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REACTOR POWER LEVEL LIMITS

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REACTOR POWER LEVEL LIMITS

G. F. Owsley and T. W. Ambrose
Process and Reactor Development
Research and Engineering
IRRADIATION PROCESSING DEPARTMENT

December 3, 1963

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HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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REACTOR POWER LEVEL LIMITS

INTRODUCTION

This document is submitted in response to a request from the Atomic Energy Commission for a report on the safety aspects of reactor operation at bulk outlet temperatures in the neighborhood of 95 C.[1] To properly describe the safety aspects of operation it is necessary to address the report to the engineering parameters associated with reactor operation and compare them to actual technical limits. Also, some discussion of administrative power level limits and bulk outlet temperature is in order. This report is essentially an updating of two reports[2,3] submitted in August 1959 and June of 1962 which considered the various effects of power level increase on physics and engineering safety limits.

SUMMARY AND CONCLUSIONS

The following table summarizes the power level experience and limitations at the various reactors:

		B,D,DR,F,H	C	KE,KW
(1)	Present Administrative Limit	2090	2310	4400
(2)	Maximum Experienced Power Level	2005*	2310	4400
(3)	Potential Winter Peak** Present flow, 95 C bulk outlet temperature.	2140	2440	4870

* The maximum power stated applies to D Reactor. DR Reactor has operated at a maximum power level of 1925, the maximum power levels at the other reactors lie between these values.

** Because of seasonal variations in inlet coolant temperature, summer power levels are approximately 80 per cent of these peak values.

The principal nuclear safety and engineering factors related to increases in reactor power levels are speed of control, total control, process tube flow instability, heat transfer burnout, fuel element temperatures, effluent system pressure, availability of backup coolant, and graphite temperature effects. Of these, effluent system pressure is the most restrictive to bulk outlet temperature. The bulk outlet temperature limit is not a nuclear safety limit but one of operating continuity. Further, a bulk outlet temperature limit of 98 C would not result in any of the nuclear safety or engineering limits being exceeded. It is concluded that operation at 95 C all year will not introduce increased hazards nor represent difficult operating conditions.

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DISCUSSION

The production reactors' power levels are restricted by several physics and engineering factors, namely: speed of control, total control, instability of flow in a process tube, heat transfer burnout, effluent system pressure, fuel temperature, adequate backup cooling, and graphite temperature effects. These are the technical limits to reactor operation and increases in power level will eventually conflict with one or more of these and represent an operating condition which is either unsafe from a nuclear standpoint or would result in reactor damage which could affect continuity of operation or limit reactor life. Thus, there are two types of limits, one affecting nuclear safety and the second, engineering limits which affect reactor life and operating continuity. Each of these limits is reviewed and measured against (1) criteria which have been established and reviewed by various review bodies, or (2) the actual technical limit.

Nuclear Safety Limits

1. Speed of Control and Total Control

The "speed of control" and "total control capacity" criteria adopted at Hanford have resulted from extensive study, and these criteria have been reviewed with both the AEC and ACRS and found to be acceptable bases for safety analyses and plant operation. These criteria and a complete discussion of their interpretation are presented in the Hazard Summary Reports[4,5] and to a lesser degree in references (2) and (3). It is concluded in the Hazard Summary Reports that reactor power levels at all of the IPD production reactors can be increased by at least ten per cent with no restriction being imposed by the speed of control criteria. The total control criteria are not particularly sensitive to reactor power level and as such do not restrict power levels.

2. Process Tube Flow Instability

The instability limit is established to assure that in the event of a flow reduction or power increase in a single process tube the reactor will be shut down automatically in time to prevent melting of the fuel jacket and the potential release of fission products. The trip span, supply pressure, Venturi throat pressure, and discharge pressure determine the instability limit. For control purposes a maximum tube outlet temperature is specified to avoid flow instability, and the correlation between instability and outlet temperature is measured experimentally for each fuel design. Exceeding the current limit of 130 C by up to 15 C to 25 C will not cause flow instability in the tube - the only danger is from a further excursion or rapid flow reduction at these temperatures.

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Thus, momentary spikes over 130 C are of minimal risk. Although no other tube temperature limit is as restrictive from a safety standpoint, tube temperatures rarely approach 130 C limit even for short periods. Further, under steady operating conditions at 95 C bulk effluent temperature the maximum tube outlet coolant temperatures are about 10 C less than 130 C. Thus, increases beyond 95 C bulk outlet temperature are acceptable from an instability standpoint.

