FISSION GAS RELEASE FROM FUEL AT HIGH BURNUP

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ABSTRACT

The release of fission gases from fuel pellets at high burnup is reviewed with regard to the required safety analysis in reactor licensing. A correction function developed by the Nuclear Regulatory Commission is described, and related information on fission gas release is summarized. A discussion of the present regulatory position is also given. The report thus serves as a guide for the analysis of high burnup gas release in licensing situations.

I. INTRODUCTION

Fission gas release from fuel pellets during irradiation is of considerable importance in assessing the long-term behavior of nuclear fuels. At high burnup the composition and pressure of the rod fill gases may be significantly altered, thus affecting heat transfer in the rod. The gas pressure in the rod also determines, in part, the stress applied to the cladding. For these reasons, fission gas production and release from the fuel must be accurately known throughout the lifetime of the fuel rod.

A number of gas release models are used in licensing (1) by U.S. commercial LWR fuel vendors. With the exception of a recently submitted Westinghouse fuel performance code (2), these models currently have little or no burnup dependence in the predicted release rate for fission gases. This situation exists in light of an obvious burnup enhancement in LMFBR fuels and comments from the research community that there is growing evidence for an increased rate of fission gas release, particularly above 30,000 MWd/t. This apparent discrepancy was recognized by the NRC, and it has been thought that increasing release rates might be perceived empirically as constant release rates because of decreases in fuel temperatures with burnup.

The NRC formally approved models proposed by the industry in the past based primarily on two considerations: (1) the industry models agreed well enough with the best available fission gas release data, which were taken at low burnup, and (2) an NRC-funded study (3)

concluded, among other things, that there was no burnup dependence at high temperatures. It should be noted, however, that the high-temperature data analyzed by Beyer and Hann in that study came from low-burnup fuel; most of the fuel (34 out of 45 rods) had burnups of less than 4,000 MWd/t, only 3 rods exceeded 10,000 MWd/t, and none exceeded 20,000 MWd/t. Burnup enhanced gas release at low temperatures (<1250°C) was considered in the Beyer and Hann study. It was thought that burnup enhancement at higher temperatures probably occured beyond the range of LWR burnups (27,500 - 33,000 MWd/t).

Serious discussion in the industry concerning burnup dependence took place within an American Nuclear Society standards subcommittee, designated the ANS-5.4 Working Group, which was chartered to investigate fuel plenum fission gas activity. The activities of this group have been presented in a recent status report (4). The NRC as well as major U.S. nuclear fuel suppliers are represented on this committee. As a participant, Westinghouse Electric Corporation (5) stated that there existed a strong burnup dependence that was not accomodated by the preliminary ANS fission gas release model (6,7). While this conclusion was initially based by Westinghouse on Saxton data, which were later criticized by Ritzman (8) as being inconclusive, the burnup dependence is supported by recent Westinghouse data (9) from Zorita as well as other experimental data to be discussed later in this report. After receiving a request for model and design basis changes in 1976 from Westinghouse, the NRC concluded that the deficiency was generic and began to form a licensing approach to the problem.

II. LICENSING ACTIONS

Mounting evidence of burnup enhancement forced the NRC staff to reconsider its previous approach to fission gas release at high burnup. In the absence of an acceptable method for describing this effect, the NRC and consultants at Battelle Pacific Northwest Laboratories (PNL) developed a correction method to evaluate the safety implications of the release enhancement. The burnup correction was based on the only large source of high-burnup non-proprietary data available at the time. Those data were LMFBR mixed-oxide (MOX) fuel data from EBR-II. No essential differences in gas release had been proposed for MOX and UO-2 fuels (10,11), and this conclusion had also appeared in the GESMO report (12). In addition, Westinghouse (5) confirmed the uniform application of a single fission gas release model to both high-burnup UO-2 and MOX data, including that from EBR-II.

Since the EBR-II data had not been released, it was decided to begin the analysis with a correlation reduced from those data by Dutt et al. (13) (and later revised by Dutt and Baker (14)). These EBR-II data have since been released, at NRC request, and are included in Appendix A. Revisions to these data are given in Appendix B.

