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HTR PROCESS HEAT APPLICATIONS, STATUS OF TECHNOLOGY AND ECONOMICAL POTENTIAL

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Abstract

The technical and industrial feasibility of the production of high temperature heat from nuclear fuel is presented. The technical feasibility of high temperature heat consuming processes is reviewed and assessed. The conclusion is drawn that the next technological step for pilot plant scale demonstration is the nuclear heated steam reforming process. The economical potential of HTR process heat applications is reviewed: It is directly coupled to the economical competitiveness of HTR electricity production. Recently made statements and pre-conditions on the economic competitiveness in comparison to world market coal are reported.

Keywords:
High Temperature Reactor, Process Heat Applications, Co-generation, Heat Loops, Nuclear Long Distance Energy, Coal Refinement, Economical Potential, Economical Competitiveness in Comparison to World Market Price Coal.

HTR Process Heat Applications, Status of Technology and Economical Potential

1. HTR for High Temperature Heat Production

1.1. In summary: The technical and industrial feasibility of the production of high temperature heat has been proven by the experimental HTR plant AVR in Jülich and the demonstration plant THTR-300 in Hamm/Schmehausen, Federal Republic of Germany, as well as with the plants Dragon, Peach Bottom and Fort St. Vrain in Great Britain and in the United States. The AVR in Jülich operated for more than 10 years with a mean helium outlet temperature of 950 °C.

1.2. In detail on the temperature niveau, on reactor types and projects:

1.2.1. The High Temperature Reactor, HTR, belongs to the family of the gas-cooled reactors. Its development and demonstration was originally oriented towards electricity production. The big advantage in comparison to water-cooled reactors with the possibility to produce lifesteam of conventional conditions for conventional steam turbine processes. For these purposes a mean helium outlet temperature of 700 to 750 °C is sufficient; therefore the demonstration plants THTR-300 and Fort St. Vrain were operated at that point.

1.2.2. The HTR experimental plant AVR in Jülich (AVR = Arbeitsgemeinschaft Versuchsreaktor, Joint Working Group Experimental Reactor) is an HTR with pebble bed core, fig. 1. It operated in total for 21 years, and for more than 10 years at a mean helium outlet temperature of 950 °C very successfully. The heat is used in the steam generator for the production of lifesteam with 515 °C; the heat is transferred via the "shortest hot gas duct of the

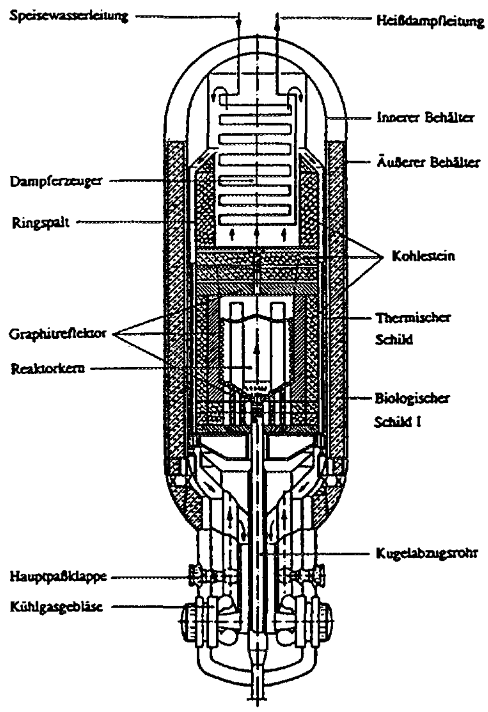


FIG. 1. AVR Jülich Pebble Bed HTR
Mean outlet temperature 950 °C

world". The operation of the AVR was terminated at 31. December 1988, as planned a few years before, when the THTR-300 had started operation. Right now (October 1995) the discharge of the fuel pebbles from the core is in function.

1.2.3. The demonstration plant THTR-300 in Schmehausen/Hamm (THTR = Thorium HTR pebble bed core, 300 MWe) was in operation for about 3 years, and the project was terminated in summer 1989 after some technical difficulties mainly for political reasons. Valuable experiences were gained with respect to the in-core-shutdown rods, the hot gas ducts and the discharge systems. Right now (October 1995) the discharge of the fuel pebbles from the core has been finished.

1.3. In extension to co-generation:
1.3.1. Nuclear process heat applications at lower temperature levels have been realized in a number of plants mostly in the form of co-generation. Examples are agro-industrial applications in Canada and district heat systems in Russia, lit. BARNERT-KRETT-KUPITZ-1991.

1.3.2. The HTR plants mentioned above were operated for pure electricity production, and not in co-generation.

2. High Temperature Heat Consuming Processes

2.1. In summary: The technical feasibility of high temperature heat consuming apparatus and components, in particular the helium-heated steam reformer, the helium-heated gas-generator for the process of "steam coal gasification, SCG", and the intermediate heat loop has been proven by experimental facilities up to the pilot plant scale. In addition the technical feasibility of the process of "Hydrogen Coal Gasification, HCG" has been proven by experimental facilities in the pilot plant scale. This was done in the HTR process heat application projects in the Federal Republic of Germany.

2.2. In detail on the various processes, the apparatus and components:

2.2.1. From a scientific point of view there is a clear ranking in the following high temperature heat consuming processes and apparatus; the ranking is, fig. 2:

1) The helium-heated steam generator (as a part of a steam turbine cycle),

2) the helium-heated steam reformer (also called methan-reformer), and

3) the helium-heated steam coal gasification, SCG, gas-generator.

Step 1) is the base, step 2) is more complicated because of the gaseous catalytic chemical reaction (and step 3) is even more difficult because of a (non-catalytic or catalytic) chemical reaction between steam and pulverized coal, a solid.

