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TECHNICAL CRITERIA AND BASES
REACTOR GAS SYSTEM - 100-K

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TECHNICAL CRITERIA AND BASES
REACTOR GAS SYSTEM - 100-K

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TECHNICAL CRITERIA AND BASES REACTOR GAS SYSTEM - 100-K

INTRODUCTION

With an increased water plant capacity, the installation of zirconium process tubes and the use of self-supported fuel elements, the power level capability of the K Reactors exceeds the current administrative limit. Exploitation of this capability, if approved, will almost certainly bring about higher graphite temperatures. Because of a continuing concern for graphite oxidation, and because the rate of oxidation increases with increasing graphite temperature, upgrading of the existing K-Reactor gas system through project action has been proposed. This document presents the technical basis for such project action.

REQUIREMENT

The reactor gas atmosphere composition (including contaminants) shall be controlled such that the chemical reaction with the moderator will not impair the structural strength of the stack supporting members so as to limit the useful life of the facility. Equipment of appropriate design and instrumentation of appropriate sensitivity and accuracy shall be provided to assure adequate reactor gas composition control.

CRITERION

The limit of useful moderator life, with respect to graphite oxidation, has been arbitrarily defined as a reduction in compressive strength of the graphite by 50 per cent. This value corresponds to approximately ten per cent uniform oxidation in the stack supporting members. For administrative purposes, this criterion has been further arbitrarily defined as a rate of not more than two per cent oxidation per thousand operating days in any significant portion of the reactor. Since oxidation with water vapor is of concern at current and projected graphite temperatures, the gas drying facilities shall be capable of meeting the following requirements:

<u>Water Input to Driers</u>	(Inlet Dewpoint to Reactor)	
	<u>Exact Dewpoint from Driers</u>	<u>Gas Flow Range</u>
Up to 24 gallons/day	-50°F	400 - 700 cfm
Up to 24 gallons/day	-60°F	> 700 cfm
Up to 200 gallons/day	0°F	Maximum present capacity (~ 5500 cfm)

It should be noted that these requirements for lower inlet dewpoint capability are based on a maximum graphite temperature of 900°C. Conservative extrapolations of in-reactor measurements and calculations of the effects of retubing indicate that graphite temperatures of this magnitude after completion of retubing could be achieved at the 5000 Mw power level attainable with the present water plant flow capacity, even with 100 per cent helium. It is conceivable, however, that the

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maximum temperature will be lower than 900°C and that a relatively small increase in the present limit of 750°C would be sufficient to achieve the full plant capacity. An additional alternate is operation at a power level less than 5000 Mw.

If the above estimate of temperature is conservative, however, the ability to operate at higher graphite temperature could be utilized to effect economic savings through reduction of helium loss rates and enriched metal requirements.

Finally, there are other considerations which may limit the graphite temperature to somewhat less than 900°C for at least a part of the time.

In addition to restrictions on the quantity of water input, air in-leakage should be "minimized." By minimized, the intent is that normally air in-leakage would be excluded--at least to within the sensitivity of analytical instruments. It should be recognized, however, that during changing, abnormal, or unusual incidents prevention of air in-leakage is virtually impossible. At start-up, air contaminant reduction to very low values is impractical and uneconomical. To meet this intent during normal operation, control of air in-leakage could be maintained by a combination of gas pressure control and analytical instrumentation to indicate whether air is actively entering or not.