From the Dutt correlation a correction method was developed as a function of two variables, F(T) and Bu. F(T) is the uncorrected gas release fraction predicted with any existing fission gas release model, and Bu is the burnup. It was intended that the correction method could be used as a simple correction applied to almost any existing empirical gas release model.

In November of 1976, the NRC staff prepared a letter to the industry that included the high-burnup correction function for fission gas release. Later the same year this letter was sent to each licensed utility and to all U. S. fuel suppliers. The recipients were informed that the NRC had reason to believe the plant safety analyses underpredicted fission gas release at high burnups. In addition, the following calculations were requested with results to be reported to the NRC within 30 days.

1) Each utility or vendor was to temporarily alter the fission gas release model in its fuel performance code such that release predictions were increased for exposures greater than 20,000 MWd/t according to the NRC correction.
2) The fuel vendors were to select several operating plants in the U. S. whose safety analyses would be most affected by an increase in gas release. Calculated data for peak-burnup gas release, rod pressure, fuel temperature, etc. with and without the gas release correction were to be supplied to the NRC.
3) The impact (if any) of these larger gas releases on LOCA and other safety analyses was also to be described.

Responses from the vendors are summarized in Table 1. In light of the vendor responses and in view of increasing experimental evidence in support of enhanced gas release, the NRC staff took the position that all vendors must improve their fission gas release models to include burnup effects. Furthermore, until such time that improved models could be approved by the NRC, the fission gas release correction method derived by NRC would be utilized in safety analyses to account for the enhanced releases.

Table 1. Fuel Vendor Responses on Enhanced Fission Gas Release.

SUPPLIER	EXCESSIVE ROD PRESSURE	LOCA EFFECTS
BABCOCK & WILCOX	NONE	>20° F PCT
COMBUSTION ENGINEERING	NONE	NONE
EXXON (BWR)	NONE	<32°F PCT
EXXON (PWR)	NONE	NONE
GENERAL ATOMIC	NONE	≤ 11°F PCT
GENERAL ELECTRIC	NONE	≤85°F PCT
WESTINGHOUSE	NEW ROD PRESSURE CRITERION	NONE

III. DERIVATION OF THE NRC CORRELATION

The approach that was taken in deriving the correction function was, effectively, to separate the variables in the Dutt and Baker (14) correlation (see Fig. 1) and to utilize that burnup dependence alone for LWR fuels above 20,000 MWd/t. It is assumed that current LWR models are adequate in the low burnup range (below 20,000 MWd/t).

To accomplish this separation of variables, a change was first made in the Dutt and Baker correlation so that it became a function of release fraction F(T) at a fixed burnup (20,000 MWd/t) rather than a function of local power. In each case the correlation also remains a function of local burnup, Bu. The basic form of the new function is

$$F'(Bu,T) = F(T) + [1 - F(T)]Y, \qquad (1)$$

where Y is an enhancement factor to be derived from the Dutt and Baker correlation. An arbitrary but convenient functional form was selected for the enhancement factor:

$$Y = \frac{1 - \exp[A(Bu-20,000)]}{1 + (B/F(T))\ \exp[C(Bu-20,000)]}, \qquad (2)$$

where A, B, and C are empirically derived coefficients and Bu is local burnup in megawatt days per metric ton of uranium (MWd/t). Non-linear regression techniques were used to fit Eqs. (1) and (2) to the Dutt and Baker correlation.

