FR9000915

COMMISSARIAT A L'ENERGIE ATOMIQUE

CENTRE D'ETUDES NUCLEAIRES DE SACLAY
Service de Documentation
F91191 GIF SUR YVETTE CEDEX

CEA-CONF --9852

R3

BRAYTON CYCLE CONVERSION SYSTEM AND TEMPERATURE CONDITIONING OF SMALL SPACE NUCLEAR REACTORS

TILLIETTE Z.P.- CARRE F.- PROUST E.
CEA Centre d'Etudes Nucleaires de Saclay, 91 - Gif-sur-Yvette (FR).
Dept. d'Etudes Mecaniques et Thermiques

Communication présentée à : 6. Symposium on Space Nuclear Power Systems
Albuquerque, NM (US)
9-12 Jan 1989

BRAYTON CYCLE CONVERSION SYSTEM
AND TEMPERATURE CONDITIONING OF SMALL SPACE NUCLEAR REACTORS

Zéphyr P. Tilliette, Frank Carré, and Eric Proust
Commissariat à l'Energie Atomique
I.R.D.I. / D.E.M.T. / D.E.M.T.
Centre d'Etudes Nucléaires de Saclay
91191, Gif-sur-Yvette, Cedex, France
(33) 1-69 08 32 87

SUMMARY prepared for :

Sixth Symposium
on Space Nuclear Power Systems
Albuquerque, New Mexico
9-12 January 1989

Address all correspondence to : Mr. Zéphyr P. Tilliette

BRAYTON CYCLE CONVERSION SYSTEM
AND TEMPERATURE CONDITIONING OF SMALL SPACE NUCLEAR REACTORS

Zéphyr P. Tilliette, Frank Carré, and Eric Proust
Commissariat à l'Energie Atomique
I.R.D.I. / D.E.D.R. / D.E.M.T.
Centre d'Etudes Nucléaires de Saclay
91191, Gif-sur-Yvette, Cedex, France
(33) 1-69 08 32 87

INTRODUCTION

A companion paper (Carré et al. 1989) presented at this Symposium gives an overview of the French preliminary studies on space nuclear power systems in progress within the framework of a three-year (1986-1989) program. Other papers (Proust et al. 1988, Tilliette et al. 1988, Tilliette IECEC 1988) supplement the information on this activity. Low power levels of about 20-kWe and both liquid metal- and gas-cooled reactors are concerned. The Brayton cycle is currently selected as the conversion subsystem.

Critical issues like safety, reliability, radiation shielding and reactor concept and technology have to be addressed more and more carefully and relevant temperature conditions are crucial. It is shown in this paper that the Brayton cycle can offer a valuable flexibility which allows the desired thermal environment. For instance, it is possible to significantly decrease the reactor inlet temperature and consequently, also given an adequate design, to favorably put forward convenient solutions for the lateral and axial bottom reflector, the shadow shield, the control drums drives and safety rods actuators and penetrations, as well as for the possibility of using efficient moderator materials like metal hydrides (ZrH or ^7LiH), which is worth being investigated as far as low power levels are concerned.

Examples of Brayton cycle conversion subsystems and possible reactor arrangements are presented for both gas-cooled and liquid metal (NaK or Na)-cooled reactor heat sources. The study follows up the research described by Tilliette (1988,IECEC).

DISCUSSION

Owing to a good temperature compatibility and a natural direct cycle configuration, gas-cooled reactors Brayton cycle power systems have to be considered.

Cycle aspects are illustrated by Figure 1. Four examples can be compared. The case n°1 features a conventional highly recuperated cycle implying a high reactor inlet temperature ($\simeq$850 K). The slightly recuperated (effectiveness = 0.40) cycle n°2, the partly recuperated, double radiator case n°3 and the non-recuperated cycle n°4 lead to a significantly lower reactor inlet temperature level lying around 600 K, which could maintain a possible ZrH moderator below 750/770 K, quite convenient temperature conditions in fact. The compressor inlet temperature of the cases n°2 and n°3 is as low as 333 K, which keeps the cycle efficiency at an acceptable value without increasing the radiator area too much. The cycle n°3 is proven particularly attractive because of its moderate compressor pressure ratio and its flexibility in the parameters selection.

