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The German Fast Breeder Program

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THE GERMAN FAST BREEDER PROGRAM

W. Häfele

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Reactor Physics and Related Safety Problems
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reactors between the European Atomic Energy Community and
Gesellschaft für Kernforschung mbH., Karlsruhe.

1. THE GENERAL PROGRAM

The German fast breeder program started in 1960, when the reactor physics group finished the design work for the Karlsruhe research reactor FR 2. The original approach was characterized by the idea to have not only a fast breeder but also a commercially competitive nuclear power station. This led us immediately into the more detailed examination of the fuel cycle; and our point of departure was then to study the oxide fuel fast breeder concept. The physics of such a reactor is notably different from that of a metal fueled breeder. It was in particular the determination of power coefficients and in this connection, the investigation of the safety features of such a reactor which was of prime importance. And reflecting on the title of this meeting, we feel that it is still of prime importance. It was quite natural therefore, that the first thing in Karlsruhe was the lay-out of a fairly large physics program. From this the constantly increasing engineering studies evolved. Here it was the choice of coolant which was the overriding problem. Attached to this was an experimental engineering program. Parallel to that, we started a fuel element development program which included the construction and operation of the necessary facilities, that is besides the FR 2, a number of hot cells and Pu fabrication facilities and others. At a somewhat later state we emphasized even more strongly R+D work on facilities related to the fuel cycle. Euratom has been associated to this work since 1963. The present association lasts until the end of this year. In the course of the work it was possible to determine more specifically the target of the project: Germany wants to have 1000 MWe fast breeder power stations by 1980. These fast breeder power stations shall be competitive with the light water reactors, then available. The target for the fuel cycle costs is 1 mill/kWh or less, and for the capital cost the target is 100 \$/kW.

In order to arrive at this goal it is necessary to have fast breeder prototype reactors. This class of reactors has to go into construction by 1970 and go into operation by 1974. This gives enough time then for one or even two parallel 1000 MWe demonstration plants. The successful operation of these plants will be the basis for the commercial phase of fast breeder reactors.

Detailed studies of Karlsruhe concluded that sodium and steam have the same industrial potential. The quality of the potential is different though. Na has a potential of a high gain breeder with the associated fuel cost benefit, and high gain breeding is ultimately, say beyond the year 2000, an absolute necessity. We still feel, that capital cost is a problem, the industrial and commercial solution of which can be demonstrated only fairly late in the game. Steam cooled breeder technology on the other hand will directly evolve from present-day light water technology with all the greatly increasing operating experience to come. Please recall that two 600 MWe light water reactor stations have been ordered in Germany a couple of months ago on a clean and competitive basis without any subsidies whatsoever. Associated with steam cooling is a somewhat lower breeding ratio which partly compensates the capital cost advantage with respect to Na plants.

In 1965/66 the important decision has been taken to prepare the early construction of one sodium and one steam cooled fast breeder 300 MWe

prototype in Germany. And at the same time it has been decided that, instead of the national laboratory, industry has to take the lead and the responsibility for these prototypes, because it is industry and not government which shall handle the expected fast breeder market after 1980. Therefore, the Konsortium Siemens-Interatom will bring up the sodium prototype and the group AEG/MAN/GHH will bring up the steam cooled prototype. The Kernforschungszentrum Karlsruhe as a National Laboratory will have a double function: On the one hand it will actively support the industrial work and accept certain tasks in the framework of the direct prototype work. On the other hand Karlsruhe will pursue a basic program under its own responsibility which broadens and strengthens the project work more generally. Therefore the Fast Breeder Project is no longer a Karlsruhe affair, it became a national effort to arrive independently at the competitive stage of reactors of the second generation, that is the fast breeders.

Looking ahead, one realizes that the market for fast breeder reactors will be tremendous and simultaneously it becomes clear that the German national basis is somewhat narrow. Since the last couple of years there has been an intensive contact to both Belgium and the Netherlands, and as a result there will be a three or ultimately even four level joint fast breeder venture. Belgian and Netherlands industrial groups, that is Belgonucleaire and Neratoom, join the Siemens Interatom Group, the national laboratories of these countries, that is Mol and Petten join Karlsruhe, and the three governments have a corresponding agreement which also provides the funds. There is hope that also the electrical utilities of these countries will come to a parallel understanding at a later stage. There is a good chance that Luxemburg will join the group too. A similar arrangement with other partners is under way for the steam cooled breeder.

The Fast Breeder Project which originated at Karlsruhe is therefore a joint venture of a fairly large size. The involved partners agreed in a fair partition of work. In so doing, the larger physics efforts remain at Karlsruhe, in cooperation with Mol and Petten. Keeping also in mind that this meeting here is concentrating more specifically on physics and safety I will do the same and narrow my report down to these topics.