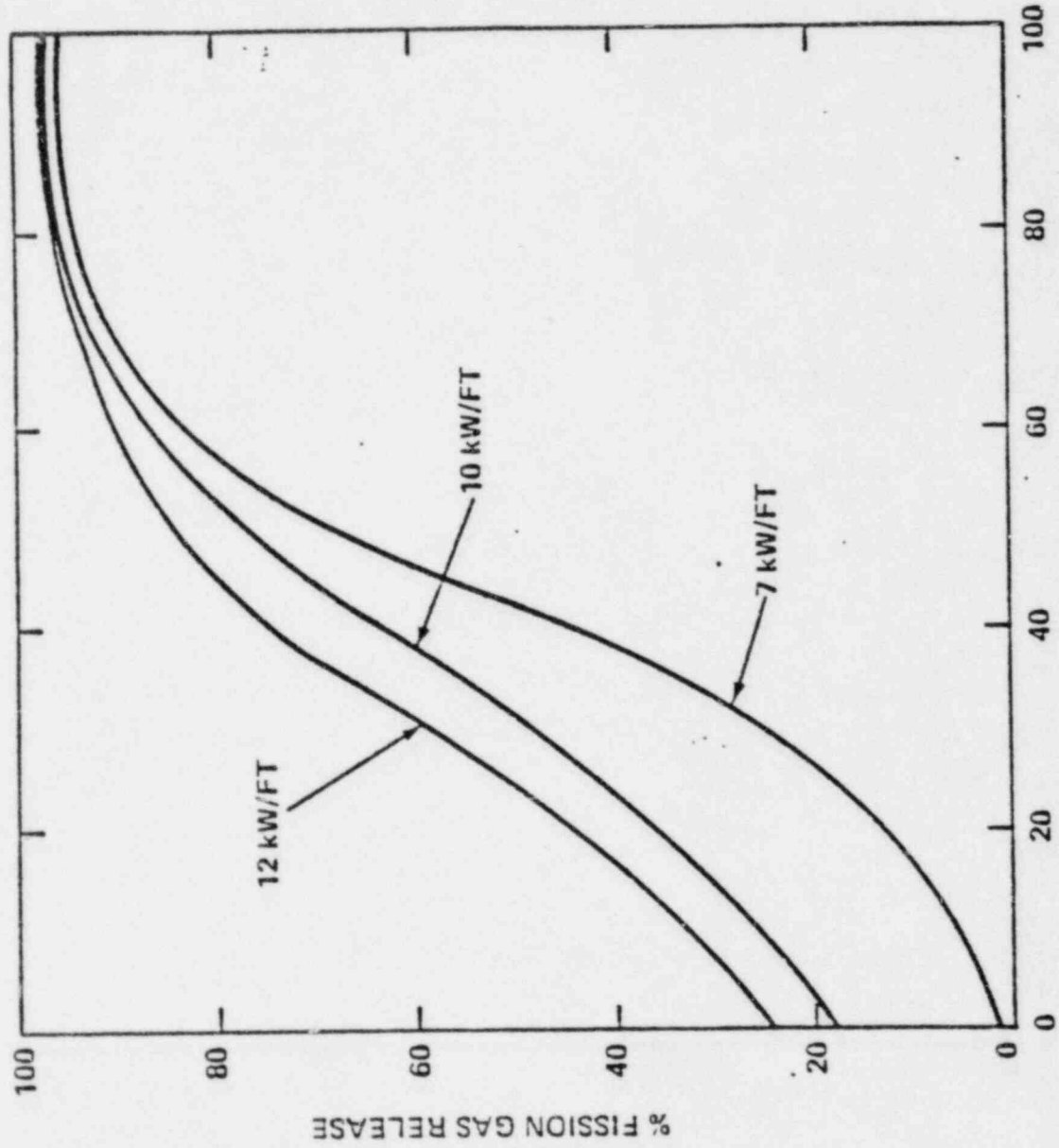

Figure 1. LMFBR Fission Gas Release as a Function of Burnup (from Ref. 14).

