dem torusförmigen Entladungsgefäss bei kontinuierlichem Reaktorbetrieb besteht aber bei allen Fusions-Reaktoren mit torusförmigem Entladungsgefäss das Hauptproblem darin, dass es praktisch unmöglich ist, ein torusförmiges Plasma bei Fusionstemperaturen über längere oder gar unbeschränkte Zeit stabil zu halten, weil die Fusionen der Reaktionspartner nicht gleichzeitig an allen Stellen des torusförmigen Plasmas in gleichem Masse auftreten und bei hauptsächlich nur in einem begrenzten Bereich auftretenden Fusionen in diesem Bereich eine Instabilitätsstelle entsteht, die zum Aufreissen des torusförmigen Plasmas an dieser Stelle und unmittelbar anschliessend zum Erlöschen der Entladung führt.

Aus diesen Gründen sind die Chancen, das Problem der kontrollierten Kernfusion mit einem der oben erläuterten bisherigen Konzepte lösen zu können, ausserordentlich gering.

2. Report „The Problem of Nuclear Fusion" mit der Beschreibung eines aussichtsreichen Konzepts für die kontrollierte Kernfusion, das auf einer Grundidee des Nestors der Kernfusion E. Teller beruht.

The Problem of Nuclear Fusion

report on a possible solution

Summary: Fusion reactor based on the „Cusped Geometry Concept" in which the problem of indefinite tight plasma confinement with inherent stability and high compression of the confined plasma in the reaction zone is solved by an electric potential pot surrounding the reaction zone and having an ion source at the upper potential pot edge.

Fusion is the source of energy of the future, if there will be successful outcome in achieving controlled nuclear fusion and using it for power production, for – contrary to the known manner of power production by combusting fossil combustibles with carbon dioxide as combustion residue resulting in the greenhouse effect, or by nuclear fission with high-toxic radio-active fission products as reaction products of the nuclear fuels resulting in problems with radio-active waste – power production by nuclear fusion results in inert helium as reaction product of the nuclear fuels and therefore in abolition of the grave environmental burdens hitherto caused with power production by combustion residues or fission products. In addition, Deuterium D and Lithium Li^6 as fuels coming in the first line into question for controlled fusion are – contrary to fissionable Uranium U^{235} and fossil combustibles as coal, mineral oil and natural gas – available everywhere on a scale sufficient for millions of years, so that supply with fuels for controlled fusion would be long-term secured. Moreover, since also in case of functional disturbances, disasters of grave consequences as with fission reactors cannot happen with fusion reactors, fusion reactors may be arranged in the underground in great depth and therefore disassembly of the contaminated reactor components after shut-down of the fusion reactor may be left undone with suitable bulk heads between the reactor and the surrounding ground, so that also the hitherto unsolved radio-active waste problems with the removal of fission reactors after shut-down can be avoided with fusion reactors.

Nuclear research labors therefore already since about 40 years for realization of controlled fusion. In spite of intensive research work and an immense expenditure of investigation funds, however, not even the „ignition of plasma" necessary for maintaining fusion within a hot plasma of reactants could be obtained, so that reaching power production by controlled fusion on the path till now taken seems to be more and more doubtful, the more as research circles give to understand that in any case before the end of further 50 years there is not to reckon with an inclusion of fusion reactors into the power production.

The researchers working in the field of nuclear fusion are also in a difficult position in that the absence of sweeping successes of their many years research work has led to a reduction of the state investigation funds and therewith also already to the suspension of a great number of research projects in the fusion field as for example the ZEPHYR-project planned in Garching (Germany) for analysis of the ignition conditions within a hot plasma. Therefore, the fusion researchers cannot leave the path till now taken even in case of own doubts about the chances of success of their projects, if they don't want to risk further drastic reductions of the investigation funds and therewith after all the suspension of their still current research projects, but on the contrary, for securing their research projects, they must confront each doubt about the rightness of the path till now taken and therewith also each proposal deviating from this path, because the success of such a proposal would inevitably result in a shifting the investigation funds on the deviating path and therewith in the suspension of the research projects lying on the path till now taken.