2.2.2. The helium-heated steam reformer has successfully been tested in semi-technical scale in the EVA plant in Jülich (EVA = Einzelrohr-Versuchs-Anlage = Single Tube Experimental Plant) and in pilot plant scale in the large scale experimental plant "EVA/ADAM-II" in Jülich in two different designs the "baffle orifice-bundle", lit. NFE-1985 and in the "counter current bundle", lit.: PNP-1992, and appendix 1, as well as lit. BARNERT-1995-1. In the large scale

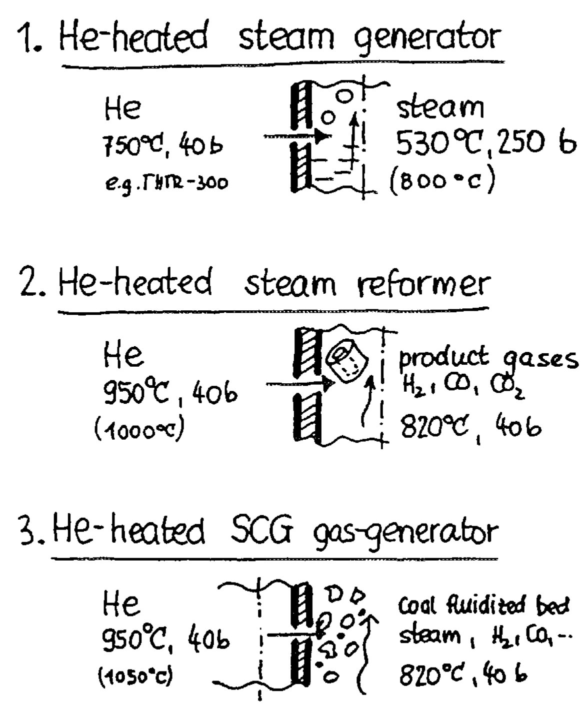


FIG. 2. High T Heat Processes Ranking with resp. to complexity

experimental facility "EVA/ADAM-II" the 950 °C helium was provided by electric heating. In the project work the helium-heated steam reformer was foreseen to be heatd by primary helium (not by secondary helium from the intermediate heat loop).

2.2.3. The helium-heated steam coal gasification, SCG, gas-generator for the process of "steam coal gasification, SCG" has been tested in the semi-technical plant with a throughput of 200 kg/h bituminous coal successfully. The heat was provided to the fluidized bed of the steam gas generator by emerged heat tranfer bundles, being heated by 950 °C from an electrical source, see appendix 1 and lit. BARNERT-1995-1. Originally the helium-heated steam gas-generator was foreseen to be heated by secondary helium (with an intermediate loop); recent studies indicate that it should be possible also to heat it by primary helium, because it is expected, that coal slurries can cross the wall of the confinement.

2.2.4. The intermediate heat loop with the intermediate heat exchanger and other components, e.g. valves, has been tested in the large experimental facility "KVK" in Bensberg (KVK = Komponenten-Versuchs-Kreislauf, Component Experimental Loop) in the pilot plant scale (10 MW) for two variants of the intermediate heat exchanger - the HELIX-variant and the U-TUBE-variant very successfully. Also in this experimental plant the 950 °C helium was provided by electrical heating. Originally the intermediate heat loop was thought to be useful for a better separation of the primary circuit of the nuclear plant and the circuits of the coal gasification plant, but later, it has been shown that an intermediate heat loop does also have disadvantages and that it might not be necessary. The tested valve has the task of an isolation valve in case of a rupture in the intermediate loop.

2.2.5. The process of "Hydrogen Coal Gasification, HCG" in its hydrogenating chemical reaction is an exotherm process, has been tested in the semi-technical and the pilot-plant scale very successfully, lit. BARNERT-1995-1. The necessary hydrogen is produced in a steam reformer step, and this is the way of the coupling of the required HTR-high temperature heat. In total, the overall process is a two-stop process, this may be an economical disadvantage.

2.2.6. The before mentioned R & D and demonstration work was performed of the two projects "Nukleare Fernenergie, NFE, (Nuclear Long Distance Energy)", lit. NFE-1985 and "Prototypanlage Nukleare Prozeßwärme, PNP, (Prototype Plant Nuclear Process Heat)", lit. PNP-1992. The NFE-project cost about 300 million Deutschmark, the PNP-project finally summed up to about 1.7 billion Deutschmark: So the overall efforts were 2 billion Deutschmark, being equivalent to about 1.4 billion US $. Both projects were done in strong cooperation between nuclear industry, coal industry and the Research Centre Jülich, KFA.

2.2.7. A large number of processes for high temperature heat applications with the HTR has been proposed and assess from co-generation for electricity and district heat to water splitting, lit. BARNERT-SINGH-1994.

2.3. In extension on water splitting:

2.3.1. In cooperation with the European research centre ISPRA and with funding from the European Community a research programme was performed on the splitting of water with thermochemical cycles, in particular the Westingshouse-Sulfuric Acid Cycle. In the sulfuric acid process the heat consuming step is the splitting of sulfuric acid.

2.3.2. For the splitting of sulfuric acid bench scale experiments were performed with 950 °C heat (from a furnace) and at 40 bars pressure in pressurized quarts-apparaturs successfully at KFA Jülich.

3. The Coupling of the High Temperature Heat Source and the Consumer

3.1. In summary: For the demonstration of the coupling of a nuclear high temperature heat source and a consuming process two projects - the projects - "AVR-II" and "AVR-reconstruction" - were performed, but not realized in the Federal Republic of Germany. According to the plans the first nuclear demonstration of the coupling is foreseen to be realized in the projects "High Temperature Engineering Test Reactor, HTTR" at JAERI, Oarai, Japan, and "HTR-Test Reactor, HTR-10" at INET, Beijing, China.

3.2. In detail on the coupling projects in FRG:

3.2.1. The 1st project for coupling as the project "AVR-II" with a modular type HTR of 50 MWt and with the process of steam reforming in the primary circuit. It was proposed to select KFA Jülich as the side. The project was not realized, mainly due to the lack of funds.

