Chromium-Nickel steels depleted of nickel stable isotope Ni-58 as a material for fast reactor claddings

G.L.Khorasanov, A.P.Ivanov, A.I.Blokhin, N.A.Demin

Institute of Physics and Power Engineering named after A.I.Leypunsky
1, Bondarenko square, Obninsk, Kaluga region, 249033 Russia

Tel.: +7-08439-98505, Fax: +7-095-2302326, E-mail: khorasan@ippe.obninsk.ru

INTRODUCTION

Presently, the creation of new materials for fast reactor (FR) claddings is one of the main tasks of the nuclear engineering [1]. Now the Russian austenitic steel grade TchS68 with 15 % of nickel content is used as a material for the Russian FR BN-600 claddings [2]. With such a cladding the BN-600 fuel rod is stably operating during 10 years up to the fuel burn-up fraction of 10 % of heavy atoms (h.a.). The cladding material becomes swelled and unfit for further service after the fuel burn-up fraction of 10 % h.a.

The task of increasing the fuel burn-up fraction up to 14 % h.a. is now the principal one for the BN-600 operation. For this purpose the new radiation–resistant austenitic steel grade EK164 with 19 % of nickel content is now developing in the Bochvar Institute, Russia [3].

It is generally assumed that steel swelling is caused by the combined action of radiation damage and helium accumulation in the irradiated material. In this case, nickel stable isotope, Ni-58 (its content in natural nickel is equal to 68%) is a source of helium creation. After neutron capture via (n,g) reaction, Ni-58 is transmuted to radioisotope Ni-59 ($T_{1/2}=7.6\cdot10^4$ years) which has a high value of (n,α) reaction cross-section for thermal and epithermal neutrons. For neutron energies of 0.5 eV – 100 keV its resonance integral of (n,α) reaction is equal to 18 –20 barns while for other nickel isotopes it is less than 10^{-4} - 10^{-5} barns.

This unique nickel isotopes property can be used within a concept of creation of materials with controlled isotopic composition for the nuclear engineering as it is proposed in Ref.4. It is clear that cladding steel contained nickel depleted of its isotope, Ni-58, will produce smaller quantities of helium and hydrogen, and such a material will be suitable for reaching higher burn-up fractions up to 14 % h.a. that is required now.

In the paper calculations of helium and hydrogen accumulation in the steels TchS68 and EK164 with various nickel isotope composition irradiated in the BN-600 neutron spectrum up to fluence $1.2\cdot10^{24}$ n/cm^2 are given.

THE CALCULATION TECHNIQUE

Structural materials of nuclear and thermonuclear reactors are designed for long exploitation and exposition to high doses. During their operation essential quantities of nuclear reaction products could be accumulated. Between them the important ones are helium and hydrogen produced via such reactions as (n,α), (n,2α), (n,nα) и (n,p), (n,2p), (n,np+pn).

Theoretical estimations of helium and hydrogen accumulation rates in materials irradiated in various installations with their neutron spectra are based on estimated nuclear data libraries.

For helium accumulation in materials irradiated with neutrons, the library consisted of recommended microscopic sections of helium creating reactions HEPRL.V1 was composed for 29 elements and their stable isotopes [5].

The library PPL-97 was composed for calculations of hydrogen accumulation in irradiated iron, chromium, nickel and their stable isotopes [6].

The libraries [5,6] were created for neutron energies up to 20 MeV.

In the paper calculations of gas accumulation in multi component materials were performed using the original program DPAGAS, based on the program SPECTER [7]. The program DPAGAS includes only the subprogram COLLAPSE from the SPECTER which helps to transform the nuclear sections σ(E) from the 132 group librarian representation into a more rough representation of neutron energies for given reactors.

For the program DPAGAS the initial files are following:
1) the material composition,
2) the reactor neutron spectrum.

In last DPAGAS versions two-stage nuclear reactions $^{58}Ni(n,\gamma)^{59}Ni(n,\alpha)^{56}Fe$ are taken into account for helium [8] and hydrogen [9] production.

CALCULATION RESULTS

In table 1 the isotopic composition of natural nickel (variant 1) and its controlled variation, directed towards nickel depleting with its isotope Ni-58, are given.