Release fraction and local burnup values were obtained by inspection of Fig. 1, which is taken from the Dutt and Baker report. In this manner, a number of values for Y, the burnup enhancement factor, were obtained for various local powers and burnups. These values are given in Table 2. The coefficients in Eq. (2) were then chosen by a least-squares method to closely approximate the Dutt and Baker correlation. That is, values of the constants A, B, and C were selected to minimize the summation

$$F = \sum_{ij} [Y_{i,j}(\text{calculated}) - Y_{i,j}(\text{experimental})]^2, \qquad (3)$$

where i = 7, 10, 12 kW/ft and j = 20, 30, 40, 50, 60 MWd/t.
The resulting correction function is

$$F'(Bu,T) = F(T) + [1-F(T)] \frac{1 - \exp[-0.0000436(Bu-20,000)]}{1 + (0.665/F(T))\exp[-0.0001107(Bu-20,000)]} \qquad (4)$$

Equation 4 is thus a reformulation of the Dutt and Baker correlation in the burnup range 20,000 to 60,000 MWd/t. This function simply replicates the shape of the Dutt and Baker curves, and the closeness of the approximation can be seen by comparing the dashed and solid curves in Fig. 2.

It was next assumed that LWR and LMFBR fuels that have the same release fraction F(T) at 20,000 MWd/t will have the same release fraction F'(Bu,T) above 20,000 MWd/t provided their respective temperatures do not change (application of this method when temperatures change is described in Section IV).

Table 2. Summary of Data from Dutt-Baker Curves.

BURNUP (MWd/t)	7 kW/ft		10 kW/ft		12 kW/ft	
	RELEASE FRACTION	ENHANCEMENT FACTOR, Y	RELEASE FRACTION	ENHANCEMENT FACTOR, Y	RELEASE FRACTION	ENHANCEMENT FACTOR, Y
20,000	0.129	0.000	0.354	0.000	0.440	0.000
30,000	0.250	0.139	0.486	0.204	0.588	0.264
40,000	0.447	0.365	0.630	0.427	0.745	0.545
50,000	0.680	0.633	0.745	0.625	0.840	0.714
60,000	0.830	0.805	0.860	0.783	0.895	0.813