DISCUSSION

Graphite oxidation results from reaction with three primary oxidants in the reactor gas atmosphere: carbon dioxide, water vapor and oxygen from air in-leakage. At graphite temperatures in excess of 400°C, the graphite-oxygen reaction becomes sufficiently rapid that essentially all oxygen introduced into the system is reacted in a single-pass through the stack. Reaction, with CO₂ at and above the 750-800°C range and with water vapor at and above the 700-750°C range, is sufficiently rapid that limits must be imposed on graphite temperature and/or oxidant concentration. Reaction rates with CO₂ and water vapor are shown graphically in Figures 1 and 2 as functions of graphite temperature and oxidant concentration. A typical graphite oxidation profile with oxygen is shown conceptually in Figure 3. Note that the oxidation increases with higher graphite temperature and reaches a maximum in the front portion of the stack. Although maximum graphite temperature in the K Reactors occurs in downstream sections of the second tube block (.130 coring zone), maximum oxidation with oxygen occurs slightly upstream where there is a combination of high oxidant concentration and sufficiently high temperature. Maximum oxidation does not occur in the region of maximum temperature because there is little or no oxygen left to react. Similar reactions occur with CO₂ and water vapor but are displaced further downstream into the higher temperature region. Following completion of the zirconium retubing program, an additional area will exist within the stack where temperatures will be similar to those currently observed only in the .130 coring zone. This area will be located in the center region of the upper tube channels and will result from the extensive graphite removal necessary for the zirconium retubing program.

The effect of gas flow rate on total input of oxidant is shown in Figure 4 in which the amount of water vapor is shown as a function of dewpoint for various gas flow rates. Note that for a constant input of oxidant, the concentration of the oxidant decreases with increasing flow rate and the required sensitivity of the monitoring instrumentation is thereby increased. Similar relations exist between oxygen concentration, gas flow rate, and input rate of oxygen.

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FIGURE 1

GRAPHITE OXIDATION RATES
DUE TO CARBON DIOXIDE

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FIGURE 2
GRAPHITE OXIDATION RATE
DUE TO WATER VAPOR

FIGURE 3
LOCATION OF GRAPHITE OXIDATION

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FIGURE 5

WATER VAPOR INPUT RATES AS AFFECTED
BY CONCENTRATION AND FLOW RATE

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While the present gas drying facilities are generally adequate at the current operating power levels and graphite temperatures, reaction of 900°C graphite with water vapor in the gas atmosphere would likely result in an appreciable increase in the total graphite oxidation. Since reaction rate is a function of both temperature and water vapor concentration, permissible graphite temperatures would necessarily be limited by the amount and concentration of water entering the stack. Thus, the gas dryer system should have the capacity of providing sufficiently dry gas that post-retubing program temperatures can be achieved under all operating conditions except those associated with the entrance of abnormal quantities of water such as large tube leaks or inadvertent water entry during reactor shutdown. If the drying systems were incapable of maintaining dry gas under these circumstances, appropriate temporary reductions in graphite temperature would be required.

Water entry into the stack stems primarily from two sources: direct entry in the liquid state from tube leaks or in the form of water vapor in the inlet gas stream. The latter can be maintained within acceptable limits with sufficient capacity drying facilities. The detrimental oxidation effects of direct water entry into hot graphite from a tube leak, however, are only slightly influenced by the capacity of the drying facilities. The severity of oxidation under these conditions is primarily influenced by local graphite temperature and the total quantity of water input. Thus, there appears little justification for sizing the dryer system capacity to handle water leaks of sufficient magnitude that continued operation at high graphite temperatures could be recommended. For example, a leak of two gallons per day on a tube block operating at 900°C could virtually completely gasify the tube block within several days. While a detailed technical basis for graphite temperature limits following the zirconium retubing program is beyond the scope of this document, it appears unlikely that continued operation at graphite temperature attainable following the zirconium retubing program could be tolerated at the water collection rates currently permitted by Process Standards. Thus, it is assumed that the requirements of a very low dewpoint would not be applicable when the total water collection rate exceeded 24 gallons per day since, presumably, graphite temperatures of 900°C could not be tolerated at these collection rates unless it could be assured that the water was not coming into direct contact with the hot graphite. Quite possibly in such situations the graphite temperature would be limited to as low as 700 to 750°C.

