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STATUS REVIEW OF THE KEWB PROGRAM

by

J. W. Flora

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I. INTRODUCTION

The purpose of this memorandum is to present a review of KEWB (Kinetic Experiments on Water Boilers) program - the objectives, the accomplishments and a summary of the work outstanding.

The program was initiated at the request and with the support of the Atomic Energy Commission in October, 1954. The objectives of the experimental and analytical studies were to investigate and reach an understanding of the kinetic behavior of aqueous homogeneous reactors typified by the title "Water Boilers". Sufficient information was not available on the potential hazards offered by such assemblies to evaluate the consequences of abnormal operation. Prospective location of this reactor type in highly populated areas emphasized the immediate need for the study. Obtaining the information required to assess a specific reactor design was delineated as the initial objective of the program. A prototype of the 50 kilowatt reactor was constructed. All design details considered to have a bearing on the kinetics of the reactor were duplicated in the test prototype with one exception. Destructive tests were considered of doubtful value, and it was deemed advisable to construct the prototype to withstand internal pressures which might lead to failure of the reference design. Accordingly, increased core vessel thickness of the prototype was allowed as the single important departure from the actual reactor design.

Design of the experimental facility was completed in a period of seven months, and the facility was occupied eleven months after initiation of the program. Reactor components and all auxiliary apparatus were installed during the ensuing nine months, one of which was required to evaluate the suitability of the dynamic pressure detectors selected to record sharp wave front explosion pressures. Inadequacies of the instruments revealed in this investigation, and the unavailability of acceptable replacements, subsequently led to the inauguration of a complementary program aimed at obtaining suitable pressure transducers.

The reactor was made critical in July, 1956. The physical constants of the reactor were thoroughly examined and transient experiments then

undertaken. Principal attention during the kinetic tests has been given to the following parameters: amount and rate of reactivity insertion (to a maximum of 4% Δk), initial core pressure and temperature, and void volume in the core vessel. The remaining parameter of importance, initial power, has yet to be investigated. Extension of measurements related to some of the other parameters are also outstanding. The response of the gas recombination system, in terms of magnitude of the explosion pressures which it initiates, similarly remains to be determined. In all, it is considered that experiments on the prototype 50 kilowatt spherical core are approximately 85% complete.

The reactor planning and testing phase of the program presently represents an investment of \$1.5 million. The instrumentation development program, which will reach culmination within the current fiscal year, represents an additional \$160,000.

II. INFORMATION PRODUCED BY THE PROGRAM

The 500 static measurements and 650 excursions that have been conducted on the reactor have produced innumerable substantive facts. Qualitatively, the behavior of the reactor is now quite well understood. The knowledge required to predict the behavior of this type of assembly accurately is, however, not yet available. Although significant progress toward the latter objective has been made, particularly of late, the basic obstruction in the attempt to predict the dynamic behavior of the reactor is the inability to account for the microscopic origin and subsequent growth of gaseous voids in the fuel solution. This phenomenon indisputably accounts for reactor shutdown in the most severe excursions, while ironically producing a major source of hazard. Shutdown of the reactor results from expansion of the fuel solution which enhances neutron leakage and thus lowers the multiplication of the assembly. The expansion required in transients resulting from large reactivity inputs is accomplished principally by the production of radiolytic gas within the solution. This expansion occurs so rapidly that a pressure wave is impressed upon the reactor core vessel. Since containment of fission products is the prime consideration in hazard evaluations this pressure wave cannot be tolerated if the magnitude is such

that the integrity of the core vessel may be compromised. Hence, it is necessary to understand thoroughly the details of the generation of these gaseous voids - their origin, their growth history, and their character at all times during their evolution. Without this information the analysis of potential hazards of homogeneous reactors must rest largely on empirical data, which allows virtually no latitude in application of the data to systems other than the equivalent of the test prototype.

The information generated in the program can be summarized in a series of qualitative statements. A detailed list of such statements appears in Appendix A; the most significant of these points are discussed in the following paragraphs.

A. Experimental

1. The power vs. period performance of the reactor is unaffected by reactor produced pressures.

This fact leads to the conclusion that the gaseous voids which produce reactor shutdown in fast (≤ 20 millisecond periods) transients must have high internal pressures. If this were not the case, the appearance of expansion pressures would be accompanied by a reduction in the void volume in the fuel solution. Power augmentation would result. Pressures in excess of 30 atmospheres have been observed with no evidence of resulting diminution of size of the gaseous voids. It must be concluded that the bubbles which exist are in a size range that permits surface tension to exert very large collapsing forces, thus causing high internal pressures. This is a fundamental discrepancy, however, in that these small bubbles are observed to grow, which is thermodynamically forbidden in the medium in which they are found. The observed growth could not occur according to any currently accepted theory.