2. EXPERIMENTAL PHYSICS

As it has been mentioned before, it was the investigation of the physics of an oxide fueled fast breeder with its low energy neutron tail that attracted the attention from the very beginning. In 1961 a four step experimental program was envisaged. It is the following:

2.1. SUAK

The pulsed subcritical assembly SUAK makes use of the accumulated experience with 14 MeV pulsed neutrons here at Karlsruhe. The fast assembly allows for decay measurements and spectrum determinations by the time of flight technique. For easier interpretation of measurements only bare assemblies are constructed which also contain as few materials as possible.

So far three assemblies have been investigated. The first assembly consisted of pure uranium (20 % enrichment) only. In the other assemblies different amounts of hydrogen containing material were added to shift the neutrons to lower energies and to study the anisotropic scattering effect of hydrogen in greater detail. The present stage of physics effort at Karlsruhe is concentrating among other things on the effect of the interface between core and blanket. The spectrum in the core is fairly constant with respect to the radius, but in the blanket there are rapid changes of the spectrum with the radius (or z axis). The large mean free path lets this effect penetrate also into the core. The clean geometry of SUAK and the easiness of experimental access enables us to investigate these interface effects at SUAK in the near future. Right now we have a joint French-German venture at SUAK, to compare exponential and pulsed experiments, also by the use of SUAK. This is the program HEUREKA of the Cadarache project. It should be kept in mind that SUAK is not designed for the use of plutonium.

2.2. STARK

The fast-thermal Argonaut reactor was the first critical assembly with fast neutrons on the European continent. The graphite column of the original Argonaut has been replaced by a fast core. Again, only enriched uranium but not plutonium can be used. STARK was of very great help to develop the fast neutron experimental techniques at an early stage, in particular spectrum measurement techniques have been developed. But also a pile oscillator for heated samples and a heated foil furnace for studies of the Doppler effect have been installed. Further, investigation on pulsed sources and with particularly large emphasis on noise analysis techniques came up. This noise analysis is of great help in order to determine the neutron life time and the reactivity features during shut down including the approach to criticality. Parallel to that, the analysis of coupled systems has been carried on. STARK will be persistently of importance to prepare experiments of the larger and more complicated SNEAK machine.

2.3. SNEAK

The fast zero power assembly is a full scale critical facility designed to perform in particular large scale Pu fuel experiments. It went critical on the 15th of December 1966, in the same night when the Cadarache facility MASURCA became critical. SNEAK is comparable not only to MASURCA but to the British zero power reactor ZEBRA and the US ZPPR in Idaho. Physics-oriented experiments are being conducted in the present phase with great emphasis on steam and the involved reactivity coefficients, and the mock up of the two German prototypes will come afterwards. The measurements in SNEAK will ultimately give the physics reference points for the whole German-Belgian-Dutch fast reactor project. You will have a fair amount of detailed information on SNEAK in the course of this meeting.

2.4. SEFOR

The South-West Experimental Fast Oxide Reactor is a joint venture of General Electric and Karlsruhe together with Euratom, the South West Atomic Energy Associates, and the USAEC. As it is well known, it is a 20 Mwth

experimental dynamic test reactor, the construction of which is fairly advanced. First criticality is expected for the early summer of next year. The objective of this reactor experiment is to obtain information on the dynamic behaviour of oxide fueled fast breeders, particularly the Doppler coefficient, under operating conditions. At the same time one acquires engineering experience on a significant scale. The experimental program provides for four distinct steps

- a) static tests
- b) oscillator and balanced oscillator tests
- c) sub prompt critical excursions
- d) prompt critical excursions.

At the recent Cadarache meeting there has been a fairly large paper on SEFOR reporting the latest stage of the work.

2.5. KRITO

KRITO is at present a thermal critical facility at the Netherlands nuclear research center of Petten. In the framework of the joint Karlsruhe-Mol-Petten program Petten will transfer this facility into a coupled facility in order to investigate the reactivity influence of the fission products. More on this subject will be presented directly by the Petten group.

The reactor physics of fission products has been neglected for quite some time. This stems from the early days of a very hard spectrum and comparatively low burn ups. But fast ceramic reactors of a high burn-up do have a considerable fission product poisoning which decreases not only reactivity but also breeding with the consequence that fuel costs are increasing again beyond a certain amount of burn-up as it is the case with thermal reactors. Thermal reactors have their optimum around 30 000 MWd/to, large fast oxide reactors seem to have their optimum somewhere near 100 000 MWd/to. More precise information on fission product cross sections is necessary to give more accurate evaluations.