The selection of a required inlet dewpoint is somewhat arbitrary in that certain assumptions are necessary. For example, if oxidation were distributed uniformly throughout the reactor stack, a considerably higher quantity of water in the inlet gas could be tolerated to meet the criteria of not more than two per cent oxidation per 1000 operating days than if the oxidation were very localized. Oxidation samples routinely installed to measure the amount and location of oxidation have shown that oxidation generally occurs over a relatively narrow slab of graphite, one to two feet thick in the forward region of the stack. For purposes of estimating inlet dewpoint requirements, it has been assumed that the region of peak oxidation will continue to be a slab approximately 1 foot thick and that an inlet dewpoint of approximately -50°F at a gas flow rate no greater than 700 cfm would be required to avoid oxidizing more than 3000 lbs. of the approximately 160,000 lbs. (two per cent) in the slab over a 1000-day period. Should the oxidation be spread out over significantly more than one foot, some relaxation in the dewpoint would be possible, although this remains to be demonstrated. At flow rates in excess of 700 cfm, the total input of water would increase and an even lower dewpoint (-60°F) would be required. If the

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required dewpoints cannot be achieved (-50°F @ 400-700 cfm or -60°F @ > 700 cfm) it must be assumed that the graphite-water reaction is proceeding beyond the acceptable rate and that a temporary reduction in graphite temperature would be required.

INSTRUMENTATION

Gas system instrumentation shall be capable of monitoring carbon dioxide, nitrogen, oxygen, argon, carbon monoxide and water vapor. The sensitivity of the instrumentation must be such that gas constituents can be monitored as indicated below:

Carbon Dioxide¹

50-500,000 ppm by volume

It may be necessary to provide two ranges for this component to cover the whole span and provide the accuracy required. If this is done, the ranges shall be split as follows:

Range 1

50,000-500,000 ppm by volume

Range 2

50-50,000 ppm by volume

Nitrogen¹

50-850,000 ppm by volume

It may be necessary to provide two ranges for this component to cover the whole span and provide the accuracy required. If this is done, the ranges shall be split as follows:

Range 1

50-100,000 ppm by volume

Range 2

100,000-850,000 ppm by volume

Oxygen Plus Argon¹

50-150,000 ppm by volume

Carbon Monoxide¹

50-50,000 ppm by volume

Accuracy

Accuracy in above components shall be ± 2 per cent of amount present or ± 50 ppm, whichever is greater.

Water Vapor

Inlet gas $+30^{\circ}\text{F}$ to -60°F dewpoint. Accuracy $\pm 5^{\circ}\text{F}$.
Outlet gas $+70^{\circ}\text{F}$ to -20°F dewpoint. Accuracy $\pm 5^{\circ}\text{F}$.

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Miscellaneous Instrumentation

Other miscellaneous instrumentation shall include means of measuring flow in the appropriate ranges, for measurement of rate of make-up of principal constituents, and improved gas pressure instrumentation. It is desirable, but not necessary, to provide a flow instrument whose calibration is not dependent on gas composition. Flow measurement should be accurate to ± 5 per cent in the normal operating ranges. The make-up gas metering instrumentation may be of the integrating type, rather than rate type and should be accurate to ± 100 cfd or ± 5 per cent, whichever is greater.

Maintenance of a positive pressure throughout the gas system as the primary means of excluding or minimizing air in-leakage would probably require a sufficient increase in pressure that a significant increase in the helium loss rate would result. Oxidation control through a combination of gas system pressure control and monitoring of reaction products appears to be a more practical solution than simply insuring a positive pressure throughout the system at all times. There are, however, some instrumentation modifications which should be considered to improve gas pressure control. These include:

1. ΔP measurements to provide for rear-face gas to rear-face air and front-face gas to front-face air differential measurement, at the bottom of the reactor.
2. Sensing line locations to minimize the effects of gas composition uncertainties in the reactor gas tap lines, and the errors due to water condensation or improper location of the air tap lines.

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