Concerning the reactor sketches of Figure 2, the solid-core, Nerva-derivative, epithermal spectrum reactor (a) is assumed to be associated with the cycle n°1 of Figure 1. The cycles n°2 or n°3 preferably are proposed for either the reactor (b) of a design similar to (a) or the particle bed, thermal spectrum reactor (c). For these last two reactors, the favorable effect of a reasonably low temperature environment affecting sensitive regions can be easily appreciated.

	①	②	③	④
HeXe REACTOR INLET TEMPERATURE, K	850	633	633	580
MODERATOR (reflector) TEMPERATURE RANGE, K	(885–940)	670–770	670–770	620–720
RADIATOR AREA, m^2	37	47.5	48	44
REACTOR THERMAL POWER, kWt	95	102.5	110	157
NET EFFICIENCY, per cent	21	19.5	18.2	12.7
HeXe MASS FLOW, kg/s	.63	.38	.43	.55

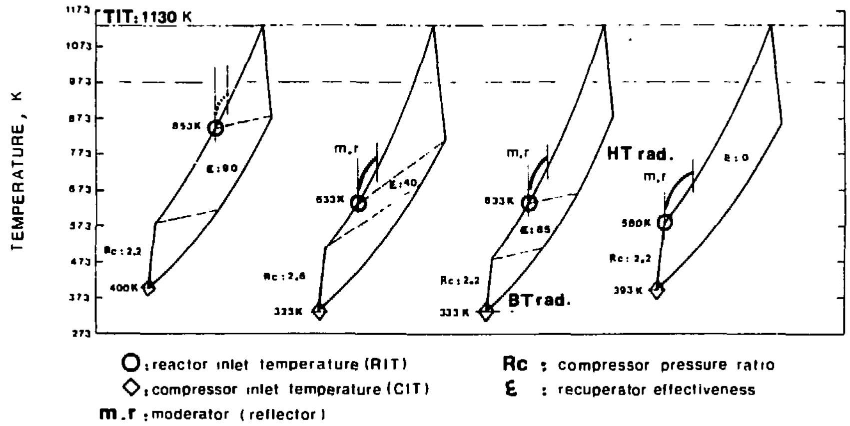


FIGURE 1. Examples of Brayton Cycles for 20-kWe Gas-Cooled Reactor Systems

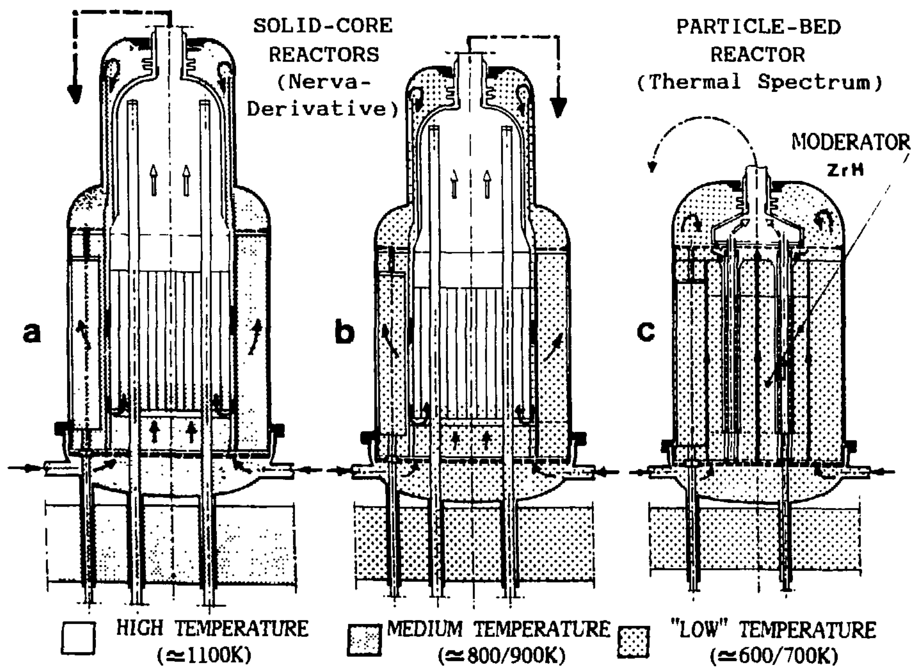


FIGURE 2. Examples of 20-30-kWe Gas-Cooled Reactors.

A similar approach can be suggested for liquid metal (NaK or Na)-cooled reactors, which implies the adoption of a relatively large temperature variation of the reactor coolant. Three examples of relevant Brayton cycles are given in Figure 3. The highly recuperated cycle n°5 could be associated with the reactor schematically represented in Figure 4a; the corresponding NaK (or Na) inlet temperature is of the order of 800 K (betwen 870 and 780 K). A significantly lower reactor inlet temperature of about 690 K could be proposed by adopting a cycle like the n°6 one. As a matter of fact, such a proposal would be meaningful in the case of a thermal spectrum reactor featuring separate fuel and ZrH assemblies, and consequently a possible smaller primary coolant mass flow. The potential interest of this kind of reactor would offset the slight radiator area increase and the higher reactor thermal power. The simple, non-recuperated cycle n°7 is too much penalized from a thermodynamical point of view to have a chance of finding an application.

