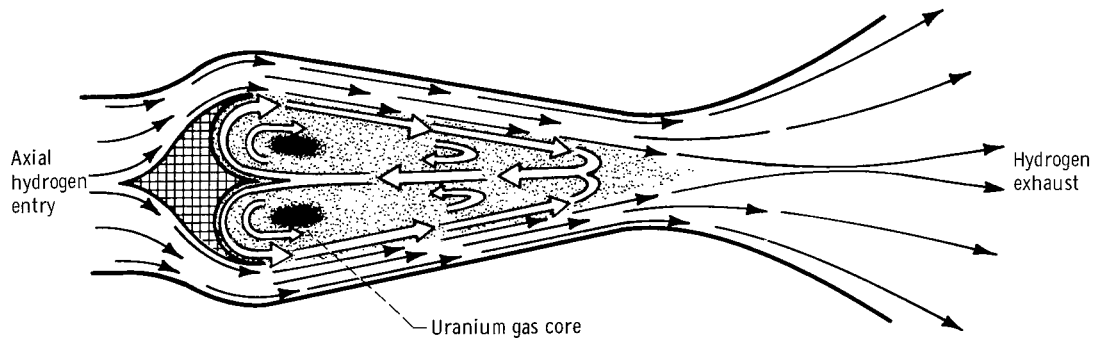


Figure 10. - "Base-flow" reactor.

quiring answers are: can the vortices in the recirculation fueled regions remain attached and stable, can "whistling" and vortex shedding be prevented, and can useful residence time ratios for the two-fluid particles be achieved. Clearly, further fundamental studies in fluid mechanics are required to answer these questions and to decide the worth of these suggestions for cavity reactors.

In conclusion, one might ask if the wheel-flow reactor concept and its modification are better or worse than other proposed geometries. The wheel-flow reactor might eliminate the uranium loss due to shear layer mixing. The wheel-flow and other arrangements proposed, however, could be basically unstable, unless a judicious choice of fluid compositions and temperature distributions were made. The seriousness of uranium loss associated with these feasible instabilities is not known. Also unknown is the effectiveness of schemes to damp the instabilities. Thus, the question remains unanswered.

Nonnuclear experiments can be visualized, however, to simulate many of the difficult fluid mechanics problems of these reactor concepts. Hence, even though the practicality of the concepts is not known, further work of a preliminary nature should give valid con-

clusions. Hence, the concepts are presented to stimulate thought and discussion among those interested in gaseous-core reactors.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, April 21, 1965.

REFERENCES

1. Kerrebrock, Jack L.; and Meghreblian, Robert V.: Vortex Containment for the Gaseous-Fission Rocket. Rept. No. TR 34-205, Jet Prop. Lab., C.I. T., Sept. 1961.
2. Rom, Frank C.; and Ragsdale, Robert G.: Advanced Concepts for Nuclear Rocket Propulsion. NASA SP-20, 1962, pp. 3-15.
3. Rosenzweig, Martin L.; Lewellen, W.S.; and Kerrebrock, Jack L.: The Feasibility of Turbulent Vortex Containment in the Gaseous Fission Rocket. Preprint No. 1516A-60, ARS, Dec. 1960.
4. McLafferty, G.H.: Analytical Study of Moderator Wall Cooling of Gaseous Nuclear Rocket Engines. Rept. No. C-910093-9, United Aircraft Corp., Sept. 1964.
5. Roback, R.: Thermodynamic Properties of Coolant Fluids and Particle Seeds for Gaseous Nuclear Rockets. Rept. No. C-910092-3, United Aircraft Corp., Sept. 1964.
6. Reshotko, Eli; and Monnin, Carl F.: Stability of Two-Fluid Wheel Flows. NASA TN D-2696, 1965.
7. Howell, John R.; Strite, Mary K.; and Renkel, Harold E.: Analysis of Heat-Transfer Effects in Rocket Nozzles Operating With Very High-Temperature Hydrogen. NASA TR R-220, 1965.

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