2. Radiolytic gas bubbles which produce voids are formed with increasing efficiency as the reactor period is decreased.

This statement reflects a most significant advance in the technology of aqueous homogeneous reactor kinetics. Before the data which led to this observation became available the only manner of treating gas generated voids in calculations of dynamic reactor behavior was to assume

a fixed fraction of the gas produced appeared instantaneously. Early in the KEWB program it became apparent that during long period excursions the maximum rate of void production did not coincide with maximum power generation, which would be the case if the assumption used for the calculations was correct. Moreover, the time increment between maximum power and maximum gas evolution could be measured in seconds. The obvious conclusion was that the system might well devoid itself of the valuable effects of radiolytic gas production as the time duration of the excursion was decreased - unless this phenomenon demonstrated a sensitivity to other reactor parameters. The latter has now been shown to be the case, and short period excursions are known to be primarily gas-controlled.

3. Ignition of the gas phase may accompany a power excursion.

On several occasions the hydrogen-oxygen atmosphere in the core vessel has been ignited during a power excursion. In the course of these experiments the gas recombination system, which has a natural ignition source in the form of the platinized-alumina catalyst agent, could not communicate with the core vessel. It has been deduced that the gas was ignited by small amounts of uranium residing in the core vessel, but not in solution form. This situation can occur during a large power excursion wherever there is the possibility of uranium entrainment within the high flux region of the reactor. During a power transient the isolated uranium is heated to the ignition temperature, which is approximately 1,000°F for the normal reactor atmosphere conditions. The significant point regarding this experimental evidence is that the explosion pressure maximum occurred within 25 milliseconds of the maximum expansion pressure. Hence, it is necessary to consider the possibility of augmentation of the expansion pressure by the explosion wave when evaluating the required strength of the core vessel.

4. Maximum expansion and impact pressures are inversely proportional to the square of the reactor period.

Two types of pressure pulses resulting from fuel solution action have been observed. The first detected during any transient is that arising directly from the evolution of gas within the fuel solution. This expan-

sion pressure causes acceleration of the solution in ^{to} the unoccupied upper region of the vessel and impact on the container wall results. The initial impact gives rise to a reflected wave which impinges on the lower portions of the vessel. The wave is frequently propagated back to its origin, sometimes enhanced in magnitude. The maxima of the original expansion and the impact pressures have been found to be a function of the inverse square of the reactor period. This relation holds for either a completely filled sphere or the conventional 15 per cent underfull loading.

5. A region of fuel volume exists wherein the magnitude of the maximum pressure developed during a transient becomes a sharply varying function.

During an investigation of the effect of initial void volume in the core it was determined that, over a very confined region, this parameter had a pronounced effect on the maximum pressures developed. An initial loading of 12.6 liters of fuel solution resulted in a 50% increase over the pressures detected with loadings differing from this amount by 1%. This "resonance" is believed due to the acoustical characteristics of the core vessel.

B. Theoretical

Conclusions which may be drawn as a result of the effort to interpret the results of the experiments theoretically are not as numerous as the experimental observations themselves. This is due chiefly to the fact that only during recent phases of the program has enough information been available (1) to indicate the most profitable avenues of exploration in the analytical work, (2) to calculate instantaneous reactivity values over the wide range of dynamic conditions, and (3) to test the conclusions drawn from some of the theories believed appropriate. Progress has been substantial, however, in recent theoretical efforts and includes the following significant results.

1. The temperature coefficient of reactivity acts as the dominant control mechanism for transients with reactor periods in two regimes: >30 seconds, and from 2 seconds to 20 milliseconds
radiolytic gas production is the dominant shutdown mechanism in the other period regions.

Formulation of the AIRCOMP* computer code has permitted calculation of instantaneous reactivities from the experimental data. Temperature effects on reactivity are known. Since these are prompt mechanisms, knowledge of them allows determination, by difference, of the reactivity compensated by gas. The results of these calculations have provided the fundamental basis upon which a meaningful test may be applied to any bubble formation and growth theory. In order to be accepted, such a theory must describe the gas produced void demanded by the reactivity values.