Figure 4b very schematically shows the regions of a liquid metal-cooled reactor which could be maintain at a relatively low temperature by taking advantage of the Brayton cycle adaptability. Core parts consisting of ZrH moderator become conceivable. Favorable consequences could be noticeable, although to a probably smaller extent than for gas-cooled reactors.

CONCLUSIONS

Some examples of Brayton cycles and of reactor arrangements give an idea of possible ways of seeking attractive conditions, mainly from a temperature level point of view, to better solve critical issues related to safety, reliability, radiation shielding, basic reactor concept, structures, and so on, in the demanding conditions of a space nuclear power system. Advantages can be taken from the Brayton cycle flexibility without a too significant thermodynamical penalty. Prospects for small thermal spectrum, long lifetime reactors should be improved.

Acknowledgments

The French space nuclear power systems studies are cosponsored by the Government Agencies "Centre National d'Etudes Spatiales" (C.N.E.S.) and "Commissariat à l'Energie Atomique" (C.E.A.). These Agencies and the authors emphasize their great interest in the U.S. developments and reports or papers on space Brayton cycle systems carried out or published by the Garrett Fluid Systems Company of the Allied-Signal Corporation and by the National Aeronautics and Space Administration (NASA).

References

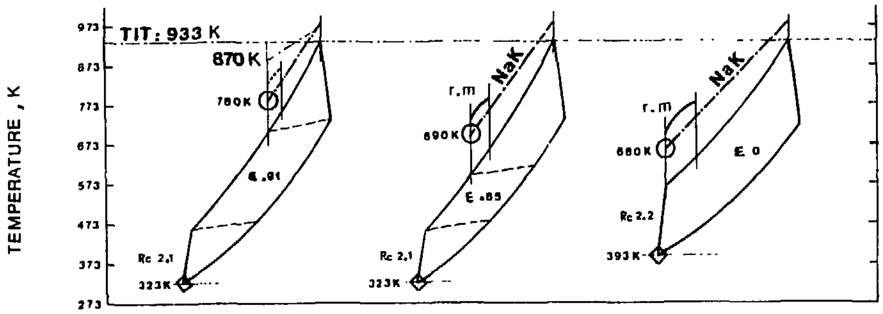
Carré, F. et al. (1989) "A Preliminary Assessment of Reactor Candidate Technologies for a 20-kWe Space Nuclear Brayton System," in Trans. 6th Symposium on Space Nuclear Power Systems, held in Albuquerque, NM, 9-12 January 1989.