2.6. Van de Graaff Accelerator

In Karlsruhe a 3 MeV Van de Graaff accelerator with a bunching facility is used for cross section measurements in the fast breeder project. The experimental program is concerned with the measurement of capture cross sections of structural material and fission products in the energy range of 10 - 200 keV. Also fission cross sections of the plutonium isotopes 239 , 240 , and 241 are measured. Further effort is under way for absolute measurements of cross sections and neutron fluxes as well as for self-shielding factors and resonances in the keV energy region. It may be mentioned in this connection that cross sections of shielding materials are studied in the MeV-range by the use of the Karlsruhe cyclotron.

3. REACTOR THEORY

Reactor theory has always been a field of special interest at Karlsruhe. As a matter of fact, reactor theory was the door to enter the fast reactor field here at Karlsruhe. Looking backward one can recognize a number of phases in the development of fast reactor theory. Originally, one-dimensional diffusion theory with 11 or 13 groups was applied for calculating

critical masses or enrichments, the spectra in core and blanket, and breeding ratios. Very soon the emphasis on the lower end of the spectrum led into a larger number of groups and the evaluation of energy self shielding effects. One should recall that there are only about 10% of all fissions below 10 keV where most of the power coefficients originate. S_N versions and other transport techniques were introduced in the multi-group procedures somewhat later.

The next round was concentrating on the calculation of the Doppler and coolant void effects. More extended perturbation codes had to be developed for this, and a detailed examination of the resonances of the neutron cross sections was necessary. The more realistic evaluation of the Na void coefficient necessitated two-dimensional calculations. In addition to the diffusion and S_N codes in two dimensions, group collapsing procedures had to be developed for this two-dimensional procedure. Multizone arrangements in core and blanket also required two-dimensional procedures. The preparation of self-shielded cross-sections, including heterogeneity-effects, one-dimensional calculations with very many groups (say 26, 60 or more), group condensation in different regions of the reactor, two-dimensional calculations with a few groups (6 or so) perturbation theory, the calculation of reaction rates, the calculation of power coefficients and neutron lifetime, and the one-dimensional burn-up code have been put together into one super-code, the Karlsruhe NUSYS system. This code has been the basis for all design work at Karlsruhe and the German industrial groups during the last two years. Emphasis is now being put on the transport effects in the region of scattering resonances. Besides applying the well-known ELMOE code, a new technique using about 200 groups is being developed.

In a third round of effort attention is concentrating on the non-idealized actual power reactor. The influence of fission products is being studied in detail, also the influence and burn-up of control rods, two-dimensional power distributions with control rods, the proper distribution of control rods, the influence of burn-up on the reactor behaviour, the change of the Na void coefficient and breeding ratio with control rod insertion and fuel burn-up, the change of power distribution with plutonium build-up in the blanket, the calculation of the different temperature coefficients in different regions of the reactor, and more engineering details are being studied. We also envisage the large-scale application of Monte Carlo techniques, for example in order to calculate streaming effects. These more elaborate and partially cumbersome procedures are mandatory for a responsible prototype design and describe to some extent the present state of the art at Karlsruhe. Fast reactor theory and calculation may arrive at its asymptotic stage if all these steps are combined into an even larger code, and ultimately we have to look for three-dimensional calculations, when power stretching is required to reach full competitiveness. As of today, explicit three-dimensional calculations will not be available at Karlsruhe for more direct design of the prototype reactors, but they will be there in time to calculate best core-blanket management schemes and control rod operation programs. We are aware of the fact that a computer of the IBM 360/91 size will be necessary for this, whereas for the prototype calculations as described above a computer of the IBM 360/65

size can handle the supercodes exceeding NUSYS. Such machines will be installed at Karlsruhe next year.

4. REACTOR SAFETY

Reactor safety is as old a concern as reactor theory and it is intimately related to it. Fast reactor safety is particularly challenging, because the configuration of an actual fast reactor is not the one with the highest reactivity, contrary to the situation with thermal reactors. In the old days it was the melt-down accident which attracted the greatest attention. Loss of sodium reduced the reactivity of the original core configuration, and it was the slow core melt-down without additional neutrons which destroyed the core and could have led to a second configuration of much higher reactivity and therefore to an extreme power excursion with subsequent production of large amounts of mechanical energy.

Large fast ceramic power reactors have a region with a positive coolant void coefficient in the inner part of the core. If the coolant is lost the production of neutrons is enhanced, and the destruction of the core is combined with the power excursion and the subsequent production of mechanical energy. Parallel to that one has to consider now the large inventories of plutonium of these fast breeders, together with the formerly unusual sizes of 1000 MWe. This leads into new orders of radiological concern. It is our conclusion that these hypothetical disasters produce mechanical energies of not much more than 1000 MWsec, even if extreme measures to obtain a small Na void reactivity effect like pancaking are not taken. 1000 MWsec is a limited figure and this is so because of the Doppler coefficient. As a matter of fact, this seems to be the most important benefit from having the Doppler coefficient. Rather sophisticated versions of the Bethe-Tait technique are now available at Karlsruhe, taking into account the cylindrical geometry and the axial structure of subassemblies, also a fair amount of work is going on to determine the equation of state for the mixed oxide fuel.