The path taken by the fusion research already in the middle of the fifties – namely to generate within a toroidal discharge chamber an annular plasma confined by magnetic fields as reaction zone for the fusion and to heat up the plasma until the „ignition temperature" – has however the fundamental drawback of lacking stability of the plasma ring in the range of the „ignition temperature", which made a heating up the plasma until ignition impossible because of instabilities arising still before reaching an ignition of the plasma. A stable plasma confinement unlimited as to time, as it would be necessary for a continuous reactor operation and therewith for the true aim of a power production by controlled fusion, is therefore not attainable on the path till now taken with toroidal discharge chambers and a plasma ring as reaction zone.

These facts and the therefore conceivable unsuccessfulness of research works on the path till now taken by the fusion research have been predicted already 1954 by the doyen of nuclear fusion, Edward Teller, with his statement of the stability criterion named after him, for according to Tellers stability criterion a stable plasma confinement unlimited as to time is not attainable with toroidal discharge chambers and an annular plasma confined by magnetic fields as reaction zone.

With his stability criterion, however, Teller has given over and above it also the fundamental teaching for the construction of fusion reactors, with which a stable plasma confinement unlimited as to time and therewith the continuous reactor operation imperatively necessary for power production by controlled nuclear fusion can be achieved. That the path to controlled nuclear fusion thereby shown by Teller has been rejected at that time nearly unanimously among experts, had no scientific reasons but was connected with the 1954 happened exclusion of the „father of atomic bomb" J. R. Oppenheimer from US-Atomic-Energy-Commission for which many scientists unjustly hold Teller responsible.

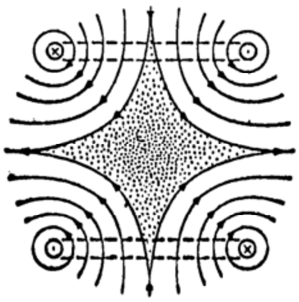

Fig. 1

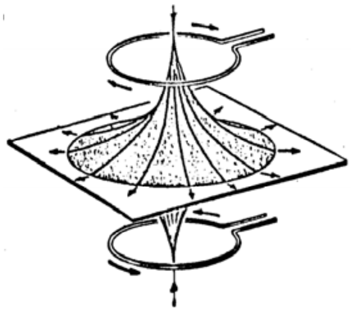

Fig. 2

Only a small group of scientists under H. Grad pursued in 1955/56 the path shown by Teller and proved that with the „Cusped Geometry Concept" (Fig.1.) complying with Tellers stability criterion, with a high density of the plasma in the reaction zone, a stable plasma confinement unlimited as to time can be achieved and that the path shown by Teller allows therefore power production by controlled fusion. Also the feared fast escaping of plasma out of the reaction zone (Fig. 2, arrows in the middle plane) considered as main difficulty for realizing a fusion reactor on the path shown by Teller would have been largely lavoidable with the „Cusped Geometry Concept" so that a plasma confinement being indeed not completely but still sufficiently tight would have been achievable. The then chief of the nuclear fusion branch of the US-Atomic-Energy-Commission A. S. Bishop writes with this respect in his 1958 published book „Project Sherwood, The U.S. Program in Controlled Fusion" [70] on page 140

> «In fact, it was found that the Plasma confinement at thermonuclear temperatures, while not as good as desired, might still be adequate to make this configuration of practical interest.
> Here, then, was a possible approach offering the two important features of inherent stability and adequate confinement.»

and

> «Leaving aside the complex problem of whether such boundaries', once established, could subsequently be maintained, the overall outlook for this approach appeared to be quite promising. Studies were even carried out on the size and characteristics of a power-producing thermo-nuclear reactor based on the cusped geometry concept.»

The only one question at this time not yet completely answered was, whether the sharp boundaries between plasma and magnetic field (Fig. 1) achievable with the „Cusped Geometry Concept" can be maintained indefinitely in time or get lost with time in consequence of said not completely tight plasma confinement or, in other words, whether such a maintaining is also possible with a not completely tight plasma confinement or whether a complete avoidance of escaping particles out of the confined plasma is required.

This question was, however, evidently not connected with unsolvable problems, for according the above mentioned statements of A. S. Bishop, studies has already been „carried out on the size and characteristics of a power-producing thermonuclear reactor based on the „Cusped Geometry Concept", so that at that time shortly would have been reckoned on a practical realization of power-production by controlled fusion on the path shown by Teller.