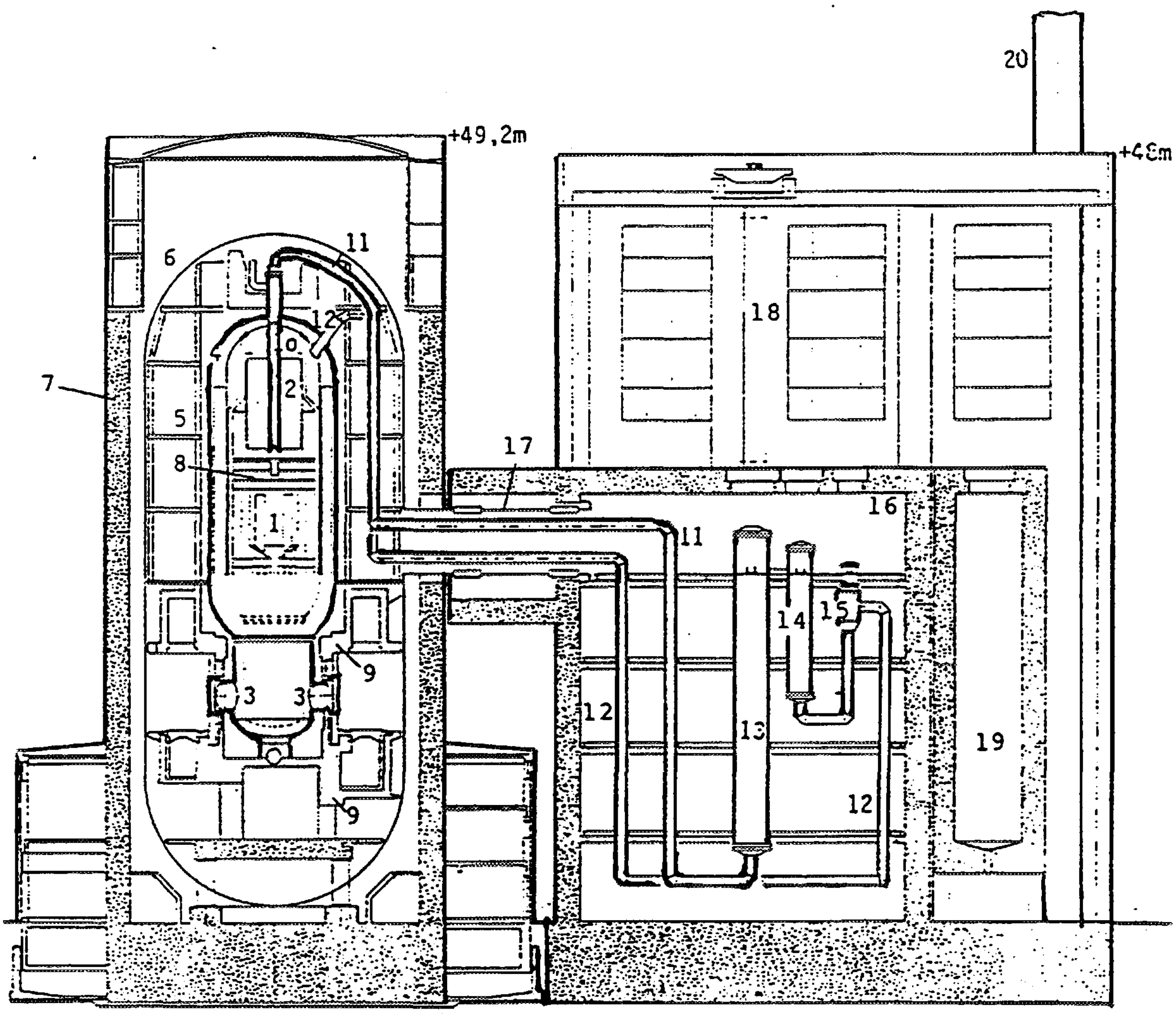
3.2.2. For this reason the project "AVR-reconstruction" was performed afterwards, making use of the existing AVR and reconstructing it from an electricity producing plant into a process heat demonstration plant with a thermal loop power of 10 MW, operating in co-generation of heat and electricity, at AVR-side, close to KFA, Jülich, fig. 3. But also this project was not realized, to some extend already because of political difficulties.

3.2.3. The German HTR process heat projects have been terminated without the demonstration of the nuclear coupling after the end of the oil price crises.

3.2.4. According to the respective R & D and demonstration programs the coupling of a nuclear high temperature heat source and an appropiate consumer will first in the world be demonstrated in the projects "High Temperature Engineering Test Reactor, HTTR" at JAERI in Oarai, Japan and "High Temperature Test Reactor, HTR-10" at INET in Beijing, China.

3.3. In recognition of the experiences on the coupling in the PNP-project:

3.3.1. The R+D+D-work on HTR process heat applications was done in parallel to the bigger efforts for demonstration and market penetration of HTR electricity producing plants. Two



AVR

1 Core
2 AVR-Dampferzeuger
3 2 Gebläse
4 Reaktordruckbehälter
5 Bühnen
6 AVR-Schutzbehälter
7 Reaktorgebäude
8 Deckenreflektor
9 ringförmige Betontragstruktur

HOCHTEMPERATUR-PROZESSWÄRMEKREISLAUF

10 Heißgasdurchführung
11 Heißgasleitung
12 Kaltgasleitung
13 Röhrenspaltofen
14 Prozeßdampferzeuger
15 Prozeßwärmekreislaufgebläse
16 Prozeßwärmekreislaufschutzgebäude
17 Schutzbehälterverbindung
18 Halle mit Kran
19 Heiße Zelle
20 Kamin .

FIG. 3. AVR Process Heat Reactor
Project FRG 1983, not realized

vendors have it developed and therefore two types of concepts existed: The HTR-monolith, HTR-1250 (1250 MWt for 500 MWe) and the HTR-Modul (200 MWt for 80 MWe per modul). For both concepts process heat-versions were developed with the mean helium outlet temperature of 950 °C. Both versions had to be adjusted to the two coal gasification processes the steam coal gasification and the hydrogen coal gasification process. Usually there is a surplus of lower temperature heat, that was converted into electricity as a side product. The main product changed due to the market conditions in the various evaluations and assessment, including substitute natural gas SNG (= CH_4), hydrogen H_2, town gas $H_2 + CH_4$, and methanol CH_3OH.

3.3.2. Conclusion from the experiences in the PNP projects are:

a) Co-generation e.g. the production of the side product electricity, is energetically meaningful , but may be of disadvantage if the price for the electricity is to low.

b) The unit size of the nuclear heat source should not be to large because the unit size of the heat consuming operators, e.g. helium heated steam reformer, is smaller than unit sizes known from nuclear electricity, as steam generators and in particular steam turbines.

c) A proper adjustment between the heat source and the heat consuming apparatus, including steam generators for electricity production, are decisive for the economical result, recycling of mass streams and recuperation of heat must be adjusted to minimum costs, lit. POTENTIAL-1987.

d) For the process of steam reforming as well as steam coal gasification it is meaningful to increase the temperature niveau of the heat vector for 50 or 100 K to a mean outlet temperature of helium to 1 000 °C to 1050 °C.

e) The application of an intermediate heat loop brings only a few advantages, but costs much.

f) The main products are substances, gases or/and liquids, which can carry radioactivity - in contrary to the main product electricity in nuclear electricity production - the so-called production limit needs to be fulfilled (Herstellungsfreigrenze, e.g. 200 pCi/g or tritium).