It seems to be possible to contain 1000 MWsec in a reactor building. Enjoying also the experience from SEFOR safety and licensing procedures we arrived at the two-containment concept, having an inner concrete containment around the reactor and the primary circuit which is nitrogen filled and designed to withstand the 1000 MWsec event but having only a 10 % tightness. Therefore a second containment which is of high tightness and houses the rest of the reactor installation is being planned.

The 1000 MWsec event can happen more or less only if the safety system fails completely. Measures of diversity and redundancy can avoid such a malfunction practically completely. There are a limited number of events like sodium voiding after a break in the primary circuit and subsequent melt-down which cannot be affected by a functioning safety system. Therefore a safe and reliable design of the primary circuit comes out to be equally important as the design of the safety system itself. But we do hope to arrive ultimately at a situation of engineered safeguards including that of the primary circuit. In such a case no reactor containment but an ordinary building is necessary. We are not confident enough to

design such all-out engineered safeguards already for the Na and steam cooled prototypes. Much more work on engineering components testing is required for that. In order to prepare this we started some time ago an effort on the mathematics and statistics of reliability and availability which is quite an exciting new area. In so doing we hope to identify the schemes and fields of excessive engineering testing thus ultimately arriving at the concept of engineered safeguards eventually to be applied to our 1000 MWe demonstration plants of about 1975/6.

Besides we will pursue a number of more obvious tasks in the field of reactor safety like aerosol research, the radiochemistry of primary circuit contamination in the case of steam cooled breeders, iodine filtering, and others.

Fast reactor physics and safety is becoming more and more a mature business which requires large-scale ventures with all features of being a field of big science.

But this will enable us to have a responsible prototype design by 1970.

References

- [1] DOSCH, P.: Leistungsschwingungen eines Reaktors im prompt-kritischen Gebiet bei rampenförmigen Reaktivitätsstörungen, Nukleonik, 4 (1962), Heft 6, 258-263
- [2] ENGELMANN, P.: Fission Gas Pressure Buildup and Fast Breeder Economy, Vienna 1961, 2 (1962), 229-245, SM-18/3
- [3] HÄFELE, W., WIRTZ, K.: Approaches to the Development of a Fast Breeder Reactor, Proc. FORATOM Conf. Paris 1962
- [4] HÄFELE, W.: The Effective Lifetime and Temperature Coefficient in a Coupled Fast Thermal Reactor, Vienna 1961, 3 (1962), 19-32, SM-18/1
- [5] HÄFELE, W.; WIRTZ, K.: Ansätze zur Entwicklung eines Schnellen Brutreaktors, Atomwirtschaft 7 (1962), 557
- [6] HÄFELE, W.: Die Bedeutung kernphysikalischer Grundlagen bei der Auslegung schneller Brutreaktoren. Phys. Verh. VDPG 2, Heft 9 (1962), KFK-118
- [7] OTT, K., JANSEN, A.: Long-Time Behaviour of Fast Breeders. Proceedings of the Seminar on the Physics of Fast and Intermediate Reactors, IAEA Vienna 1961, 2 (1962), 213-228, SM-18/2
- [8] SCHMIDT, J.J.: Nuclear Data Requirements for Fast and Intermediate Reactor Calculations. Proceedings of the Seminar on the Physics of Fast and Intermediate Reactors, by the IAEA, Vienna 1961, 1 (1962), 3-20, SM-18/4
- [9] SCHMIDT, J.J.: Neutron Cross Sections for Fast Reactor Materials Part I: Theory and Compilation, Part II: Tables, Part III: Graphs KFK-Report 120 and EANDC-E 35 (U), 1962
- [10] BÖHM, H.: Parameter Dependence of the After-Meltdown Accidents. Proc. of the Conference on Breeding, Economics, and Safety in Large Fast Power Reactors, ANL-6802, Argonne 1963
- [11] BORGWALDT, H.: Bestimmung der Extrapolationslänge schneller Reaktoren in der Mehrgruppen- P_1 -Näherung, Nukleonik 5 (1963), Heft 1, 27-31
- [12] BORGWALDT, H., SANITZ, D.: Die Impulskorrelation zweier Neutronendetektoren im stationären Reaktor, Nukleonik 5 (1963), Heft 6, 239
- [13] DOSCH, P.: Regelung und Instrumentierung von schnellen Reaktoren, ATM März 1963, R 25-36, Lieferung 326, KFK-146