2. Void formation rate during fast transients is dependent on both instantaneous power and the power integral.

As mentioned previously, early theoretical work was based on the assumption that a constant fraction of the radiolytic gas produced was instantly effective in reactivity compensation. That this premise was not factual became readily obvious with the production of experimental data. The model yielded burst characteristics having little in common with the experimental power traces. It has now been established that for transients having reactor periods shorter than about 10 milliseconds the void formation rate is proportional to the product of the instantaneous power and the power integral. One constant of proportionality yields a good fit to experimental data on peak power over the entire period range. Burst shape comparisons are also vastly improved. On a macroscopic basis this model must be accorded a large measure of success.

3. The energy coefficient of reactivity undergoes substantial changes in magnitude over the period range investigated.

It has been determined, through calculation of instantaneous reactivity values, that the energy release in the fuel solution which is required to compensate a given amount of reactivity changes as much as a factor of six within the period range of 100 to 2 milliseconds. These calculated values support the observation that void formation occurs with increasing efficiency as the period is decreased. This information produces a second meaningful test that may be applied to any model proposed

* The computer codes used are discussed under item B-5.

to describe bubble growth. Such a model must not only predict accurately the void generation rate in a given transient, but must now also show correlation between transients having widely different periods.

4. Effects resulting from reflector neutron migration times become important in transients having periods of a few milliseconds.

The KEWB test reactor has been exposed to shorter period transients than any other thermal reactor. Practical limitations have restricted investigations on other reactors to periods in excess of 5 milliseconds. The KEWB reactor safely withstands periods as short as 1.8 milliseconds. This difference in attainable period is significant from two viewpoints. First, the 2 millisecond period requires twice the reactivity insertion that is involved in producing a 5 millisecond period. Compensating mechanisms must, therefore, be present in greater magnitude. This increased magnitude allows better definition, separation, and precision of measurement of the individual reactivity compensation mechanisms. Secondly, the most rapid transient provides a better opportunity to detect and evaluate time dependent phenomena. An example of the latter is the unusual inhour equation found to apply to the KEWB reactor. For periods as short as five milliseconds the inhour equation would not necessarily be suspected as unusual. For periods less than five milliseconds no conventional inhour equation applies. The cause of this inconsistency is currently believed to be a reflector effect. The migration time of neutrons entering the reflector and ultimately returning to the core as thermal neutrons is considerably longer than for those neutrons that spend the predominant part of their life in the core. This time difference is sufficient to cause the reactor to subsist increasingly on "core neutrons" as the period is shortened below five milliseconds. The importance of this new parameter is best appreciated when it is realized that a reactor achieves a shorter period for a given reactivity input when this type of reflector effect is present. This further reduction of already short periods decreases the efficiency of time dependent shutdown mechanisms. It is anticipated that when fully understood this phenomenon will play a significant role in the analytical treatment of problems in reactor dynamics. Such systems as fast-slow reactors, where the core-reflector coupling is highly important are outstanding examples of potential application of knowledge which will be generated on the subject.

5. Development of the AIREK and AIRCOMP computer codes.

The AIREK code is based on a modified curve fitting formula (Runge-Kutta), and accepts up to 49 feedback loops and 20 delayed neutron groups. The input for an IBM-704 may be in the form of a tabular or analytical reactivity presentation, or initial power coupled with either period or delayed neutron concentration. All parameters of interest, e.g., power, temperature, void volume, super-saturation, etc, are included in the output, as well as those of importance in individual feedback loops. The AIRCOMP code was designed to accept power and reciprocal period functions as obtained from experimental data. The reactor kinetic equations are solved continuously, producing reactivity as a function of time.

The two codes have a common output which permits direct comparison of any theoretical model with experimental observations. These comparisons are a source of diagnostic information on the model under investigation.

III. EXPERIMENTS REMAINING TO BE DONE WITH THE SPHERICAL CORE

The remaining effort on the spherical core will be concentrated in two principal areas: (1) effect of initial power, and (2) response of the recombination system to power excursions. In addition, some miscellaneous experiments are also required to complete those parameter investigations which have been largely accomplished.

The importance of initial reactor power to an excursion has not yet been defined. These tests will consist of inserting fixed amounts of reactivity under conditions of equilibrium operation at powers up to about 25 kilowatts. Initial temperature and pressure will be held constant. These tests will involve an important variation in initial conditions. Bubbles near atmospheric pressure will exist throughout the fuel solution, changing both the solution compressibility and, to at least some degree, the environment affecting bubble growth.