3.3.3. Within the R & D work to improving and confirm the design and economics and to prepare the market introduction of "nuclear coal gasification techniques", lit. PNP-1992 and PNP-ANHANG-1992 a study on a process heat HTR, called AHTR-500 (AHTR = Advanced HTR, 500 MWt), has been performed for the process of steam coal gasification at KFA Jülich, fig. 4 to 6. The design features are: Increased helium gas outlet temperature of 1 000 °C, increased helium-inlet temperature of 350 °C (to avoid side-product electricity), adjusted thermal output of 500 MWt for two streets of gasification plants, each 250 MWt helium loop power, lower primary pressure to 25 bar (which is preferable for the chemical reactions in the gas generator), primary helium heated gas generator of vertical design in counter current heat transfer arrangement. For the process of steam reforming a similar design of the process heat plant (as in fig. 6) is feasible.

3.3.4. The process heat reactor AHTR-500, fig. 4, can fulfill the modern requirements of catastrophe-free nuclear energy technology because of the low power density of 2.5 MWt/m^3, in minimizing the reactivity response in the case of water ingress, and provided that pebbles and other graphite and carbon structures are coated with silicon carbide to improve corrosion resistance in case of air ingress. The design base incident "heat up" has maximum temperatures of about only 1 400 °C, fig. 5, that means less than design limit 1 600 °C.

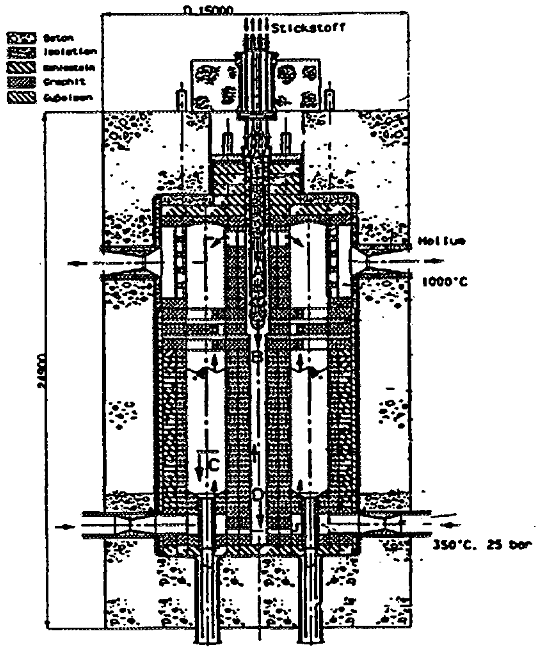


FIG. 4. AHTR 500 Process Heat Reactor General Design T = 350 - 1000 °C

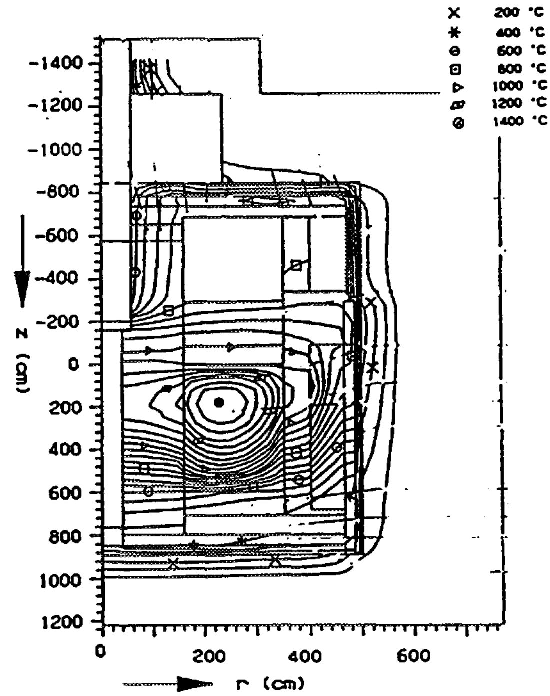
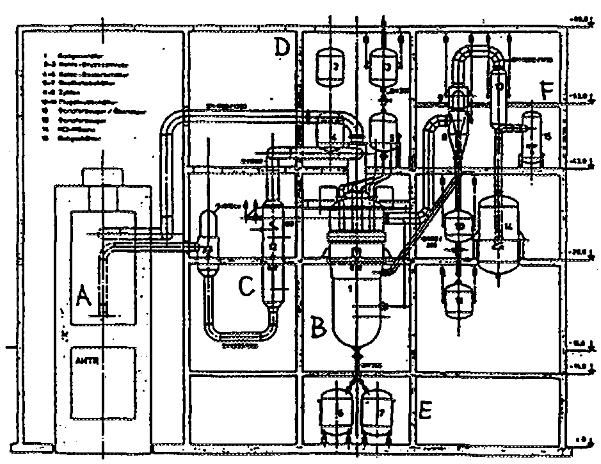


FIG. 5. AHTR 500 Process Heat Reactor Design Basis Incident: Heat Up



A Process Heat Reactor AHTR 500
B Gas-Generator Steam Coal Gasification SCG
C Steam Generator and Super Heater
D Coal Feed System
E Fine Coke or Ash
F Product Gas H_2 CH_4 Co CO_2

FIG. 6. HTR Process Heat Plant Steam Coal Gasification SCG

4. On the Economical Potential of HTR Process Heat Applications

4.1. In summary: Nuclear process heat applications are economically attractive if nuclear electricity production is economically competitive. This applies also to the HTR. A technical answer to the historical cost increases could be: catastrophe-free nuclear energy technology and simplification. Relevant theoretical evaluations have shown that HTR modul power plants could be economically competitive in comparison to world market coal under the assumption of a construction in series of about 800 MWe per year.

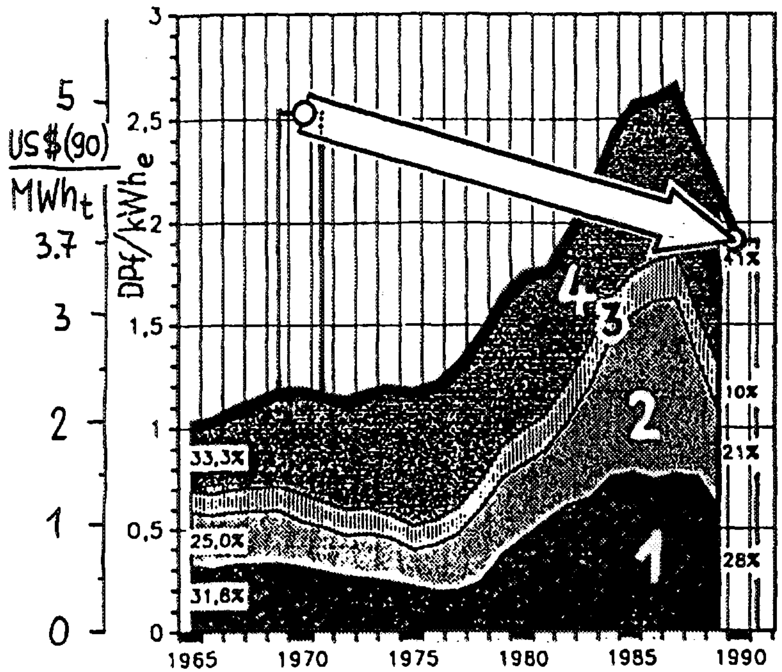
4.2. In detail on experiences from LWR on HTR-modul and conclusions for HTR process heat applications:

4.2.1. In many countries of the world nuclear electricity production has been - and is up to now - a commercial success. To some extend this success was pushed also by the oil price crisis. Question marks have to be put for the future, mainly because of the historical experience of increases of capital costs. Will nuclear electricity be competitive in comparison to world market coal?