- [14] DOSCH, P., KRAUS, H.J., UHRIG, H.: Design and Experimental Evaluation of an Electromagnetic Acceleration System for Fast Safety Rods, Proceedings of the "Symposium on Physics and Material Problems of Reactor Control Rods", IAEA Wien 1963, SM-46/8
- [15] FRAUDE, A.: Über den Einfluß eines prompten negativen Temperaturkoeffizienten auf das Verhalten eines schnellen Reaktors nach einem Reaktivitätssprung, Nukleonik 5 (1963) Heft 7, 290-293; KFK-186 (1963)
- [16] FRAUDE, A.: Über eine Lösung der kinetischen Gleichungen bei periodischen Reaktivitätsänderungen. KFK-144 (1963); Nukleonik 5 (1963), p. 62
- [17] FRÖHLICH, R., OTT, K., SCHMIDT, J.J.: Dependence of Fast Reactor Doppler-Coefficients on Nuclear Data Uncertainties, Proceedings of the "Conference on Breeding Economics and Safety in Large Fast Power Reactors", Argonne 1963, ANL-6802
- [18] FRÖHLICH, R., OTT, K., SCHMIDT, J.J.: Calculations of Doppler-Coefficients of Dilute Fast Reactors, ANL-6792, p. 777 (1963)
- [19] HÄFELE, W.: Das Projekt Schneller Brüter, Atomwirtschaft 8 (1963), Heft 4, p. 206
- [20] HÄFELE, W.: Prompt überkritische Leistungsexkursionen in schnellen Reaktoren, Nukleonik 5 (1963) Heft 5, p. 201, KFK-175
- [21] HÄFELE, W.: Principles and Problems of the Development of a Fast Reactor Fuel Element ANL-6792, Argonne 1963
- [22] KUNZE, H.: On the Theory of Space-Dependent Neutron Spectra in Heterogeneous Reactors, KFK-137
- [23] OTT, K.: Theoretical Methods available for Calculation of Neutron Spectra, EAES-Symposium on Fast and Epithermal Neutron Spectra in Reactors, Harwell, December 1963
- [24] OTT, K., SCHROETER, K.E.: Comparison of Doppler and Na-Void-Coefficients of Dilute Fast Reactors, ANL-6792, Argonne 1963
- [25] OTT, K.: Theorie verzögerter überkritischer Exkursionen zur Messung der Doppler-Koeffizienten schneller Reaktoren, Nukleonik 5, 1963, Heft 7, 285-290, English: KFK-153 (1963)
- [26] SCHMIDT, J.J.: Nuclear Physics Work at Karlsruhe Related to the Fast Breeder Reactor Project, Report EANDC, ECSR/P. 17 (1963)

- [27] SCHMIDT, J.J., OTT, K., FRÖHLICH, R.: I. Dependence of Fast Reactor Doppler Coefficients on Nuclear Data Uncertainties. II. Calculation of Doppler Coefficients of Dilute Fast Reactors, Proc. Conf. on Breeding, Economics and Safety in Large, Fast Power Reactors, Argonne, ANL-6802, Oct. 1963
- [28] SMIDT, D.: Optimization and Safety of Helium Cooled Fast Breeders, Argonne Conference 1963, ANL-6792
- [29] SMIDT, D.: Parameterstudien an gasgekühlten schnellen Reaktoren, Nukleonik 5 (1963) Heft 8, p. 353
- [30] BECKURTS, K.H., HÄFELE, W., et al.: The Karlsruhe Fast-Thermal Argonaut Reactor Concept, KFK-217
- [31] CALDAROLA, L.: A New Type of Oscillator Experiment. The Balanced Oscillator Experiment to Measure Doppler Reactivity Coefficients and Thermal Parameters of Fuel Rod in Fast Reactors, Nukleonik, 7 Heft 3, 1965, p. 120, KFK-253
- [32] CALDAROLA, L., SCHLECHTENDAHL, G.: Reactor Temperature Transients with Spatial Variables - First Part: Radial Analysis, KFK-223
- [33] CALDAROLA, L., HÄFELE, W., SCHIKARSKI, W.: Experiments to Evaluate Reactivity Coefficients with Reactor Operating at Steady State Conditions (Static Experiment), KFK-260
- [34] FRÖHLICH, R.: Eine verallgemeinerte Galerkin-Methode zur numerischen Lösung der Neutronentransportgleichung, Nukleonik 6 (1964), Heft 4, p. 211
- [35] HÄFELE, W., et al.: Das Karlsruher Projekt Schneller Brüter, 3. Int. Conf. on the Peaceful Uses of Atomic Energy, Geneva, A/Conf/28/p.539
- [36] HÄFELE, W., ENGELMANN, P.: Fast Reactor Programs - Ein Bericht über die Arbeiten auf dem Gebiet der Schnellen Reaktoren - 3. Genfer Konferenz, ANS Nuclear News, Vol. 7, Nr. 10 (1964) Atomwirtschaft, Heft 11 (1964), p. 541
- [37] HÄFELE, W., OTT, K., CALDAROLA, L., et al.: Statische und dynamische Experimente zur Bestimmung des Doppler-Effekts in einem schnellen Versuchsreaktor, 3. International Conference on the Peaceful Uses of Atomic Energy, Geneva, A/Conf/28/p.644
- [38] JANSEN, A., OTT, K., et al.: The Karlsruhe Fast Breeder Project. 3. Int. Conf. on the Peaceful Uses of Atomic Energy, Geneva, A/Conf/28/p.539
- [39] SMIDT, D., MÜLLER, A.: Reaktortechnik auf der 3. UN International Conference on the Peaceful Uses of Atomic Energy, Atomwirtschaft, Heft 11 (1964), p. 545