The instrumentation development program, devoted to obtaining pressure detecting and recording apparatus capable of reporting explosion pressures has produced a suitable system. Multiple channels of this instrumentation are being procured. It will now be possible to determine the magnitude

and distribution of pressures accompanying a gas explosion resulting from a power excursion. The explosion force applied to the spherical portion of the vessel is of greatest interest, since this is the most vulnerable portion of the reactor. The time scale upon which this force is applied will also be determined.

The miscellaneous measurements to be made include extension of the study of initial temperature effects to larger reactivity inputs and pile oscillator experiments. Reactivities of approximately 1.5 and 3.0% Δk will be introduced with the reactor at various initial temperatures up to 70°C. The tests will assist in evaluating potential accidents involving the higher temperatures that accompany powers in the kilowatt-level regions. The oscillator experiments are a follow-up of work done early in the experimental phase of the program. A rotary oscillator capable of driving the reactor at frequencies up to 200 cycles per second was constructed and data taken. The power recording instrumentation did not have sufficient time response to allow accurate deduction of phase shift between the forcing function and the reactor power. Corrections for the instrumentation lag were dubious and it is hoped the future experiments will allow resolution of the data. The experiment would ultimately yield the ratio of the delayed neutron fraction to the prompt neutron lifetime -- a quantity which is used extensively in the reactor kinetic equations.

IV. CAPSULE EXPERIMENTS

It became apparent several months ago that it would be necessary to measure directly the evolution of radiolytic gas during a power surge under a wide variety of circumstances. The reactor system alone provided no feasible means of accomplishing this. Therefore, it was decided to use the reactor as a driving source to produce the necessary neutron flux in a capsule filled with fuel solution and located alongside the core vessel. The first model of a capsule believed suitable for these measurements has been designed and fabricated. It consists of an expandable bellows closed at both ends and having a capacity of about 25 ml. The bellows may expand in one direction only. The movable end is attached to a force arm which in turn is linked to the core of a highly sensitive linear differential transformer.

Expansion of the bellows, which reflects a volume increase, is monitored by the transformer. The capsule is also equipped with pressure and temperature instrumentation. This first model is currently being calibrated, and preliminary data should be available before the spherical core tests are terminated.

These experiments will yield otherwise unobtainable information. For example, fuel solution characteristics, i.e., concentration of uranium, acid, catalysts - which differ between reactors, can only be investigated by such an in-pile experiment. Further, the importance of power density variations within the reactor on bubble growth can be defined simply by locating the capsule in different flux regions. Initial pressures imposed on the fuel solution within the capsule can be varied over the wide range required to establish the internal pressures existing in the gaseous voids that are generated. In addition to the foregoing, the capsule studies will produce data on void volume as a function of time which will agree with reactivity computations only if the latter properly evaluate the function. If correlation is obtained, two facts will be evident: (1) the equations properly reflect the physical system, and (2) no mechanism which affects reactivity is being overlooked.

V. NEED FOR EXPERIMENTS ON THE CYLINDRICAL CORE

Following completion of the spherical core investigation it is proposed to replace that reactor core vessel with one of different geometry but generally similar dimensions. The vessel will be of cylindrical geometry. The diameter will be essentially the same as the present core.

The needs for continuation of the program through a series of experiments on this second core fall into three prime areas.

A. Pressure Function Correlation with Theory

The capsule studies will produce information on the effects of the individual parameters determining bubble growth. This information will permit evaluation of theories which predict such effects. If the theory is acceptable in terms of capsule data, it must then be found in accord with the integral reactor data in order to be accepted. In order to apply this test

it is necessary to transcribe the void growth theories to a macroscopic basis to obtain the end result, which is accurate prediction of the pressure function generated during transients. The prediction of pressure from a theoretical model is inordinately complicated by the spherical core geometry. The impact and reflection pressures, in addition to the decreasing free surface area during solution expansion, give rise to large pressure gradients within the solution. The cylindrical core will have a constant free surface area, limiting geometry changes to only one major axis. Reflected pressure waves will be eliminated during the time of interest. These conditions will allow direct comparison of theoretical predictions and the experimental results.

B. Extension of De-Coupling Information

The impact pressure is the limiting factor in determining the minimum safe period for the spherical core. The expansion pressures are about 2.5 times lower in magnitude than the impact pressures. Since only the expansion pressures will be applied to the shell of the cylindrical core a significantly shorter reactor period can be tolerated. It is predicted that the cylindrical core will be subjected to a maximum pressure of only 700 psi if the reactor is put on a stable period of one millisecond. The core vessel will be designed to withstand 1500 psi before yielding and about 3500 psi before failure occurs. It will be statically tested to 1,000 psi before installation. The capability of this geometry to withstand one millisecond period excursions will permit an extension of the investigation into core-reflector decoupling mentioned previously. These data will provide a basis upon which space-dependent reactor kinetic theories may be developed.