Table 1

Isotopic composition of nickel

Variant	Ni^{58}	Ni^{60}	Ni^{61}	Ni^{62}	Ni^{64}
1	68,077	26,223	1,140	3,634	0,926
2	1	67	4,8	18,5	8,7
3	1	1	1	1	96

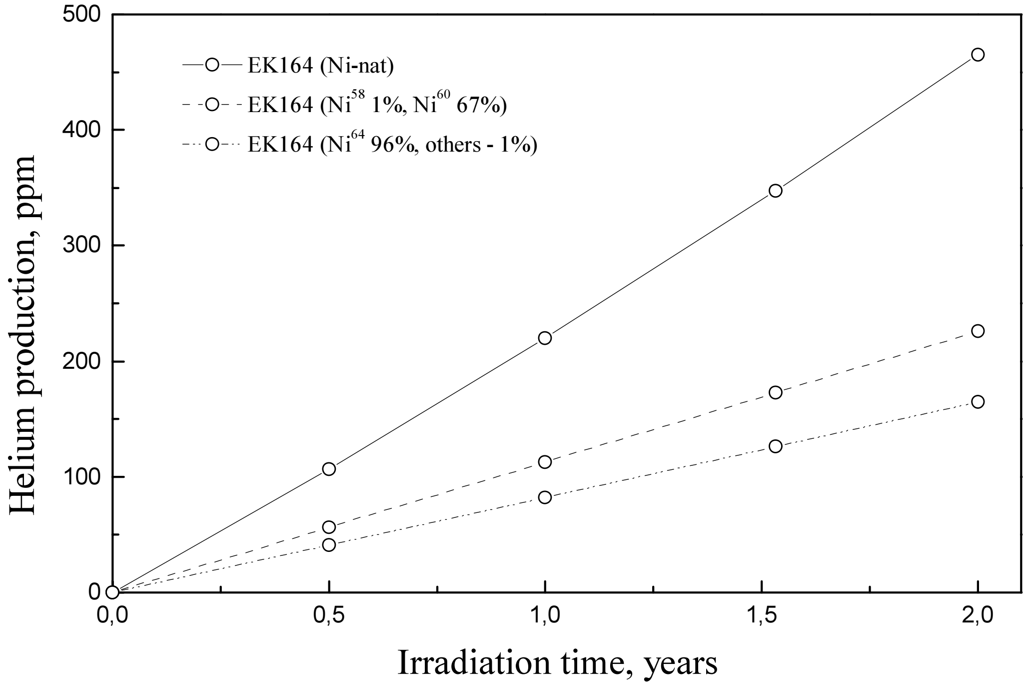

Fig.1. Helium accumulation in the steel EK164 contained nickel with various isotopic composition during its irradiation in the BN-600 core neutron spectrum.

In Fig.1 the results of helium accumulation in the irradiated in the BN-600 steel EK164 contained nickel with various isotopic composition are given: the upper line corresponds to natural nickel and the lower line - to nickel enriched with nickel isotope, Ni-64, up to 96 %.

It could be seen that after 2 years exploitation in the BN-600 the steel EK164 accumulates approximately 500 ppm of helium, while the same steel contained nickel enriched with Ni-64 up to 96 % accumulates only 120 ppm of helium.

In fig.2 the results of similar calculation performed for steel TchS68 are given. It is clear that in this case as well nickel depleting with Ni-58 leads to essential decreasing of helium accumulation in this material.