4.2.2. The main driving force for economical attractiveness of nuclear energy is the fact that nuclear fuel is by a factor of 3 to 4 cheaper than fossil alternatives. The price of nuclear fuel in FRG is about 3.7 US \$ (90)/MWh_t, equivalent to 1.9 DPf (90)/kWh_e, lit. HANSEN-1993, S. 223, calculated with an efficiency of 31 % for LWR-fuel. The over all trend of the development of the nuclear fuel prices in FRG is a reduction of 25 %, fig. 7. This is an encouraging positive fact for nuclear energy from the historical development.

4.2.3. The price for nuclear fuel of about 3.7 US \$ (90)MWh_t has to be compared to e.g. energy prices to consumers in the European Community in 1990 (average) for industry of steam coal of 13, heavy fuel oil (3.5 %) of 13, and natural gas of (also) 13 US \$ (90)/MWh_t, lit. BARNERT-1995-7, p. 19. For those prices the advantage factor of nuclear fuel compared to fossil fuel is 3.5 (13/3.7). The maximum value of the oil price during the oil price crisis of 40 US \$ (87)/barrel is equivalent to 23,5 US \$ (87)/MWh_t, corrected by the US consumer price index CPI (1990: 130,7; 1987: 113,6; lit.: ALMANC-1992, p. 150) to 27 US \$ (90)/MWh_t. Compared to this maximum value of the oil price the advantage factor of nuclear fuel is even 7.7 (27/3.5).

4.2.4. The negative cost stories, putting a question mark to the economic viability of nuclear energy in comparison to e.g. cheap coal, were produced by the historical development of the capital costs. In FRG, for 20 PWRs and BWRs, the capital cost increased by a factor of about 4 from 600 to 2 500 US \$(90)/kWe in two decades of market penetration with much competition between vendors, fig. 8. This factor of 4 is a real factor (excluding inflation), because the actual figures have been adjusted by the consumer price index CPI of FRG (1990:



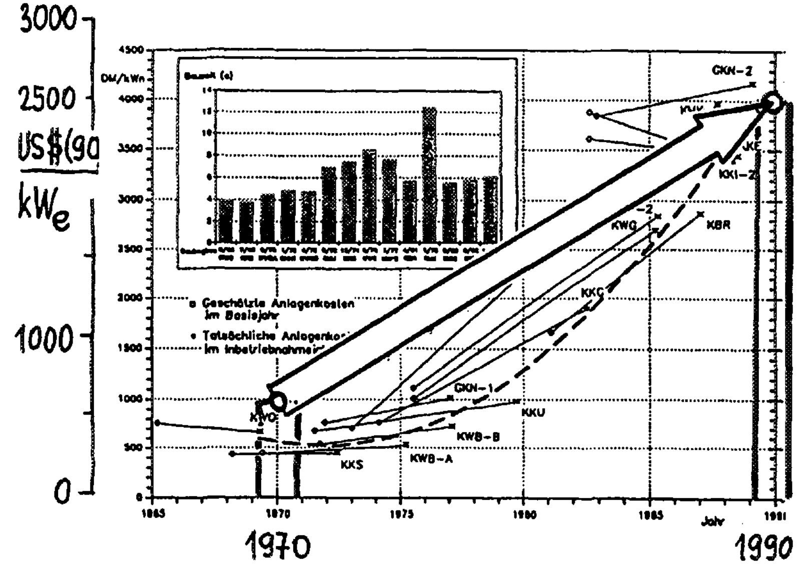
Actual Values:

1 Uranium, incl. Conversion
2 Separation Work
3 Fuel Fabrication
4 Disposal

Real Values:

○ Adjusted with CPI, FRG
1990: 100 ; 1970: 47

FIG. 7. Nuclear Fuel Price, FRG
Hist. Dev.: Reduction by 25 %



Actual Values:

◇ Estimated Plant Costs in year of order

✶ Real Costs in year of start of operation

Real Values:

○ Adjusted with CPI, FRG
1990: 100 ; 1970: 47

FIG. 8. Nuclear Capital Costs, FRG
Hist. Dev.: Increase by factor 4

100, 1970: 47; lit. AKTUELL-1995, S. 250; -1988, S. 143; -1987, S. 148) to the value of money of 1990 in fig. 8; in actual money the factor of the increasement of capital cost is about 8.

4.2.5. For the reason of the increase of the capital cost the utilities in the US and in Europe have formulated goals (limits) for the capital costs of future nuclear plants. The European Utility Requirements, being in the state of preparation this year, formulated the goal for the capital cost C = 1 100 ECU/kW$_e$ (ECU = European Currency Unit), lit.: BRÖCKER-ESSMANN-1995, S. 83, equivalent to 1447 US $ (95)/kW$_e$ (1,8681 DM/1 ECU x 1 US $/1,42 DM, Oct. 1995).

4.2.6. The question is: what are the reasons for this immense increases of capital costs, recognizing that no technical progress in the temperature niveau of the produced heat and in the efficiency to produce electricity has been achieved? Obviously the reasons are the nuclear controversy, the reduced acceptance of large scale risks in the public and in the utilities, the build-up of a big bureaucracy, the fact that nuclear energy became a political issue after Chernobyl. In summary: the reason is the lack of safety.

4.2.7. Discussions of these question in the Federal Republic of Germany finally led to the 7th amendment of the Atomic Energy Act, lit. ATOMIC-ENERGY-ACT-1994, see appendix 2, with the requirement "no impact outside of fence".

4.2.8. A technical answer to this situation could be: Catastrophe-free nuclear energy technology and thereby simplification by omittance of costly safety devices, which are not needed anymore.