Proust, E. et al. (1988) "Space Nuclear Power Studies in France - Overview of the Erato Program," ASME/IECEC Paper No. 889239, in Proc. ASME/IECEC 23rd Intersociety Energy Conversion Engineering Conference, held in Denver, CO, 31 July-5 August 1988.

Tilliette, Z.P., Proust, E., Carré, F. (1988) "A four-year Investigation of Brayton Cycle Systems for Future French Space Power Applications," ASME Paper No. 88-GT-157, 33rd Gas Turbine Congress, held in Amsterdam, Netherlands, 5-9 June 1988.

Tilliette, Z.P. (1988) "Adaptability of Brayton Conversion Systems to Fast, Epithermal, and Thermal Spectrum Space Nuclear Reactors," ASME/IECEC Paper No. 889240, in Proc. ASME/IECEC 23rd Intersociety Energy Conversion Engineering Conference, held in Denver, CO, 31 July-5 August 1988.

	⑤	⑥	⑦
REACTOR INLET TEMPERATURE (NaK), K	780	690	660
REFLECTOR MODERATOR TEMPERATURE RANGE, K	(820 - 865)	723-790	693-780
RADIATOR AREA, m^2	82	88 (7+81)	96
REACTOR THERMAL POWER, kWt	93	141	250
NET EFFICIENCY, per cent	21.5	14.2	8
HeXe MASS FLOW, kg/s	.74	.72	1.27



○ : reactor inlet temperature (NaK) (RIT)
◇ : compressor inlet temperature (CIT)
r.m : reflector.moderator
Rc : compressor pressure ratio
ε : recuperator effectiveness

FIGURE 3. Examples of Brayton Cycles for 20-kWe Liquid Metal-Cooled Reactor Systems.

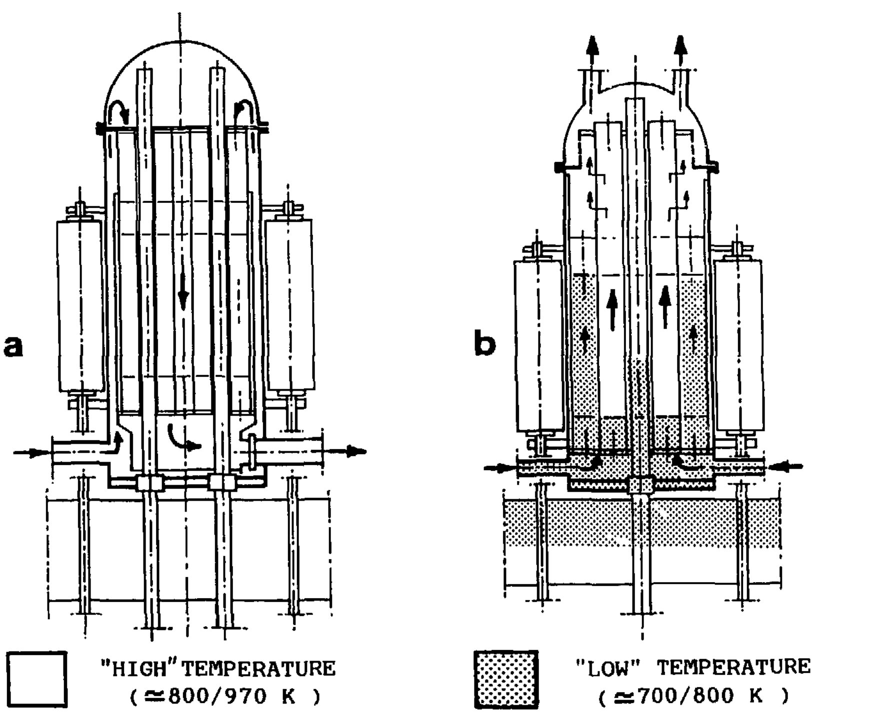


FIGURE 4. Examples of 20-30-kWe Liquid Metal-Cooled Reactors.