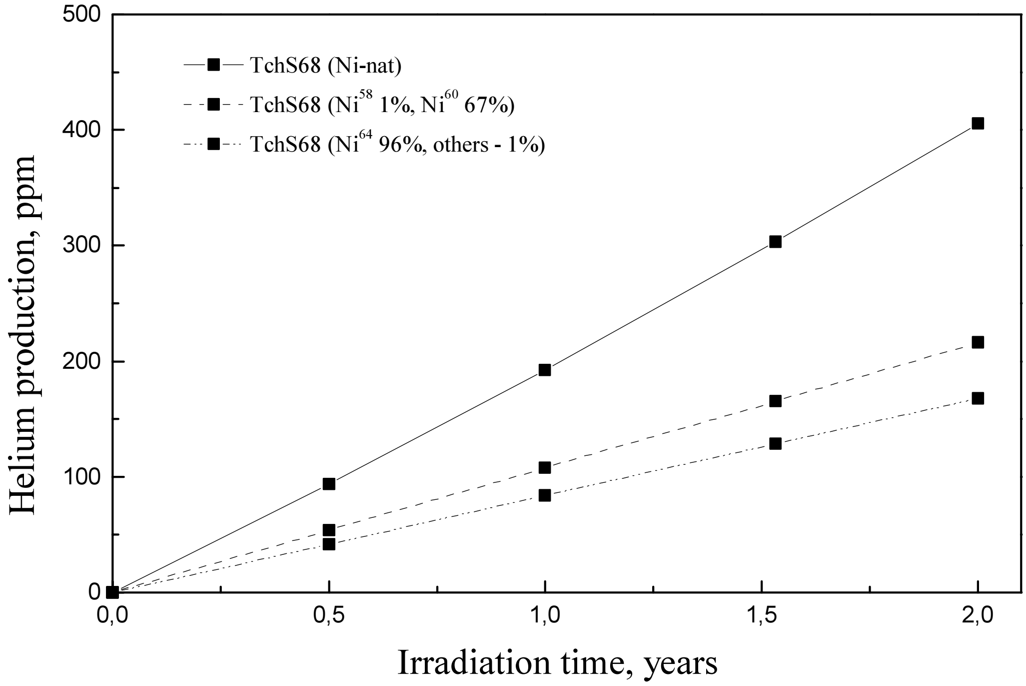

Fig.2. Helium accumulation in the steel TchS68 contained nickel with various isotopic composition during its irradiation in the BN-600 core neutron spectrum.

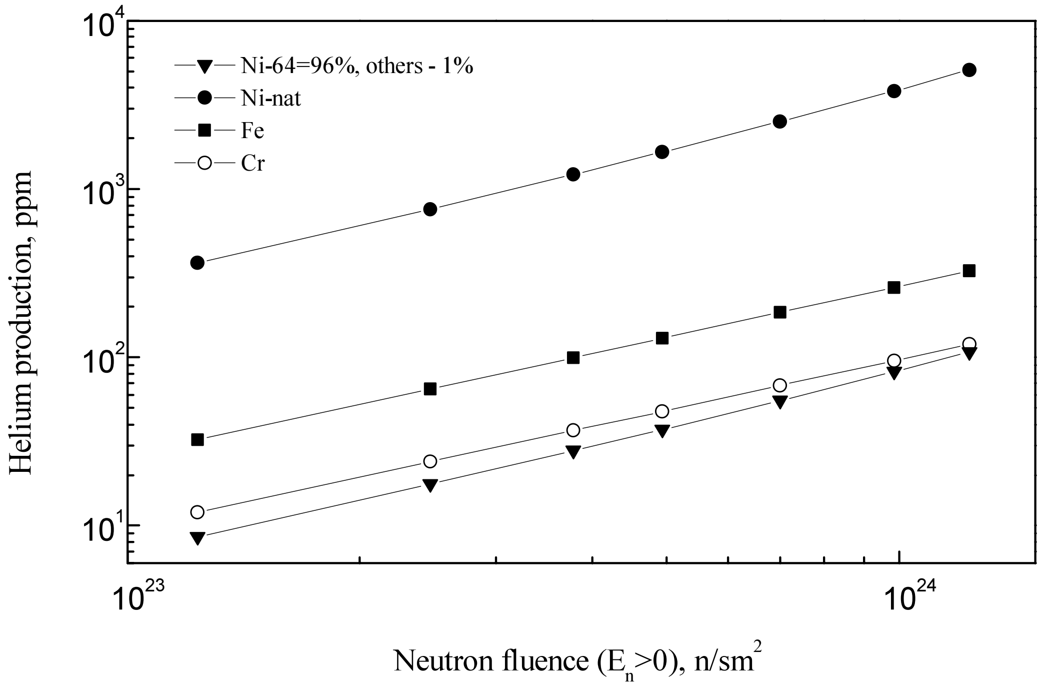

Fig.3. Helium accumulation in iron, chromium and nickel (with various isotopic composition) during its irradiation in the BN-600.