4.3. Recent cost statements on the HTR-modul:

4.3.1. In a hearing of the inquiry emission "protection of the atmosphere of the earth" of the German Parliament, lit. LIPPOLT-1993, the question "which production cost of electricity can be expected with the HTR?" has been answered by Mr. A. Hüttl, president of the board of directors, Energy Production KWU and member of the board of directors of Siemens AG with the following statements:

4.3.1.1. "Relevant theoretical evaluations have shown that HTR-modul power plants could be economically competitive in comparison to import coal (that is cheap world market coal) under the assumption of a construtcion in series of about 800 MWe per year, this is equivalent to 4 power stations with each a twin modul". And it was added:

4.3.1.2. "The pre-condition for the market penetration of the HTR-modul of in total some billion Deutschmarks for a demonstration plant, for a large scale supply of fuel elements, as well as for the production facilities for the series production, should be earned by the construction and operation of a number of larger HTR module power plants. This requires first of all the establishment of the necessary security of investment". The last sentence was, of course, ment for FRG.

4.3.2. In contrary to these positive statements it must be reported from FRG that right now (October 1995) the HTR modul is still in "hibernation", political efforts to reach a consensus on the "security of investment" failed.

4.4. In detail on the economical potential of process heat applications:

4.4.1. The primary product of the conversion of nuclear fuel in all types of nuclear reactors is heat. For electricity production this heat is converted into electricity via a thermodynamical cycle in the same way as in non-nuclear thermal powerstations. Therefore the statement can be made: Nuclear process heat applications are economically attractive if nuclear electricity production is economically competitive.

4.4.2. This also applies to the HTR, because high temperature heat is attractive for electricity production, e.g. in combi-cycles, lit. BARNERT-KUGELER-1995, as well as for process heat applications.

4.4.3. The main driving force for studies, R+D programs and the large experimental demonstrations for HTR process heat applications in FRG has been the large market of non-electrical secondary carriers, the oil price crises and the huge resources of bituminous coal (which has been the base for the industrialization) and of lignite. But it turned out that it is difficult to reach competitiveness against the established non-electrical secondary energy carriers steam coal, heating oil, motor fuel, fuel gases and others more.

4.4.4. In the final assessments on the competitiveness of process heat application for coal gasification in "R+D Work to Improve and Confirm the Design and Economics and to Prepare the Market Introduction of Nuclear Coal Gasification Technology", lit.: PNP-1992 and PNP-ANHANG-1992, it was concluded that in the best lay-outs nuclear processes had an competitiveness advantage of 25 % compared to conventional processes, but that this was not competitive in comparison to conventional fuel.

4.4.5. The CO_2-climate change problem has up to now not gained enough public interest to become a driving force for more nuclear applications; but this may change in future. The reduction of the product specific emissions of carbondioxide CO_2 and methane CH_4 by HTR coal refinement is in the order of about 25 %; but not more. This is a drawback. Therefore it has been proposed to use biomass, and even garbage as a source for the carbon atom for the production of liquid secondary energy carriers, e.g. methanol, lit. BARNERT-1995, -7 and -4.

5 Summary and Conclusion

5.1. Total summary: The technical (and industrial) feasibility of the production of high temperature heat from the HTR and of a number of high temperature heat consuming processes and apparatus has been demonstrated. The demonstration of the coupling needs to be done. A technical answer to the historical cost increases of nuclear energy could be: catastrophe-free nuclear energy technology and simplification.

5.2. Detailed summary from the previous chapters:

5.2.1. The technical and industrial feasibility of the production of high temperature heat has been proven by the experimental HTR plant AVR in Jülich and the demonstration plant THTR-300 in Hamm/Schmehausen, Federal Republic of Germany, as well as with the plants Dragon, Peach Bottom and Fort St. Vrain in Great Britain and in the United States. The AVR in Jülich operated for more than 10 years with a mean helium outlet temperature of 950 °C.

5.2.2. The technical feasibility of high temperature heat consuming apparatus and components, in particular the helium-heated steam reformer, the helium-heated gas-generator for the process of "steam coal gasification, SCG", and the intermediate heat loop has been proven by experimental facilities up to the pilot plant scale. In addition the technical feasibility of the process of "Hydrogen Coal Gasification, HCG" has been proven by experimental facilities in the pilot plant scale. This was done in the HTR process heat application projects in the Federal Republic of Germany.

5.2.3. For the demonstration of the coupling of a nuclear high temperature heat source and a consuming process two projects - the projects - "AVR-II" and "AVR-reconstruction" - were performed, but not realized in the Federal Republic of Germany. According to the plans the first nuclear demonstration of the coupling is foreseen to be realized in the projects "High Temperature Engineering Test Reactor, HTTR" at JAERI, Oarai, Japan, and "HTR-Test Reactor, HTR-10" at INET, Beijing, China.

5.2.4. Nuclear process heat applications are economically attractive if nuclear electricity production is economically competitive. This applies also to the HTR. A technical answer to the historical cost increases could be: catastrophe-free nuclear energy technology and simplification. Relevant theoretical evaluations have shown that HTR modul power plants could be economically competitive in comparison to world market coal under the assumption of a construction in series of about 800 MWe per year.

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APPENDIX 1

Research Centre Jülich GmbH, KFA
Institute for Safety Research and Reactor Technology, ISR
Prof. Dr.-Ing. Heiko Barnert

Objectives and Results of the Project "Protoype Plant Nuclear Process Heat, PNP"

The PNP-Project was founded by the three partners Bergbau-Forschung, Rheinische Braunkohle and KFA Jülich in 1972. In 1976 the actual contract was made and two additional partners from reactor industry joint the co-operation. GHT Gesellschaft für Hochtemperaturreaktor-Technik GmbH of the Siemens Konzern and Hochtemperatureaktorbau GmbH, HRB, of the former BBC Konzern.
The PNP-Project was terminated 1992, June 30. Partners were

Forschungszentrum Jülich GmbH, KFA
former
Kernforschungsanlage Jülich GmbH (KFA)
Jülich

GHT Gesellschaft für Hochtemperatur-Technik mbH
Bergisch-Gladbach

Hochtemperatur-Reaktorbau GmbH
Mannheim

DMT Gesellschaft für Forschung und Prüfung mbH
former Bergbauforschung
Essen

Rheinische Braunkohlenwerke AG
Köln

1. To the Objectives

In the contract on the co-operation between Industrial Companies and the Research Centre Jülich GmbH, KFA in the frame of the project "Prototype Plant Nuclear Process Heat, PNP" the following has been fomulated on the objectives:

a) to develop a high temperature reactor for high values of the gas outlet temperature (950°C) for the application as a source for process heat to be applied in processes of coal refinement, including the components for heat transfer, being necessary for this purpose and

b) to develop and to demonstrate components and pilot plants for the process of steam gasification of coal and for the process of hydrogenating gasification of coal.