In spite of that, working on this project has been suspended still before a practical realization and the whole research capacity in the field of nuclear fusion has been concentrated on projects with toroidal discharge chambers and an annular plasma, i.e. about in the end of 1956 came a general switch-shifting in the direction of the above mentioned path till now taken by the fusion research, and this path once taken has been followed up by the fusion research in principle until now. After now about 40 years research work on this path taken by the fusion research without a sweeping success, it seemed to be time to call to mind the success-promising path for controlled fusion shown by Teller and to undertake – under postponing eventually still existing mental reservations against the person of Teller – at least an attempt to create a fusion reactor capable of operating on the base of the „Cusped Geometry Concept".

Such an attempt is specified in the US patent 5,160,694 [64] where a small pilot plant of a fusion reactor operating on the base of the „Cusped Geometry Concept" is described . The patent discloses a solution for the above mentioned still unanswered question of maintaining sharp boundaries between plasma and magnetic field or, more exactly, for a complete avoidance of escaping ionized reactants out of the plasma confined in the reaction zone enabling such a maintaining, and on the base of this solution, construction and method of operating of the disclosed fusion reactor are specified in the patent (US-Pat.. 5160694, col. 25 to col. 56). Since evidence of functional capability of a fusion reactor according to the „Cusped Geometry Concept" does not require super-projects as the hitherto existing research reactors but can be demonstrated already with a reactor of the size of a medium-sized laboratory-apparatus, only a small pilot plant with only 10 kW cross power and only 20 liter volume (without appertaining accessory aggregates) is conceived in the patent on the base of the aforementioned solution and the construction principles for fusion reactors according to the „Cusped Geometry Concept" resulting from this solution, so that the expenditure for the construction of the pilot plant can be held relatively low (US-Pat. 5160694, col. 38, l. 18 to 26). For the pure verification of the functional capability of the pilot plant , a part of the accessory aggregates necessary for regular operation can be omitted or for the time being replaced by laboratory equipment already present, so that the expenditure necessary in the beginning can be restricted substantially to the construction costs for the real reactor aggregate (US-Pat. 5160694, col. 55, l.65, to col. 56, l.34). The conceived pilot reactor together with the accessory aggregates is shown in Fig. 3 below (= Fig. 6 of US-Pat. 5160694). The real reactor aggregate is shown there in a sectional view on a scale of 1:4.25. The measures of the different reactor parts can be taken with this scale from this Fig. they are not in particular specified in the patent. Design and mode of operation of the reactor and its different parts are specified and explained in detail in the patent (US-Pat. 5160694, col. 25 to col. 56).