C. Power Density Effect on Bubble Growth

The maximum power in a one millisecond period excursion will be approximately 1500 Mw. The flux density in the reactor will therefore be a factor of three greater than that in the spherical core during a two millisecond transient. As stated previously, the gaseous void volume at any time appears to be a function of the instantaneous power as well as the energy released. The most promising theory of bubble growth is based on the interaction of fission fragments and the extremely small high internal pressure bubbles

resulting from previous fission events. If this is actually the case, extension of the maximum power density will result in a marked increase in the growth rate, again providing a broader basis upon which to develop and test the theory. It should also be noted that the maximum expansion pressure created in a one millisecond transient will occur at a much more informative time, which is just prior to and during peak power. This will automatically provide data of increased accuracy on gross bubble size and internal pressure.

VI. SCHEDULE OF WORK REMAINING IN KEWB PROGRAM

A schedule which outlines the completion dates for significant portions of the work remaining to be accomplished in the program is presented in Appendix B.

VII. SUMMARY

The KEWB program has produced a significant amount of data on the kinetic behavior of aqueous homogeneous reactors. The immediate objective of the program has been the investigation of a particular reactor design. This work has led to a considerable amount of knowledge regarding the gross behavior of the reference design. These data, coupled with development of calculation techniques, have however, clearly demonstrated the inadequacy of presently available theories to explain and predict the dynamic behavior of this general type of reactor. The facts available point consistently toward the evolution of radiolytic gas as the phenomenon which must be fully understood before acceptable theories become available. It has been determined that the most expeditious course of investigation into the character of this phenomenon is a program of companion experiments. One experiment will consist of in-pile capsule studies aimed at defining those parameters of importance, their degree of importance, and providing the data required to check the accuracy of reactivity calculations which deduce the instantaneous void volume in the reactor core. The associated

experiment involves integral reactor tests on a core geometry which will permit observation of the fundamental pressure function which results from production of the radiolytic gas. The present core geometry does not allow such observation because of reflection waves and its diminishing free surface volume, which cause large pressure gradients and make it virtually impossible to perform meaningful calculations. The ultimate objectives of the two experiments are to provide sufficient microscopic data to establish all the basic requirements of a model of bubble production and growth, and to produce data against which a model that is successful on a microscopic level may be tested on a macroscopic basis.

Other advantages to changing the core geometry are also evident. The small homogeneous reactor has access to a period regime thus far denied any other thermal reactor. This regime represents large reactivity inputs, which facilitates calculations. The cylindrical geometry enhances this property markedly. Some of the phenomena having both time and space dependence, can presently be studied effectively only in a reactor capable of these very short periods. The core-reflector de-coupling effect is an example. There is reason to believe that one can capitalize on the fact that the homogeneous reactor can be used in the period region that proves destructive to other reactor types. For example, the dynamic behavior of solid fuel element reactors, such as the SPERT series, have been analyzed by and large from the standpoint of thermal effects. Evidence exists that a mechanism more prompt than steam formation, such as radiolytic gas production might play a predominant role in shutdown. This evidence was produced by thick fuel plate experiments (BORAX IV) and a special SPERT test series with fuel elements that were coated with a thermal insulator. Capsule tests involving sample fuel plates are one means of investigation of the problem. The separation of "prompt" and delayed effects, such as steam formation, is greatly facilitated by reducing the time interval over which the forcing function operates. It is in this respect that a reactor capable of a one millisecond period burst, which delivers 90% of the energy released in only five milliseconds, becomes a powerful analytical tool.

In conclusion it can be said that the KEWB program is currently passing from the stage of observation of gross reactor behavior and the pertinent deductions arising therefrom, to a concentrated effort on determining

the details of the causes of the witnessed behavior. The first core has provided the insight into the importance of individual parameters, and the second core, coupled with capsule experiments, should permit a thorough understanding of the parameter of greatest importance.

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APPENDIX A

RESUME OF INFORMATION PRODUCED DURING SPHERICAL CORE INVESTIGATIONS

The following particularly significant experimental and analytical information has been generated during the course of the program on the specific reactor tested.