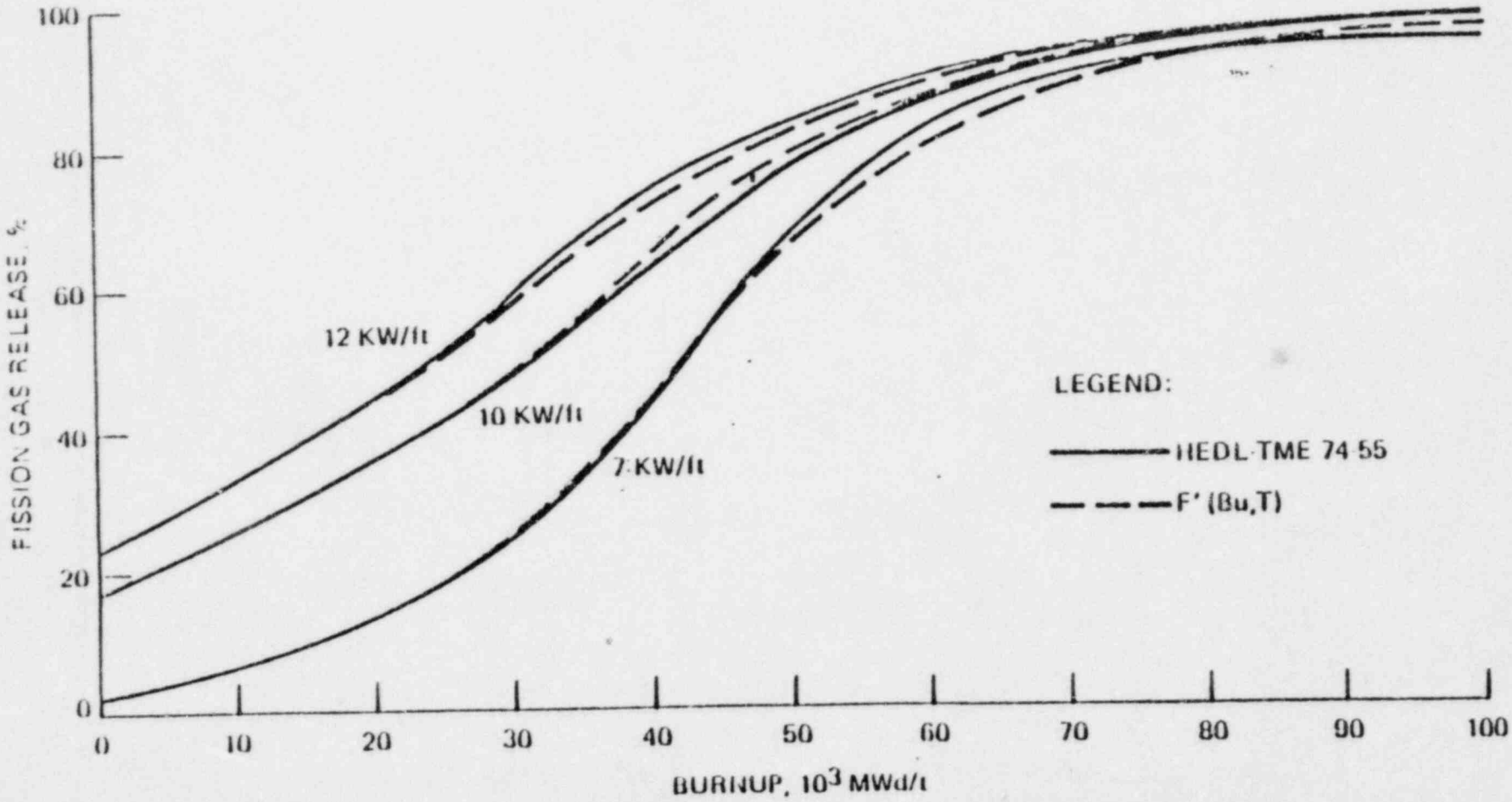

Figure 2. Comparison of LMFBR Fission Gas Release and NRC Correlation.

Therefore F(T) is interpreted as the fission gas release fraction calculated with an existing LWR (i.e., low burnup) release model. In this manner Eq. (4) becomes applicable to LWR fuel, and F'(Bu,T) is the release fraction corrected for high burnup release enhancement. If the boundary condition,

$$(Bu-20,000) = 0 \quad \text{for } Bu < 20,000 \text{ MWd/t}, \tag{5}$$

is imposed, Eq. (4) is inherently well behaved. The corrected gas release always approaches the uncorrected release at 20,000 MWd/t, and the corrected release never exceeds the physical limitation of 100% release. The method was chosen because of its simplicity and ease of application to existing LWR gas release models.

IV. APPLICATION OF THE NRC CORRELATION

It is assumed that current fission gas models are adequate for burnups to 20,000 MWd/t. To apply the correction for a burnup interval starting at 20,000 MWd/t, the local release fraction F(T) is first calculated with an uncorrected fission gas release model. If the release fraction F(T) were 0.30, for example, a curve, which starts at 30% release at a burnup of 20,000 MWd/t and continues to any required higher burnup, would be generated by means of the correction function. The corrected release values would be taken from this curve for the duration of the burnup interval for which the temperatures are considered constant. The correction function thus produces a family of such curves as shown in Fig. 3, and all of these curves have the shape of the Dutt and Baker curves.

If fuel temperatures change above 20,000 MWd/t, because of either a power change or other cause, a new F(T) would be calculated with the existing uncorrected model. Then a different curve in Fig. 3, based on a new F(T), would be followed for the burnup interval of the new fuel temperature to obtain releases at the new temperature. If the gas release model in an existing code already has a (weak) burnup dependence, the burnup variable in that submodel (only) would be artificially set to 20,000 MWd/t in order to calculate F(T) for burnup intervals above 20,000 MWd/t. In other words, the burnup dependence is superseded above 20,000 MWd/t by the correction method; it is not supplemented.