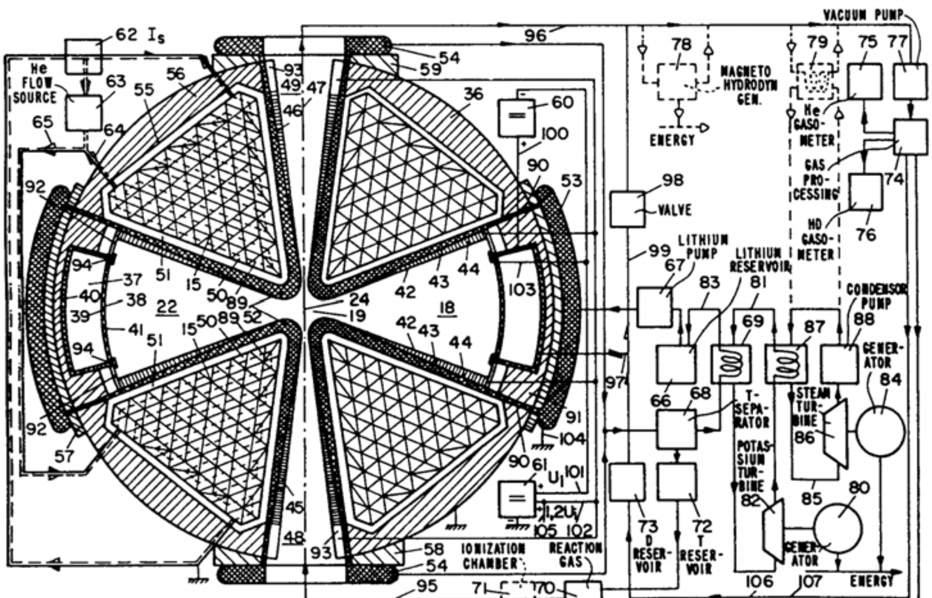

Fig. 3

The question still unanswered with the fusion reactor conceived by H. Grad in 1955/56, namely the question of maintaining sharp boundaries between plasma and magnetic field or of a complete avoidance of escaping of ionized reactants out of the plasma confined in the reaction zone enabling such a maintaining, has been solved with the fusion reactor described in the patent thereby that the range, where in the fusion reactor conceived by H. Grade because of said not completely tight plasma confinement still ionized reactants could escape out of the plasma confined in the reaction zone (Fig. 2, arrows in the middle plane) has been surrounded by a range with rising electric potential, a so-called electric potential pot (Fig. 4, hatched range), where the ionized reactants escaping from the reaction zone (similarly as balls moving upwards the wall of a bowl) loose their velocity until zero under conversion of their kinetic energy into potential energy and are then (similarly as said balls moving again downwards the wall of the bowl) led back again to the reaction zone under reconversion of their potential energy into kinetic energy. Because therefore all reactants either remain within the reaction zone or come back to the reaction zone with equal energy and temperature in case of a short-time escaping, actually a completely tight plasma confinement is obtained by said potential pot. The potential pot shown as hatched range in Fig. 4 extends of course much more wide in radial direction as could be shown in Fig. 4, for the potential between the reaction zone at the bottom of the potential pot and the upper potential pot edge must be at least so large that the whole kinetic energy of a ionized reactant escaping out of the reaction zone with fusion temperature of e.g. 100'000'000 °K can be converted into potential energy before reaching the upper potential pot edge and must therefore be in said example of 100'000'000 °K at least 10 kV and practically advisable above 50 kV, and for a secure controlling such high voltages, of course a distance between the upper potential pot edge and the reaction zone as great as possible and being preferably greater than 5 times the diameter of the reaction zone will be necessary.

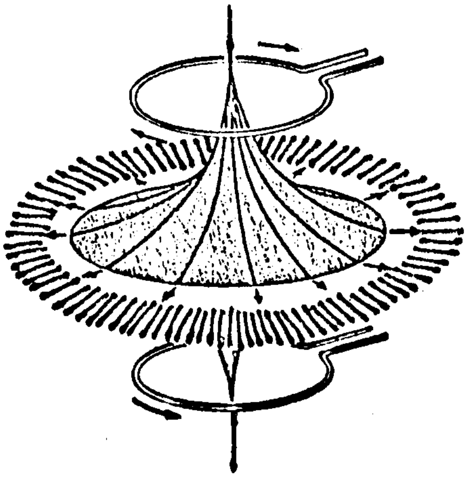

Fig. 4

With such a great potential pot, however, the magnetic field lines of the magnetic field produced by the both coils or wire loops shown in Fig. 4 would not run in parallel but at an angle to the field lines of the electric field in the potential pot at least in the upper part of the potential pot, and in consequence thereof, the ionized reactants would not run along the electric field lines in the potential pot but would be diverted by the magnetic field of the coils. To prevent that and to create within the potential pot a field with magnetic field lines running substantially in parallel to the electric field lines, the both coils 15 with substantially triangular winding cross-sections shown in Fig. 5 are provided in the fusion reactor described in the patent instead of the both wire loops shown in Fig. 4, which coils 15 produce within the potential pot (range 18) a magnetic field 16 with magnetic field lines 17 running substantially in the same direction as the electric field lines. By means of the designshown in Fig. 5 of coils 15 and the magnetic field produced therewith, a magnetic disturbing of the mode of operation of the potential pot is excluded and it is secured that ionized reactants escaped from the reaction zone during their return are accelerated exactly in the direction to the reaction zone 19 in the center of the potential pot and come therefore always back again into the reaction zone.

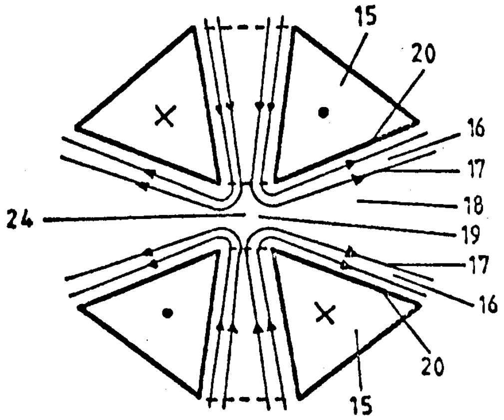

Fig. 5

In addition to the question still unanswered with the fusion reactor conceived by H. Grade in 1955/56 and now solved with the fusion reactor described in the patent by means of said potential pot in connection with said coils with substantially triangular winding cross-sections, namely the question of maintaining sharp boundaries between plasma and magnetic field or of a complete avoidance of escaping of ionized reactants out of the plasma confined in the reaction zone enabling such a maintaining, there was originally according to the statements on page 140 of said book „Project Sherwood“ [7]