- [40] SMIDT, D., et al.: 1000 MWe Na-gekühlter Schneller Brüter (Na-1), KFK-299
- [41] BORGWALDT, H., STEGEMANN, D.: A Common Theory for Neutronic Noise Analysis Experiments in Nuclear Reactors, Nukleonik 7, Heft 6 (1965) p. 313, KFK-363
- [42] CALDAROLA, L.: The Balanced Oscillator Experiment, Nukleonik 7, Heft 3, 1965, p. 120
- [43] ENGELMANN, P.: Das Verhalten Schneller Nulleistungsreaktoren bei Reaktivitätsstörungen, KFK-332
- [44] FISCHER, M., HÄFELE, W.: Shock Front Conditions in Two-Phase Flow Including the Case of Desuperheat, Argonne-Konferenz, 1965
- [45] FRÖLICH, R.: Theorie der Dopplerkoeffizienten schneller Reaktoren unter Berücksichtigung der gegenseitigen Abschirmung der Resonanzen, KFK-367
- [46] FRÖLICH, R. OTT, K.: About the Influence of Resonance Overlapping on Calculated Doppler-Coefficients of Fast Reactors, Nuclear Science and Engineering 22 (1965) p. 490
- [47] FRÖLICH, R., OTT, K.: Results of Doppler Coefficient Calculations for Fast Reactors and Comparison of Different Methods, Argonne-Conference, 1965, ANL 7120
- [48] HÄFELE, SMIDT, D., WIRTZ, K.: The Karlsruhe Reference Design of a 1000 MWe Sodium Cooled Fast Breeder Reactor, Argonne-Conference, 1965, KFK-369
- [49] MÖLLER, U.: Monte-Carlo-Methoden, Wiss.Zeitsch.d.Univ.Rostock 14 (1965) Math.-Nat.Reihe, Heft 3/4, p. 329
- [50] MÖLLER, U.: Lösung der Transportgleichung mit Hilfe der Monte-Carlo-Methode, KFK-297
- [51] MÖLLER, U.: Unterprogramme zur Lösung neutronenphysikalischer Probleme mit Hilfe der Monte-Carlo-Methode, KFK-298
- [52] KIEFHABER, E., SCHROETER, K.E.: Calculation for Intercomparison to be made at Conference on Safety, Fuels and Core Design in Large Fast Power Reactors, cf. lecture by J.Okrent, Argonne-Conf., 1965, ANL 7120
- [53] KIEFHABER, E., OTT, K.: Survey Parameter Study of Large Steam-cooled Fast Power Reactors, Argonne-Conf., 1965, ANL 7120
- [54] KIEFHABER, E., OTT, K.: Interpolationsformel für Selbstabschirmfaktoren, KFK-384