As an example of applying the correction to a fission gas release model

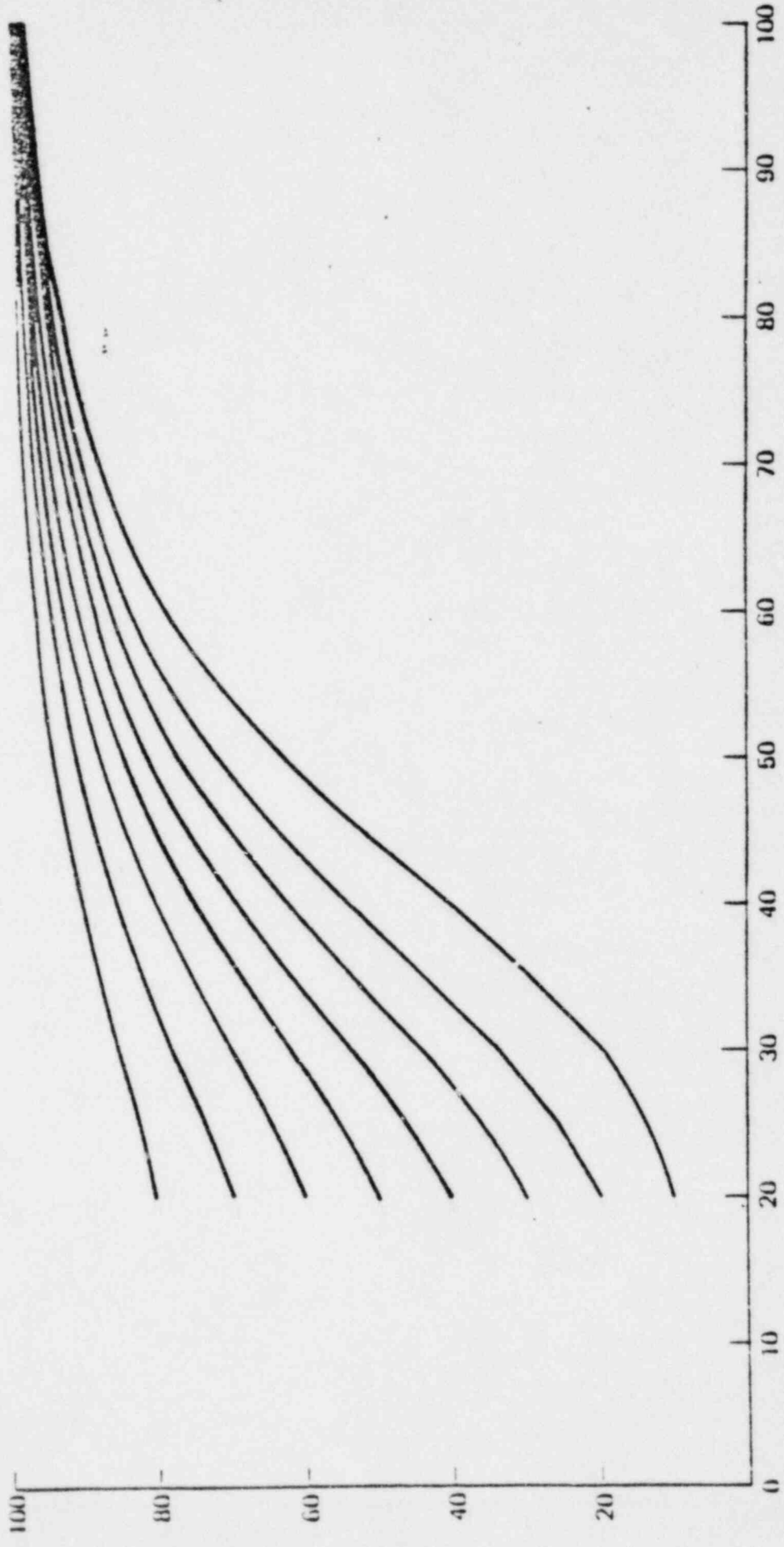

Figure 3. NRC Correlation for Several Initial Release Fractions.