> «How, for example, is it possible to create initially a configuration of this type, with sharp boundaries between plasma and field? Is it not essential to begin with a low-density plasma and then raise it up to high values? If so, is not the leakage intolerably great during the transition period until the boundary is formed?»

still the question, how the sharp boundaries between plasma and magnetic field can be established initially or how the high-density plasma in the reaction zone necessary for achieving these sharp boundaries can be reached initially so to speak suddenly. According to the statements of A. S. Bishop on page 140 in connection with pages 144/145 of his book „Project Sherwood“ [7]

> «The problem of producing a sharp initial boundary was, in turn, largely resolved by subsequent developments in shock techniques (see Chapter 15)».

this problem has been solved in principle thereby that before each of the both apexes of the substantially double-conical reaction zone (Fig. 2), a high-density plasma has been generated by means of an arc discharge and has been carried shock-wisely through the apex into the reaction zone (Fig. 2, arrows before the apexes) by means of a magnetic pulse caused by the discharge current of the arc discharge. With this so called shock-technique therefore the (substantially neutral) plasma of ionized reactants and electrons has been produced outside the reaction zone and has been carried then immediately afterwards extremely fast into the reaction zone.

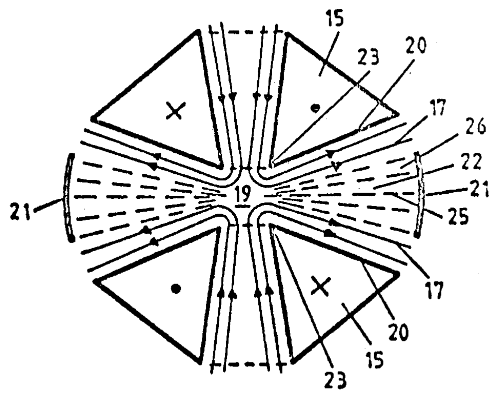

Fig. 6

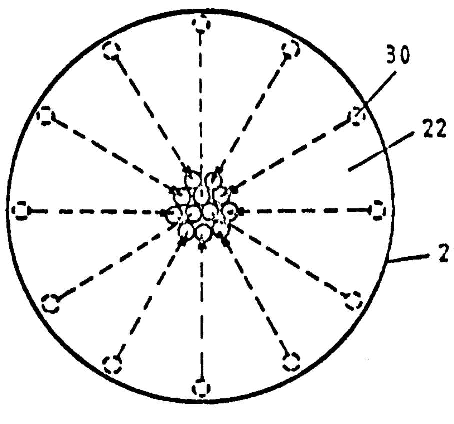

Fig. 7

In contrast, the problem of initially shock-wisely producing a high-density plasma has been solved with the fusion reactor described in the patent in principle thereby that the reaction zone 19 is supplied on the one hand with ionized reactants from a ring-shaped ion source 21 (Fig. 6) arranged at the upper edge of the potential pot 22 and on the other hand with electrons from metallic electrodes having glow-temperature and being arranged in the next surrounding of the reaction zone 19, and that the separately supplied ions and electrons form then only within the reaction zone 19 together the high-density plasma. The high density of the plasma results therewith without special measures only on the base of construction and operation of the reactor practically of itself, because on the one hand the ionized reactants 30 supplied by the ion source 21 concentrate in the center of the potential pot 22 in the reaction zone as shown in Fig. 7 with an ion density of about 1000 times the ion density near the ion source 21 and on the other hand the below 1 kV lying emission potential of the already before switching-on the ion source to about 1300 °K heated metallic electrodes in the next surrounding of the reaction zone (US-Pat., col. 32, l. 56 to 63, in connection with col. 39, l. 3 to 9) as well as the space-charge of the ions in the reaction zone or more exactly the difference in space-charge between ions and electrons in the reaction zone provides for an electron density nearly equal to the respective ion density in the reaction zone. The electron density following after the ion density is thereby, because of the time delay caused by said following as well as because of said emission potential requiring a difference between ion density and electron density, always somewhat lower then the ion density so that a potential tub of about 1 kV depth is formed within the range of the reaction zone where the electrons collect in the center of the reaction zone. The potential tub in connection with the sharp boundary of the plasma by the magnetic field with „Cusped Geometry“ prevents the electrons having only a kinetic energy corresponding to said emission potential from leaving the reaction zone. In the fusion reactor described in the patent, the potential pot therefore provides not only for a practically completely tight plasma con finement within the reaction zone but makes in connection with the ion source at the upper potential pot edge also possible said suddenly producing a high-density plasma in the reaction zone necessary for establishing said sharp boundaries between plasma and magnetic field.