1. Rate of production of radiolytic gas during stable reactor operation is independent of power and temperature, but decreases slightly with increasing pressure.
2. Static measurements indicate the bubble residence time is approximately 1 second, which is substantiated by transient measurements which show that no gas leaves the core by the time of peak power in excursions having periods less than 1 second.
3. For periods longer than 0.1 second lower initial core pressure reduces transient peak power, whereas higher initial pressures lead to an increase in peak power. Initial pressure has no effect for shorter periods.
4. Although radiolytic gas bubbles are not formed instantaneously, they are formed with increasing efficiency as the reactor period is decreased below about 100 milliseconds.
5. Maximum transient pressures (on the core vessel) experienced with an underfull core loading result from fuel solution striking the container walls, rather than the expansion pressure occurring below the level of the solution.
6. A core completely filled with fuel solution does not suffer sharp impact pressures.
7. A region of fuel volume exists wherein the magnitude of the maximum pressure developed during a transient becomes a sharply varying function of the initial void volume in the core.
8. Expansion and impact pressures are both inversely proportional to the square of the period for both the full and underfull core loadings.

9. The power vs period performance of the reactor, for periods between 10 and 2 milliseconds, is unaffected by reactor produced pressures.
10. Ignition of the gas phase within the reactor vessel may occur as a result of a power excursion. The ignition source is believed to be fission heated uranium.
11. The shock wave created by a radiolytic gas explosion is attenuated in amplitude, and the rise time is increased, in the spherical portion of the core vessel by the presence of fuel solution.
12. No divergent instability results from ramp inputs of reactivity up to 4% for a full core, or inputs up to 2.5% for an underfull core. (The 2.5-4% range has not been investigated for underfull core as yet).
13. The maximum power resulting from a control rod induced ramp input is independent of the total reactivity inserted, but dependent on the rate of reactivity insertion.
14. The equilibrium power following the power pulse resulting from a ramp input increases with both the total reactivity input and heat removal rate.
15. Ramp transients, with large reactivity inputs, cause ignition of the radiolytic gases by the recombination system. (Response of recombiner to step transients has not yet been investigated.)
16. Ignition of radiolytic gas following a ramp-induced power transient results in a relatively low grade combustion when the gas circulation pump is operating, with only minor pressures being observed in the core.
17. Ignition of radiolytic gases by the recombination system following a ramp excursion results in the highest pressure in the core vessel when the gas circulation pump is off.
18. Oscillatory operation can be induced by control rod manipulation in the underfull core, and is a natural consequence above a particular power in the full core. No tendency to diverge without limit has been observed.
19. Periods shorter than 2 milliseconds do not result in damage.

20. The peak powers observed over most of the period range investigated are 50-100 times less than those detected in heterogeneous reactors of the pool type.
21. Energy releases resulting from step inputs of reactivity have not exceeded 4 Mw-sec for the underfull core.
22. The transfer function of the high impedance power recording channels has been investigated in detail.
23. Thermocouples having response times as short as 0.5 millisecond have been developed.
24. The temperature coefficient of reactivity acts as the dominant control mechanism for transients with periods in two regimes: >30 seconds, and from 2 seconds to 20 milliseconds.
25. Radiolytic gas production acts as the dominant shutdown mechanism in a longer period range (30 seconds to 2 seconds), and for fast excursions (less than 20 milliseconds).
26. For very fast transients (approximately 2 millisecond periods) gas production accounts for reductions in peak power, and in energy release, of factors of 5 and 6 respectively over the temperature-control-only case.
27. Even in the period region where temperature compensation dominates in establishing peak power, gas production significantly reduces the total energy in the burst.
28. Void formation rate during fast transients is dependent on both instantaneous power and the power integral.
29. The rate of gas evolution is retarded in the early phases of a transient, but suddenly increases in magnitude within a narrow range of energy release. This rapid evolution of gas is accompanied by the onset of inertial pressure.
30. The proportionality constant relating energy at peak power and period times peak power is 1.5 for short (less than 10 milliseconds) periods and 2.0 for longer (greater than 30 milliseconds) periods.

31. The energy coefficient of reactivity changes markedly as a function of period for different transients and also during the course of a single transient.
32. According to a theoretically produced transfer function the reactor is stable over the range of normal operating powers.
33. Three computer codes have been originated. TRADE reduces raw data to tabular form. AIRCOMP computes reactivity as a function of time from TRADE data. AIREK is an extremely versatile code for the solution of theoretical reactor kinetic problems.
34. Effects resulting from reflector neutron migration times become important in transients having periods of a few milliseconds.

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