that includes a burnup (or time) dependence, suppose the original model was of the form

$$F = k \sqrt{t} \exp(-Q/RT), \tag{6}$$

where F is the release fraction; k, Q, and R are constants; t is time; and T is temperature. For burnups less than 20,000 MWd/t, the gas release fraction is calculated by Eq. (6) as it stands. The local burnup in each node is also calculated to determine the time at which the burnup is 20,000 MWd/t in that node. This may be denoted as time t_{20}. For burnups greater than 20,000 MWd/t, fission gas release is given by

$$F'(Bu,T) = F_{20} + [1 - F_{20}]\, Y(F_{20},Bu), \tag{7}$$

where $Y(F_{20},Bu)$ is the correction function given in Eq. (2) and

$$F_{20} = k \sqrt{t_{20}} \exp(-Q/RT). \tag{8}$$

Although there remains an implicit dependence on burnup through the temperature variable T, F_{20} is now independent of any explicit dependence on time or burnup. F_{20} must, of course, be recalculated each time the local temperatures are changed. Since the Dutt and Baker correlation, from which the correction function Y was derived, accounts for temperature variations, this implicit dependence on burnup should not be removed. The correction method is relatively easy to apply in this manner and requires very little modification to most existing gas release models.

The approximation afforded by the correction function is dependent on obtaining an accurate release fraction at 20,000 MWd/t. Overpredictions at 20,000 MWd/t would of course be propagated by this method, and such errors would be conservative. On the other hand, underpredictions at 20,000 MWd/t could lead to important nonconservative errors at high burnup. Therefore, a minimum gas release fraction should be assumed as discussed below.

Several sources (15,16) of low temperature (i.e., athermal) release data indicate very low releases on the order of 0.2% at burnups as high as 20,000 MWd/t. The accuracy of these data is unclear, however, because of uncertainties in (a) measurement techniques for very small releases, (b) fuel density effects, and (c) measurement temperature effects. While relative uncertainties are large, the absolute uncertainties are not, and we, therefore, believe low temperature releases are closely and conservatively approximated by an assumed value of 1%; releases of less than 1% at 20,000 MWd/t are not currently justified in safety analyses.

Several additional observations are relevant. (1) Our experience with some vendor models programmed into GAPCON (18) has given near-zero values of F(T) and erratic (and unreliable) release values at high burnups. (2) The difference between 0.1% and 1% release on fuel performance analysis at 20,000 MWd/t is not significant.

In view of the above discussion, a minimum value of 1% should be assumed as a conservative measure of F(T), the uncorrected prediction of fission gas release at 20,000 MWd/t. This limit can be implemented by simple programming logic.

V. SUPPORTING EVIDENCE

Figure 4 shows Westinghouse fission gas release data (9) from the Zorita (Spain) LWR. Individual rod time-averaged power ranged from 3.3 to 9.4 kW/ft in these commercial UO-2 fuels. These data clearly show the burnup enhancement and the general trend is predicted well by the NRC correction factor. The approximation afforded by the correction function is of course dependent on obtaining an accurate release fraction at 20,000 MWd/t, here set at the lower limit of 1%. Any errors or conservatisms present in F(T) will be propagated at higher burnups. It appears from these data that F'(Bu,T) might increase too rapidly at very high burnups, but such an error would be conservative. It should be emphasized that the NRC correction function was not derived from these data so that this is an independent check. Because of the variation in linear heat generation rate (LHGR) for the Westinghouse data, the burnup dependence tends to become obscured by the LHGR dependence. We have noted (17) that a proprietary constant-power subset of these data eliminates the problem.