- [55] KÜSTERS, H., METZENROTH, M.: The Influence of Some Important Group-Constants on Integral Fast Reactor Quantities, Argonne-Conf., 1965, ANL 7120
- [56] KÜSTERS, H.: Theorie der Neutronenthalisierung in einer zylindersymmetrischen Zwei-Zonen-Reaktorzelle, Nukleonik 7, Heft 3 (1965), p. 130
- [57] KUNZE, H.: Eigenwertprobleme der Reaktorthorie und Raumgruppen, Nukleonik 7, Heft 8 (1965), p. 429
- [58] OTT, K.: Theoretical Methods Available for Calculation of Fast and Epithermal Neutron Spectra, Nukleonik 7, Heft 3 (1965), p. 161
- [59] SMIDT, D., et al.: Safety and Cost Analyses of a 1000 MWe Sodium Cooled Fast Power Reactor, Argonne-Conf., 1965
- [60] SMIDT, D., SOMMER, W.: Application of the Vented Fuel Concept to a Sodium Cooled Power Breeder with 1000 MWe, Argonne-Conf., 1965
- [61] AULOUX, M., CALDAROLA, L., et al.: The Balanced Oscillator Tests in SEFOR, Int.Conf. on Fast Critical Experiments and their Analysis, Argonne, 1966
- [62] BRAESS, D., FRÖLICH, R., JANSEN, A., KÜSTERS, H., et al.: The Calculation of Large Fast Reactors, London Conf. on Fast Breeder Reactors, 1966
- [63] CALDAROLA, L., HÄFELE, W., SCHIKARSKI, W.: Experiments to Evaluate Reactivity Coefficients with Reactor Operating at Steady State Conditions (Static-Experiments), KFK-260, 1966
- [64] CALDAROLA, L., TAVOSANIS, M.: Design Criteria and Preliminary Calculations of SEFOR Second and Third Core"
- [65] DALLE DONNE, M.: A New And simple Method of Estimating the Liquid Superheat due to Surface Conditions in Nucleate Boiling and its Application of Sodium, Nukleonik 8, Heft 3, 1966, p.133
- [66] DALLE DONNE, M.: Comparison of He, CO₂, and Steam as Coolants of a 1000 MWe Fast Reactor, KFK-447
- [67] ENGELMANN, P.: Untersuchungen über das inhärente dynamische Verhalten schneller Nulleistungsreaktoren bei Reaktivitätsstörungen, Nukleonik, 8, Heft 3, 1966, p. 152

- [68] ENGELMANN, P., et al.: Initial Experiments in the Karlsruhe Fast Critical Facility, SNEAK, Int. Conf. on Fast Critical Experiments and their Analysis, Argonne, 1966, KFK-472
- [69] FISCHER, E.A.: Interpretation of Doppler Coefficient Measurements in Fast Critical Assemblies, Int. Conf. on Fast Critical Experiments and their Analysis, Argonne, 1966, KFK-473.
- [70] FISCHER, E.A.: The Overlap Effect of Resonances of Different Fuel Isotopes in Doppler-Coefficient Calculations for Fast Reactors, Nukleonik, 8, Heft 3, 1966, p. 146
- [71] FISCHER, E.A., KELLER, K.: Einfluß der Entmischung von oxydischem Brennstoff auf den Verlauf von Leistungsexkursionen in schnellen Reaktoren, die durch den Dopplerkoeffizienten abgefangen werden, Nukleonik 8, Heft 8, 1966, p. 471
- [72] FRÖLICH, R., OTT, K.: Einfluß von Festkörpereigenschaften auf die Berechnung des Dopplerkoeffizienten, Nukleonik 8, Heft 3, 1966, p. 137
- [73] GRASS, G., KOTTOWSKI, H., MILLIOT, B.: Beitrag zur Untersuchung des Siedens von Flüssigmetallen bei erzwungener Korrektur, Nukleonik 8, Heft 5, 273 (1966)
- [74] HÄFELE, W.: Schnelle Brutreaktoren, ihr Prinzip, ihre Entwicklung und ihre Rolle in einer Kernenergiewirtschaft, KFK-480
- [75] HÄFELE, W.: Safety of Large Fast Reactors - A Round-Table Discussion, Nucleonics 24, Feb. 1966, p. 62
- [76] HÄFELE, W.: Das Prinzip des Brütens, und Das Projekt Schneller Brüter Karlsruhe, Atomwirtschaft 11 (1966) Nr. 6, p. 290, 293
- [77] HÄFELE, W.: Zur Entwicklung der Schnellen Brutreaktoren, Brennstoff-Wärme-Kraft 18 (1966) Nr. 6
- [78] KÖHLER, W.H.: Variational Method for Prompt Neutron Kinetics, Nukleonik 8, 1966, Heft 4, p. 203
- [79] KÜSTERS, H.: Bericht über die London Conference on Fast Breeder Reactors im Mai 1966, Atomwirtschaft 11 (1966), p. 6
- [80] KÜSTERS, H.: Bericht über die Argonne Konferenz über Sicherheit, nukleare Auslegung und Wirtschaftlichkeit schneller Reaktoren Argonne 1965, Atomwirtschaft 11 (1966), p.3