Engineering Limits

1. Subcooled Heat Transfer Burnout

The accepted maximum fuel heat flux is to be no more than 70 per cent of calculated subcooled fuel burnout heat flux. Under normal operation, the specific heat flux is less than 50 per cent of subcooled burnout although under peak conditions, conservatively assuming a highly peaked axial specific power distribution, a value in the range of 50 per cent to 60 per cent of calculated subcooled burnout is achieved in some process tubes. Consequently, heat fluxes could be increased in excess of 20 per cent and not exceed the maximum specified heat flux.

2. Specific Fuel Temperature

The specific fuel temperature of metallic fuel appears to be limiting in the range of the alpha-beta phase transformation temperature of uranium (662 C). Approaching or exceeding the phase transformation has led to fuel element failures from core cleavage. Present production I&E fuel elements operate with a normal maximum temperature in the range of 375 C, while the former solid elements operated with maximum temperatures of about 515 C, and, as determined from post-irradiation fuel examination, the alpha-beta phase transformation was occasionally achieved. Cleavage failures in production I&E fuel elements from excessive operating temperatures have been nonexistent. Thus, with the I&E fuel, specific fuel temperature is not close to being limiting.

3. Effluent System Pressure

The most critical point in the effluent system at all reactors is the junction between the crossover pipe and the top of the downcomer. The limitations of this location are indicated below.

Reactor	Location	Allowable Working Pressures
B,C,F	Top of downcomer	2 psig
DR, H	Top of downcomer	2 psig
C	Top of downcomer	1 psig
KE,KW	Downcomer Approach section	5 to 8 psig

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Pressure versus Temperature. Experimental results on the DR Reactor and on various reactor downcomer models indicate that top of downcomer pressures will exceed by one to two pounds the water vapor pressure associated with a given bulk outlet temperature. It also appears that this disparity increases with temperature and with the abruptness of an effluent temperature surge.

The bulk outlet temperature limit is established to provide a margin between the operating temperature and the threshold temperature at which pressurization damage would occur to the downcomer. Detailed theoretical and experimental evaluation have been made of various events which could result in bulk temperature spikes. These analyses indicate that the margin provided by the 95 C limit is sufficient to avoid damage from the more probable surges in bulk outlet temperature, and that the risk of damage from the less probable surges, of greater magnitude, is offset by the incremental production achieved by operating the reactors at a bulk outlet temperature above that which would assure no damage would occur from any surge. Principal events which have been considered are control rod withdrawal at maximum speed, supplemental control discharge, pump shaft break, and loss of primary power (BPA).

A program is being pursued to better characterize the magnitude of temperature surges from various incidents and the resistance of the downcomer to pressures associated with higher temperatures for various periods of time. In addition, positive protection is being provided to minimize the probability and limit the magnitude of temperature surges. This effort is directed toward not only improving the assurance of downcomer protection at 95 C operation, but also the feasibility of further increases in the bulk temperature beyond 95 C.

Of considerable importance are the consequences of downcomer damage. Failure of the downcomer would not result in fission product release so such failure is not a nuclear hazard, but would require expensive repair. Repair time for major downcomer ruptures has been estimated to be in the order of 30 to 60 days. Consequently, failure of the downcomer must be considered as a major maintenance problem but not a nuclear safety limit. This position has been repeatedly expressed before the ACRS and the AEC.

4. Backup Coolant Availability

In the event primary power is lost, the backup coolant must be capable, from either the secondary or last-ditch coolant system, of providing sufficient flow during the resulting automatic shutdown transient to the steady shutdown heating level to prevent melting of fuel and, in fact,

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any fuel damage. The flow provided by the energy stored in the primary pump flywheel decay and subsequently the last-ditch system is most critical. In the current state of operability the backup flow availability would probably permit a power level increase of up to ten per cent over the current administrative limit at some reactors, and increases in the administrative level to that permitted by the coolant backup requirements would be sufficient to permit operation up to 98 C year around with present bulk flow.

5. Graphite Temperature

Maximum graphite temperatures in the range of 650 C at the small reactors and 750 C at the K Reactors are currently achieved. Although even higher temperatures are thought to be acceptable with a very dry gas atmosphere and with very little air contaminant (carbon oxidizes readily at these temperatures), a ten per cent increase in power would be possible by increasing helium concentration with only slight increases in graphite temperature.