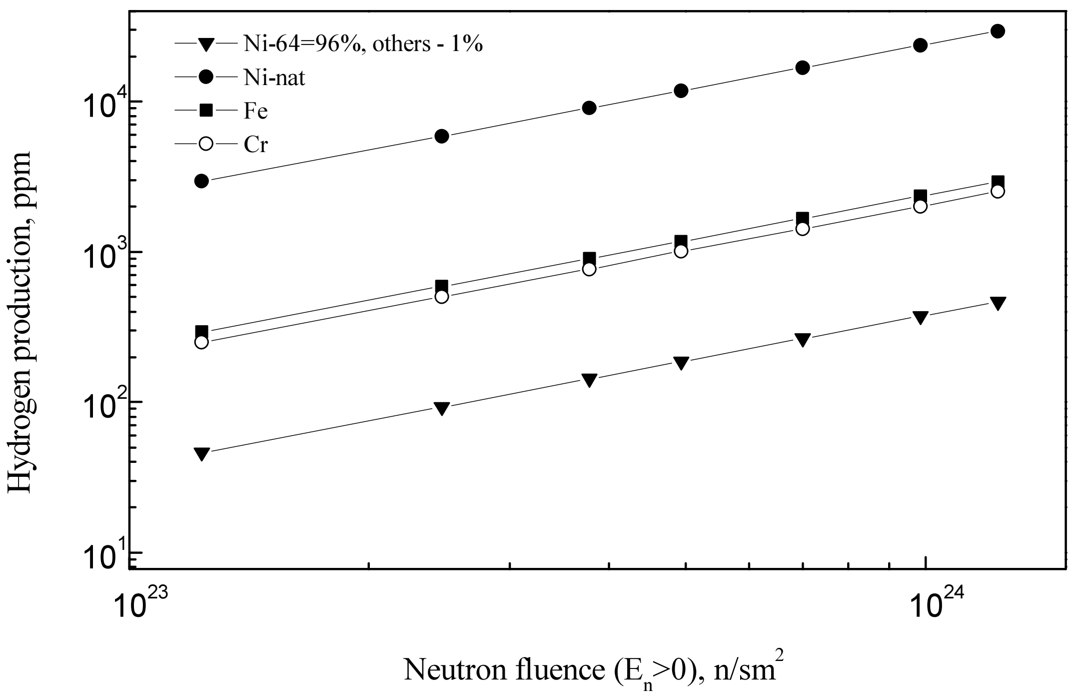

Fig.4. Hydrogen accumulation in iron, chromium and nickel (with various isotopic composition) during its irradiation in the BN-600.

In Figures 3, 4 the calculated levels of helium and hydrogen accumulation in irradiated metals – iron, chromium, nickel – are represented. From these data it follows a very important conclusion that nickel enriched with its isotope, Ni-64, generates less helium and hydrogen than natural iron and chromium do it.

In Fig.5 helium accumulation in nickel with various isotopic composition of nickel, including 100 % enrichment with nickel isotope, Ni-64, during its irradiation in the BN-600 is given. It could be seen that nickel enriching with Ni-64 up to 96 % is enough to decrease the helium accumulation to the level that iron and chromium produce in TchS68 and EK164 steels.

It should be mentioned that at the RNC "Kurchatov Institute" – Institute of Molecular Physics a new, based on a gaseous centrifuge, technology of obtaining nickel isotopes in kilogram quantities is successfully utilized [10].

For the realization of the proposed concept to create slightly swelling claddings, relatively small quantities (tens or hundreds kilograms) of nickel depleted of Ni-58 are required taking into account that in modern FRs, such as the Russian BOR-60 and BN-600, thin-walled claddings of steels with 15-20 % nickel content are used.