- [81] MATTHES, W.: Theory of Fluctuations in Neutron Fields, Nukleonik 8, Heft 2 (1966), p. 87
- [82] MÜLLER, A., et al.: Referenzstudie für einen dampfgekühlten Schnellen Brutreaktor (D-1), KFK-392 (1966)
- [83] PÖNITZ, W.: Bestimmung von s- und p-Wellen-Stärkefunktionen aus dem Isomerenverhältnis nach dem Einfang mittelschwerer Neutronen, Physikertagung Freudenstadt 1966
- [84] SCHMIDT, J.J.: Principles and Problems in Neutron Nuclear, Data Evaluation, Proc. IAEA Conf. on Nuclear Data for Reactors, Paris 1966 (Paper CN-23/124), KFK-457
- [85] SMILIT, D.: Die Londoner Konferenz über Schnelle Brutreaktoree, Atomwirtschaft II (1966) Nr. 6, p. 308
- [86] BICKEL, W., et al.: Safety Considerations for the Karlsruhe Fast Critical Facility SNEAK, Int. Conf. on Safety of Fast Breeders, Aix-en-Provence 1967
- [87] BRAESS, D., et al.: Safety Features of a Sodium Cooled Fast Breeder Reactor of 300 MWe (Na-2), Aix-en-Provence 1967 Int.Conf.
- [88] BRAESS, D., et al.: Improvement in Second Excursion Calculations, Aix-en-Provence 1967 Int.Conf. on Safety of Fast Breeders
- [89] CALDAROLA, L., RUSSELL, C.: The Second Balanced Oscillator Experiment, Nukleonik 9, Heft 7, 1967, p. 323
- [90] CALDAROLA, L.: Analysis of Reactor Power Excursion by Means of Solutions with Asymptotic Expansion, Nukleonik 9 (1967), Heft 3, p. 129
- [91] EDELMANN, M., MURLEY, T.E., STEGEMANN, D.: Investigation of Prompt Neutron Kinetics in the Fast-Thermal Argonaut-Reactor STARK by Noise Analysis, KFK-522 (1967)
- [92] ENGELMANN, P.: Physikalische Aufgaben für SNEAK, Atomwirtschaft XII, Nr. 4, 1967
- [93] ERBACHER, F.J., et al.: Influence of the Design and Arrangement of the Components in Various Cycles on the Safety of Steam Cooled Reactors, Aix-en-Provence 1967
- [94] FISCHER, E.A.: Bemerkungen zur Bedeutung des adjungierten Flusses in der Raaktortechnik, Nukleonik 9, Heft 7, 1967, p. 332
- [95] FISCHER, M., et al.: Safety Aspects of Steam Cooled Fast Breeder Reactors, Int.Conf. on Safety of Fast Breeders, Aix-en-Provence 1967
- [96] GAST, K., SCHIKARSKI, W.: Containment of a large sodium-cooled fast breeder reactor, KFK-547

- [97] GAST, K., et al.: Na-2 Design (300 MW German FCR),
ANS Conf. on Fast Reactors, San Francisco, 1967
- [98] GUPTA, D., HÄFELE, W., KUMMERER, K., et al.: Third Foratom
Congress London, German Contributions to Sessions I,II,III,
IV, VI,
KFK-546 (1967)
- [99] HELLER, F., HÄFELE, W., SCHIKARSKI, W.: The Principles of
Double Containment and the Behavior of Aerosols in its
Relation to the Safety of Reactors with a High Plutonium
Inventory,
Int. Conf. on Safety of Fast Breeders, Aix-en-Provence,
1967
- [100] PEPPLER, W., et al.: Sodium Boiling and Fast Reactor Safety,
Int. Conf. on Safety of Fast Breeders, Aix-en-Provence 1967
- [101] SCHIKARSKI, W.: Überlegungen zu schweren Reaktorunfällen,
KFK-530
- [102] SCHLECHTENDAHL, E.G.: Sicherheitsaspekte schneller Reaktoren,
VDI-Nachr. 21/21, 1967
- [103] SCHRÖDER, R.: Zur Simulation von Spaltprodukten in schnellen,
kritischen Anordnungen, Nukleonik 10, Heft 1, Juni 1967, S.18
- [104] SEIFRITZ, W., STEGEMANN, D.: Ein Zwei-Detektor-Kreuzkorrela-
tionsexperiment zur Bestimmung von Reaktorparametern aus dem
Neutronenrauschen, Nukleonik 9, Heft 4, p. 169 ff (1967)
- [105] SEIFRITZ, W., STEGEMANN, D.: An On-Line Reactivity Meter Using the
Two-Detector Cross-Correlation Technique for Shutdown Reactivi-
ty Measurements,
Transactions Am.Nucl.Soc. 10, No. 1, 283 (1967)
- [106] SMIDT, D.: 3rd Foratom-Kongress in London, Industrielle Aspekte
eines Programms für schnelle Brutreaktoren,
Atomwirtschaft, 1967
- [107] SMILT, D., et al.: Na-2. Entwurfsstudie für einen 300 MWe Na-
gekühlten Schnellen Brutreaktor,
KFK-660, in print

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