6. Process Tube Corrosion

Tube and fuel corrosion is most sensitive to process tube outlet temperature. Although the tube corrosion problem actually resulted in operation below 95 C and the administrative power level limits at several reactors last winter, this problem has now been resolved such that tube corrosion is not limiting to further coolant temperature increases. Operation at high bulk outlet temperatures all year around is acceptable from a technical standpoint; the optimum bulk temperature from a corrosion standpoint is primarily a matter of economics.

Administrative and Bulk Outlet Temperature Limits

The reactors have been limited over the past few years by a combination of administrative power levels and the bulk outlet temperature limits; neither of these restrictions are based upon nuclear safety limits. The administrative limits represent a blanket ten per cent increase over the 1959 administrative power level limits. It is noted that during 1959 (reference 1), power levels in excess of the present administrative limits for all reactors were judged feasible with increased water flow capability at the K plants which has been effected. No significant changes in procedures, reactor physics characteristics, or mechanical equipment were associated with these increased power levels. To be economically practical, however, the fuel performance would have to be improved. With the large improvements in fuel performance achieved during the past three years, this restriction is no longer valid. The following table summarizes the power level experience and limitations at the various reactors:

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** Because of seasonal variations in inlet coolant temperature, summer power levels are approximately 80 per cent of these peak values.

The bulk outlet temperature limit has in practice been the engineering limit which has been most restrictive to reactor operation, and for about the past six years, a level of development effort has been directed toward achieving a 95 C bulk outlet temperature for routine year around operation. As with all extensions of major engineering limits, a pilot reactor was first operated at this temperature. One reactor was operated at 95 C for a period in 1960 (DR Reactor), three others reached 95 C in 1961 (C and K Reactors), and all reactors operated at 95 C routinely during the summer of 1963. In operating on their administrative power level limits, C and the K Reactors maintained 95 C during the winter of 1961-62 except at the very lowest inlet water temperature condition. Process tube corrosion prevented the other smaller reactors from reaching 95 C bulk outlet temperatures before the summer of 1963. Resolution of the tube corrosion problem through tube replacement, lower coolant pH, and better optimized tube dimensional specifications now permit operation at 95 C bulk outlet temperature year around without significant economic penalty reducing the direct gain resulting from power level increase.

Depending upon the results of engineering studies and possibly mockup testing, the exploration of higher temperature operation may be appropriate during CY 1964. If higher temperature operation appears prudent, the test procedure would probably recommend incremental increases for one reactor on a pilot basis with a conservative schedule for increased operating temperatures at other reactors.

The various nuclear and engineering limits have been discussed above, and, in no case, are any of the limits in danger of being exceeded by operating at 95 C bulk. In fact 95 C could be exceeded 3 C without violating a nuclear safety or engineering limit. As noted above, considerable operating experience has been achieved at 95 C bulk and, as anticipated, no difficulties have been encountered.

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In general, operation at 95 C bulk outlet and at power levels beyond the present administrative limits have been judged feasible for several years, and now with superior fuel and the process tube corrosion problem alleviated, it is economically attractive to increase power levels.

Philosophy of Operation

It continues to be the policy of the General Electric Company to operate the reactors in a safe, prudent, and productive fashion with safety being paramount and with due consideration being given to reactor life and operating continuity. Although there is a risk of significant fission product release associated with reactor operation, this risk is extremely low. Coolant and control criteria have been established and administrative controls are exercised to assure that deterioration and modified operation will not increase the risk of fission product release. Thus, no changes are permitted which would decrease the assurance of safe operation of the production reactors. The practice has been that all equipment modifications and procedural changes will embody, wherever possible, provisions for increasing the assurance of safe operation over that which existed before the changes are made. Thus, improvements in instrumentation, equipment, and procedures associated with power increases in the past have improved the nuclear safety status of the reactors very substantially over that which existed at the outset of the Hanford operation.

The other aspect of the Company's safety philosophy is that operational changes, e.g., increases in power level and temperatures, are made deliberately after considerable study, testing, and experience at previous conditions. Further, such changes are undertaken in small steps and with a pilot reactor first to focus more intensive technical attention on the changes and to minimize the safety and economic risk.

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4. "Hazards Summary Reports - Six Oldest Hanford Production Reactors," June 1963, HW-74094 - Volumes I, II and III. (Secret)

5. "Hazards Summary Reports - Hanford K Production Reactors," July 1963, HW-74095 - Volumes I, II and III. (Secret)

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