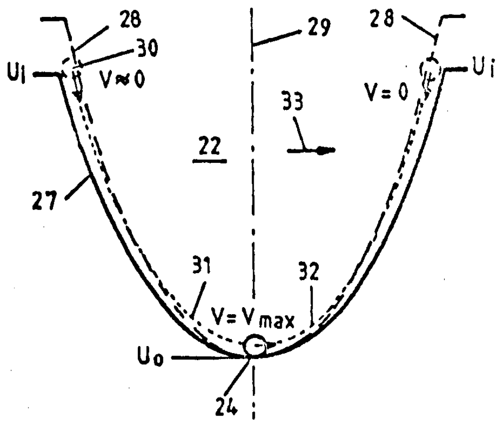

Fig.8

First of all, however, the potential pot in connection with the ion source at the upper potential pot edge serves the purpose of initiating and maintaining the nuclear fusion in the reaction zone : For, the ionized reactants 30 fed to the potential pot 22 by the ion source 21 at the upper potential pot edge are accelerated by the potential drop within the potential pot 22 till a kinetic energy sufficient for fusion so that every reactant entering the reaction zone 19 in the center 24 of potential pot 22 or being within this zone has fusion energy and comes therefore in case of collision with an other reactant to fusion reaction. In case of non-collision with another reactant in the reaction zone, the ionized reactants pass with their high velocity v_{max} corresponding to their high kinetic energy the center 24 of the potential pot 22 and run on the side of the potential pot 22 opposite to their feeding-side against the potential drop with decreasing velocity in the direction to the upper potential pot edge until their kinetic energy shortly before reaching the potential pot edge has been completely converted into potential energy (Fig. 8). This process of accelerated motion in the direction to the center 24 of the potential pot 22 and of succeeding retarded motion in the direction to the upper potential pot edge happens then again and again until collision and fusion reaction with another reactant within the reaction zone, so that a great deal of the ionized reactants fed to the potential pot by the ion source comes to fusion. The potential pot provides therefore also for, that the relatively great mean free path of the ionized reactants until fusion and the relatively long running time until fusion resulting therefrom does not cause problems, i.e. the potential pot excludes therewith also the difficulties with maintaining a plasma at fusion temperature over a time corresponding to said relatively long running time arising on the path till now taken by the fusion research and not yet overcome until now.

As ion source at the upper potential pot edge 38 serves the glow-discharge chamber 37 shown in Fig. 3 which comprises a cathode 39 constructed in principle like a so-called Lenard-window and being therefore pervious to canal rays, this cathode is formed of a thin metallic foil and a cooled support-member supporting the metallic foil and being provided with cylindrical passages for the canal rays. The glow-discharge chamber 37 and the potential pot 22 are separated gas-tightly from each other by this metallic foil so that the gas pressure within each of these both spaces can be adapted to the respective requirements. In the glow discharge chamber, a deuterium-discharge is maintained out of which monatomic deuterium ions pass as canal rays said metallic foil and are therefore supplied to the potential pot 22 and over to the reaction zone 19 as ionized reactants.

The deuterium ions are in a phase of starting-up serving for incubating tritium the only one supplied reactants. Then, in the steady operation, tritium is supplied over the supply-channel 48 as further reactant, which originates from nuclear reactions of neutrons coming from fusion reactions with lithium flowing through the blanket 52 and serving for carrying-off the produced energy. Except of neutrons, the reaction products as well as reactants not attained to reaction are carried-off over the carrying-off channel 49.

The mode of operation of the other reactor parts inclusively the accessory aggregates is specified in the patent and in itself known from nuclear fusion technique and does therefore here not need further explanation.

Finally, it is to emphasize that the elimination of the causes of the greenhouse-effect is a task, the mastering of which cannot – despite all understanding for the above mentioned difficulties of the fusion research – be postponed for further half a century but should started on now immediately on the path shown by the doyen of nuclear fusion, Edward Teller, and for an early start, the present report shall make a contribution.