2. Results in Summary

A) The technical feasibility of a Nuclear Process Heat Plant for the Refinement of coal has been established. The main parts "High Temperature Reactor for Process Heat Production" and "Refinement Plant for Coal" have sufficiently been developed and demonstrated for the realization of a prototype plant. This means: the technical objectives of the project have been achieved. Nevertheless the costs of the plant are guessed to be much higher than originally been expected.

B) The economical competitiveness of a nuclear process heat plant for the refinement of coal is in comparison to the conventional alternatives of coal refinement in principle achievable, including the realizability of potentials of improvement. But the economical competitiveness of the refinement of coal in total does not exist any more under the market conditions since the end of the oil price crisis.

C) The process of the refinement of coal using nuclear energy contributes to the fundamental goals "security of energy supply", "diversification of the resources" and "environmental friendliness".

Remark:
Remaining work to be done in the future: Definition of reference concepts, R & D work for ensuring of the technical feasibility as well as planning, construction and operation of a pilot plant for process heat application for refinement of coal.

APPENDIX 1 (cont.)

Results in Detail

1. The development of the High Temperature Reactor for the production of high temperature heat with high values of the outlet temperature of the coolant (950 °C) for the application as source for process heat is conceptually accomplished to a very large extend: Several concepts of reactors have been established ready for construction.

2. The fuel element being envisaged for application in the HTR for process heat production: "Pebble type fuel element, low enriched fuel, coated particle with TRISO coating", have been successfully qualified in mass tests in the AVR reactor in Jülich.

3. Components for the high temperature heat transfer are qualified: Examples are the successful tests for hot gas ducts including insulations and liners in the sacle 1:1 test facilities "Component Experimental Loop (Kühlversuchskreislauf KVK, SIEMENS, INTERATOM, IA Bergisch Gladbach and in the Experimental Plant ADI and the succesful tests on magnetic bearings for circulators, (HRB Jülich).

4. Verifications on the safety of a HTR for process heat have successfully been accomplished. Examples are the explosion tests with hydrogen (SIEMENS/INTERATOM; Bergisch Gladbach) and the tests on earthquakes for the core with pebble type fuel elements including support structures (earthquake test facility MAVIS; Jülich, former SAMSON, HRB Jülich), as well as experimental work on the retention of tritium (KFA Jülich and others more).

5. The realizability of the production of process heat in a nuclear reactor, in the form of high temperature-helium with 950 °C, has successfully been demonstrated by the operation of the HTR experimental reactor AVR in Jülich by its many years of operation with such a mean helium outlet temperature.This has been reconfirmed by the project "reconstruction of the AVR into a process heat plant" (it has not been reslized), also with respect to the licenseability.

6. The technical feasibility of components of HTR for process heat in the industrial scale has been supported by the operation of the HTR demonstration plant THTR-300 in Schmehausen with its valuable experiences. The operation of the THTR-300 was finished in 1989, also due to political difficulties.

7. The qualification of the metallic materials for high temperature applications is very advanced: For the materials of the reformers and of the intermediate heat exchangers the prognostic lifetimes of more than 100 000 hours have been achieved. The newly developed material for the helium-heated gas generator of the process of a steam gasification of coal withstand very hard corrosion conditions in the gasification of coal.

8. Methods for the design, including detailed design and production of documents for the licensing process for the components of high temperature heat transfer and high temperature heat consuming apparatus have been developed completely.

9. The development and demonstration of the process of reforming of methane with a helium-heated reformer has successfully been performed. Two variants of the reformer - baffle-variant and tube-variant - have been tested successfully in pilot-scale in the large scale experimental plant EVA/ADAM-II (KFA Jülich).

10. The development and demonstration of the helium intermediate loop for the transfer of high temperature heat has been performed successfully. Two variants of the intermediate heat exchanger - the Helix-variant and the U-tube-variant - have been tested successfully in the large scale experimental plant "Component Experimental Loop (Komponenten Versuchs-Kreislauf, KVK, SIEMENS/INTERATOM-Bergisch-Gladbach) together with hot gas tubes and fittings.

11. The development and demonstration of the process of the hydrogenating gasification of coal, HGC, in experimental facilities in the semi-technical scale and in the pilot-scale (Union Kraftstoff, Wesseling) have been performed successfully. The process has been developed in the main for lignite, the applicability for hard coal has also been tested successfully.

12. The development and demonstration of the process of steam gasification of coal, has been performed successfully in an experimental faciltiy in the semi-technical scale (Deutsche Montan Technologie, DMT, former Bergbauforschung Essen). The process has been developed in the main for hard coal.

13. Assessments of the technical feasibility and the economical competitiveness of the processes for the refinement of coal using nuclear energy assessment have been performed in the year 1987 (ROeG study and RBW assessment). Both studies confirm the techncial feasibility. On the economical competitiveness the following is stated:

    For the process of the steam gasification of coal: The cost values of the processes using nuclear energy are higher than those of the conventional processes and there is a potential to decrease the costs "but without the possibility to be cheaper than the conventional alternatives. However, it had also be shown that it would be necessary to have an optimal coupling between the HTR and the heat consuming processes", and

    for the hydrogenating gasification of coal: "The product costs are remarkable higher than the market prices of today and also above the conventional alternatives, with the conclusion at an economical competitive may be achieved only in the long term".

APPENDIX 1 (cont.)

14. The R & D work for the improvement and the securing of the technical feasibility and the economical competitiveness and for the preparation of the market penetration of coal refinement using nuclear energy in phase I: "Development of concepts and assessment" (1989-1992) have identified potentials of improvement. With these improvements the economical competitiveness of nuclear process heat for the refinement of coal in comparison to conventional alternatives has been achieved: the best value is 75 % of the cost value of the conventional alternative. But the economical competitiveness of coal refinement as a whole is not achieved in comparison to the market conditions after the end of the oil price crisis for the moment (1992).

15. The licenseability of nuclear heat application for coal refinement has been evaluated in 1980 by the assessment committee of the Bundesminister des Innern (Federal Ministry of the Interior) and has received a positive votum: requirements can be fulfilled and proofs can be made. This votum has been revitalized by the evaluations in the frame of the project "Reconstruction of the AVR into a process heat plant" in 1984. The primary helium-heated reformer fulfills all requirements being important in a licensing process.

16. The environmental friendliness of nuclear coal gasification with respect to emissions from the coal refinement processes has been proven by the experimental plants: The products specific emissions of carbondioxide of the nuclear coal refinement is in comparison to the conventional alternative smaller by the factor of 1.5 to 1.8. With the nuclear coal refinement the "CO_2-disadvantage" of the coal in comparison to oil and gas can be diminished.