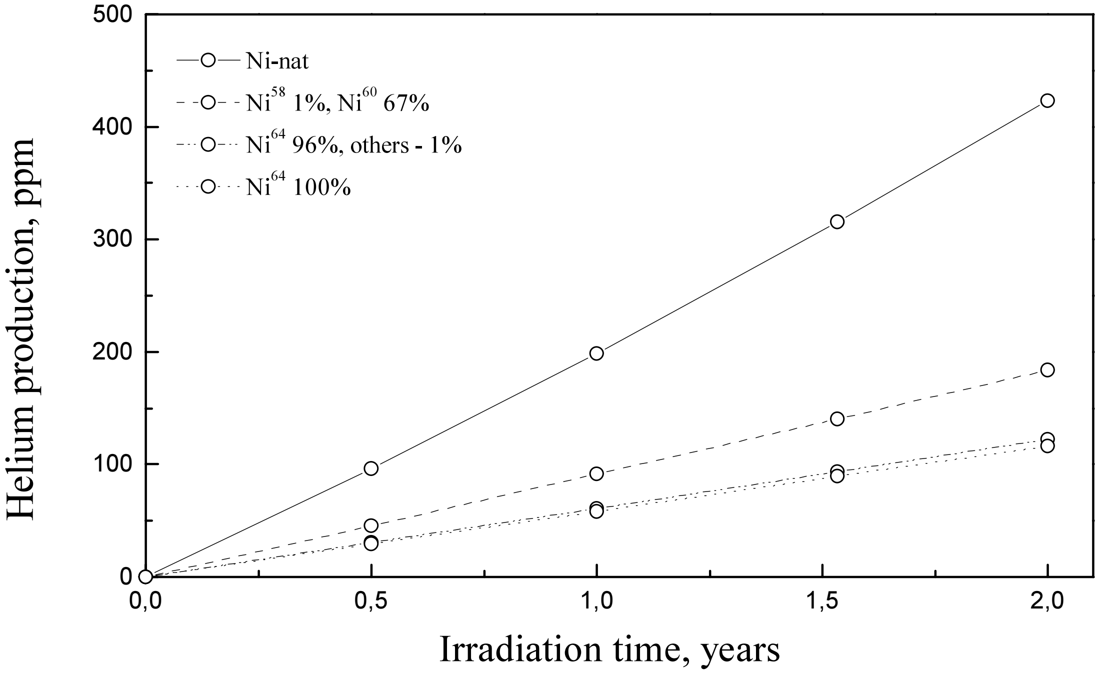

Fig.5. Helium accumulation in nickel with various isotopic composition, including its 100 % enriching with isotope, Ni-64, during its irradiation in the BN-600.

CONCLUSIONS

With the aim of helium and hydrogen accumulation decreasing in the irradiated austenitic steels, it is proposed to enrich nickel with its isotope, Ni-64, and thus to exclude a source of creating nickel radioisotope, Ni-59, which is responsible for helium and hydrogen production.

Calculations performed confirm the possibility of essential decreasing of gaseous product creation in austenitic steels that are commonly used as materials for FR fuel rod claddings.

It is done a very important conclusion that nickel enriched with its isotope, Ni-64, generates less helium and hydrogen than natural iron and chromium do it in the Russian austenitic steels grade TchS68 and EK164 with 15 –20 % of nickel content.

It is pointed the real possibility of obtaining large quantities (ten and hundred of kilograms) of nickel enriched with nickel isotope, Ni-64.

REFERENCES

1. A.V.Vatulin. In: The newspaper "Atom-pressa" issued by the Ministry for Atomic Energy of the Russian Federation, 2002, No. 46 (523), p.1.

2.A.N.Ogorodov et al. Analysis of deformations of the BN-600 claddings made of EP172 and TchS68 steels. In: The III Russian Conference on the Reactor Material Science, October 27-30, 1992, Dimitrovgrad, Russia. Dimitrovgrad: RIAR, 1994, v.2, p.68-70.

3.N.M.Mitrofanova et al. Status of developing the steel EK164 for the BN reactor claddings. In: The VII Russian Conference on the Reactor Material Science, September 8-12, 2003, Dimitrovgrad, Russia. Dimitrovgrad: RIAR, 2003, p.258.

4.G.L.Khorasanov, A.P.Ivanov, A.I.Blokhin. Materials with controlled isotopic composition for the nuclear engineering. In: The VII Russian Conference on the Reactor Material Science, September 8-12, 2003, Dimitrovgrad, Russia. Dimitrovgrad: RIAR, 2003, p.93-94.

5.N.A.Demin, K.I.Zolotarev, M.V.Skripova, Yu.S.Strebkov, A.V.Subbotin. Recommended nuclear data library and calculation code for helium accumulation in structural materials of fusion facilities. Moscow: ENTEK, Annual Report, 1996, p. 247.

6. N.A.Demin, K.I.Zolotarev, V.N.Manokhin, M.V.Skripova, Yu.S.Strebkov, A.V.Subbotin. Recommended nuclear data library and calculation code for hydrogen accumulation in structural materials of fusion facilities. Moscow: ENTEK, Annual Report, 1997, p. 46-49.

7.L.R.Greenwood, R.K.Smither. SPECTER: Neutron damage calculations for materials irradiations. Argonne National Laboratory, ANL/FPP/TM-197, 1985.

8.L.R.Greenwood. A new calculation of thermal neutron damage and helium production in nickel. J. Nucl. Mater., 1983, v. 115, p.137-142.

9.L.R.Greenwood, F.A.Garner. Hydrogen generation arising from $^{59}Ni(n,p)$ reaction and its impact on fission-fusion correlation. J. Nucl. Mater., 1996, v. 233-237, p. 1530-1534.

10.G.L.Khorasanov, A.P.Ivanov, A.I.Blokhin, A.N.Cheltsov, L.Yu.Sosnin. Low activation chromium-nickel steels with 8-10% highly enriched nickel-58 content. In: Proceedings of the VIII-th International Conference "Physical and Chemical Processes on Selection of Atoms and Molecules", October 6-10, 2003, Zvenigorod, Russia. Moscow: TSNIIatominform, 2003, p.288-291.