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APPENDIX 2

Atomic Energy Act

Federal Republic of Germany

7th amendmend

effective 28.July '94

Translation „word by word", in parts
to improve technical understanding
5 pages (1 of 5)

Research Center Jülich GmbH, KFA
Institute for Safety Research and Reactor Technology ISR
H. Barnert
07.09.94

Atomic Energy Act, Germany (2 of 5)

Article 7. Licensing of Plants
Paragraph (2)

The licence may only be granted

if

Item 3:

the precautions

- against damages
- required
  according to the state of art

have been taken
- through
  the construction and
  operation of the plant.

Atomic Energy Act, Germany, 7th Amendment (3 of 5)

Article 7, Paragraph (2a) (that is the new)

With respect to plants
- for the fission of nuclear fuel
  = serving to produce electricity

paragraph (2), item 3
is legal with the restriction
that
- as a further precaution
  = against risk to the public

the licence may only be granted
if
- due to the nature and operation of the plant

even such events,
whose occurance is practically excluded
- by the precaution
  = to be taken against damages

would not necessitate
decisive measures
- for protection
  = against damaging effects
  of ionizing radiation
- beyond the enclosed boundary of the plant,...

Atomic Energy Act, Germany, 7th Amendment (4 of 5)
Explanation, 1st paragraph:

Over and above
- the existing concept
  = for the design of nuclear power plants
    ≡ against incidents and
  = for plant-internal emergency protection

  = within the scope of precautions
    ≡ against damages
    ≡ required
      according to the state of art
      (paragraph 2, item 3)

it appears appropriate
- in view of the advancing state of art
- for future reactors

to take precautionary measures

against any events,
such as

accidents with core melt,

- that may occur
- in spite of the precautions
  = against damages
- already practised.

Atomic Energy Act, Germany, 7th Amendment (5 of 5)
Explanation, 2nd paragraph:

The measures,
- e.g. for controlling
  = accidents with core melt,

must be such
- that the licensing authority is convinced

that no releases will occure

that would necessitate

any decisive measures,
such as evacuation,

- for protection
  = against damaging effects
    ≡ of ionizing radiation.

Bundesgesetzblatt 1617

Teil I Z 5702 A

1994 Ausgegeben zu Bonn am 28. Juli 1994 Nr. 46

Tag	Inhalt	Seite
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Artikel 4

Siebentes Gesetz zur Änderung des Atomgesetzes

Das Atomgesetz in der Fassung der Bekanntmachung vom 15. Juli 1985 (BGBl. I S. 1565), zuletzt geändert durch Artikel 6 Abs. 77 des Gesetzes vom 27. Dezember 1993 (BGBl. I S. 2378), wird wie folgt geändert:

1. In § 7 wird nach Absatz 2 folgender Absatz 2a eingefügt:

   „(2a) Bei Anlagen zur Spaltung von Kernbrennstoffen, die der Erzeugung von Elektrizität dienen, gilt Absatz 2 Nr. 3 mit der Maßgabe, daß zur weiteren Vorsorge gegen Risiken für die Allgemeinheit die Genehmigung nur erteilt werden darf, wenn auf Grund der Beschaffenheit und des Betriebs der Anlage auch Ereignisse, deren Eintritt durch die zu treffende Vorsorge gegen Schäden praktisch ausgeschlossen ist, einschneidende Maßnahmen zum Schutz vor der schädlichen Wirkung ionisierender Strahlen außerhalb des abgeschlossenen Geländes der Anlage nicht erforderlich machen würden; die bei der Auslegung der Anlage zugrunde zu legenden Ereignisse sind in Leitlinien näher zu bestimmen, die das für die kerntechnische Sicherheit und den Strahlenschutz zuständige Bundesministerium nach Anhörung der zuständigen obersten Landesbehörden im Bundesanzeiger veröffentlicht. Satz 1 gilt nicht für die Errichtung und den Betrieb von Anlagen, für die bis zum 31. Dezember 1993 eine Genehmigung oder Teilgenehmigung erteilt worden ist, sowie für wesentliche Veränderungen dieser Anlagen oder ihres Betriebes."

Deutscher Bundestag
12. Wahlperiode

Drucksache 12/6908
25. 02. 94
Sachgebiet 750

Gesetzentwurf
der Bundesregierung

C. Kernenergie

Einzelbegründung

Zu Artikel 4 (Siebentes Gesetz zur Änderung des Atomgesetzes)

Zu Nummer 1 (§ 7 Abs. 2a)

Über das bisherige Konzept der Auslegung von Kernkraftwerken gegen Störfälle und der Maßnahmen des anlageninternen Notfallschutzes im Rahmen der nach dem Stand von Wissenschaft und Technik erforderlichen Vorsorge gegen Schäden (Absatz 2 Nr. 3) hinaus erscheint es bei künftigen Reaktoren angesichts des fortschreitenden Standes von Wissenschaft und Technik sachgerecht, Vorsorgemaßnahmen gegen etwaige, trotz der schon bislang praktizierten Schadensvorsorgemaßnahmen eintretende Ereignisse wie Unfälle mit Kernschmelze zu treffen. Die Beherrschung solcher schon nach dem bisherigen Konzept als extrem unwahrscheinlich anzusehenden Ereignisse wird durch den neuen Absatz 2a zum Schutz der Allgemeinheit vorgeschrieben (Satz 1). Der neue Absatz 2a fügt sich damit in die geltende Systematik der Schadensvorsorge ein, die sich unterteilt in den Bereich der — stets drittschützenden — Gefahrenabwehr sowie den der grundsätzlich allgemeinschützenden Risikovorsorge, indem Satz 1 einen Teil der allgemeinschützenden Risikovorsorge umschreibt.

Die Maßnahmen z. B. zur Beherrschung von Unfällen mit Kernschmelze müssen so beschaffen sein, daß es zur Überzeugung der Genehmigungsbehörde feststeht, daß es nicht zu Freisetzungen kommen wird, die einschneidende Maßnahmen zum Schutz vor der schädlichen Wirkung ionisierender Strahlen wie eine Evakuierung erforderlich machen. Maßgeblich hierfür ist, daß nach der Einschätzung der Genehmigungsbehörde die in der Publikation Nr. 63 der Internationalen Strahlenschutzkommission, ICRP 63, sowie die von der deutschen Strahlenschutzkommission empfohlenen unteren Eingreifrichtwerte für eine Evakuierung nicht überschritten werden.

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