Figure 5 shows low temperature data from AERE (15). These low temperature UO-2 data of Bellamy and Rich were reported for small diameter fuel rods clad in stainless steel. Fission gas releases were measured at burnups up to 48,000 MWd/t. For comparison with the high burnup correction method, F(T) was again set at the lower limit of 1%. Although the NRC correction is somewhat conservative for this exceptionally high density material (98% T.D. in this case), the fit is still reasonable. This good fit may be somewhat fortuitous, however, since low temperature releases are produced by a different mechanism (recoil) than high temperature releases (thermally activated migration) responsible for the LMFBR

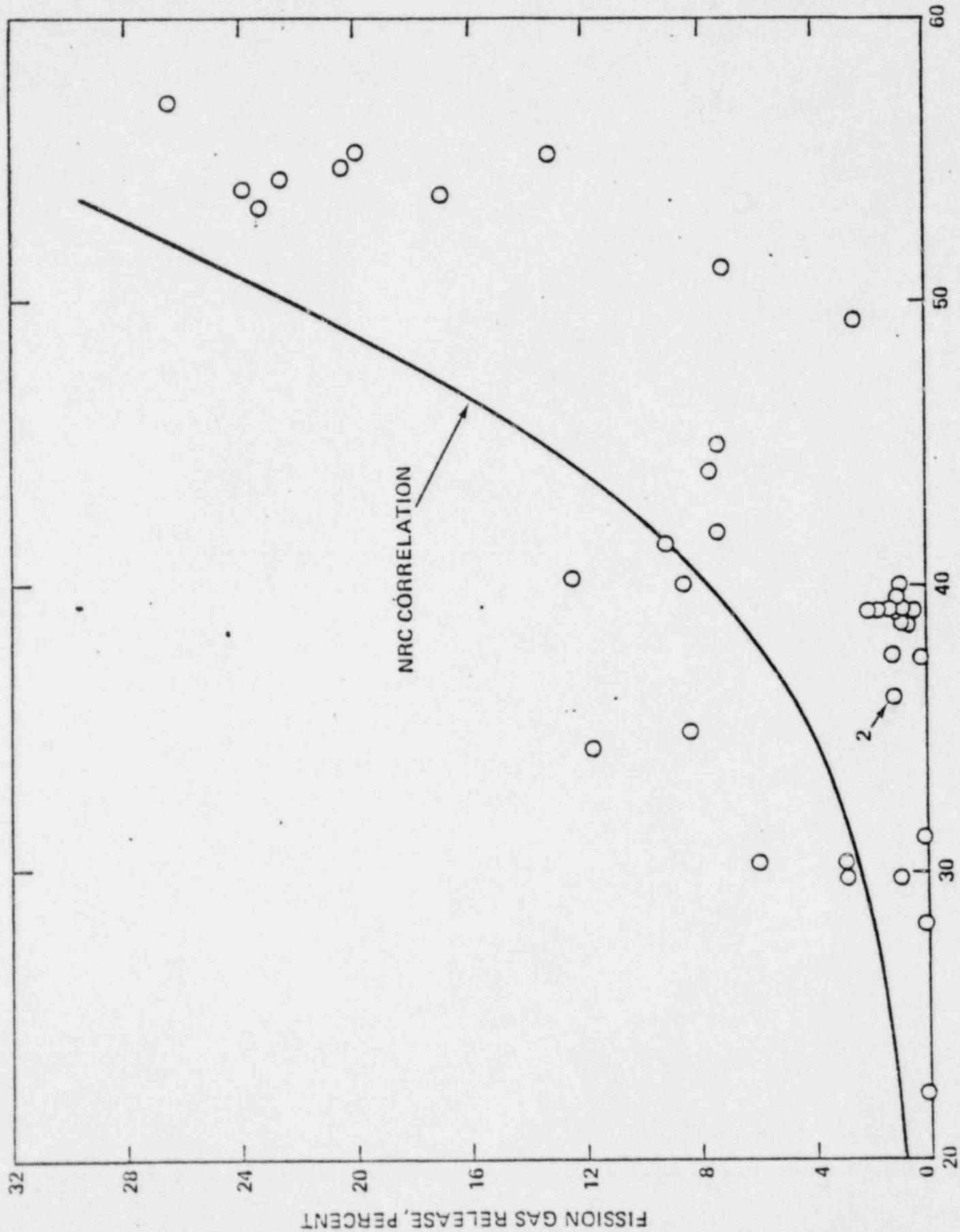

Figure 4. Ideal Lughouse Fission Gas Release Data (From Ref. 9).

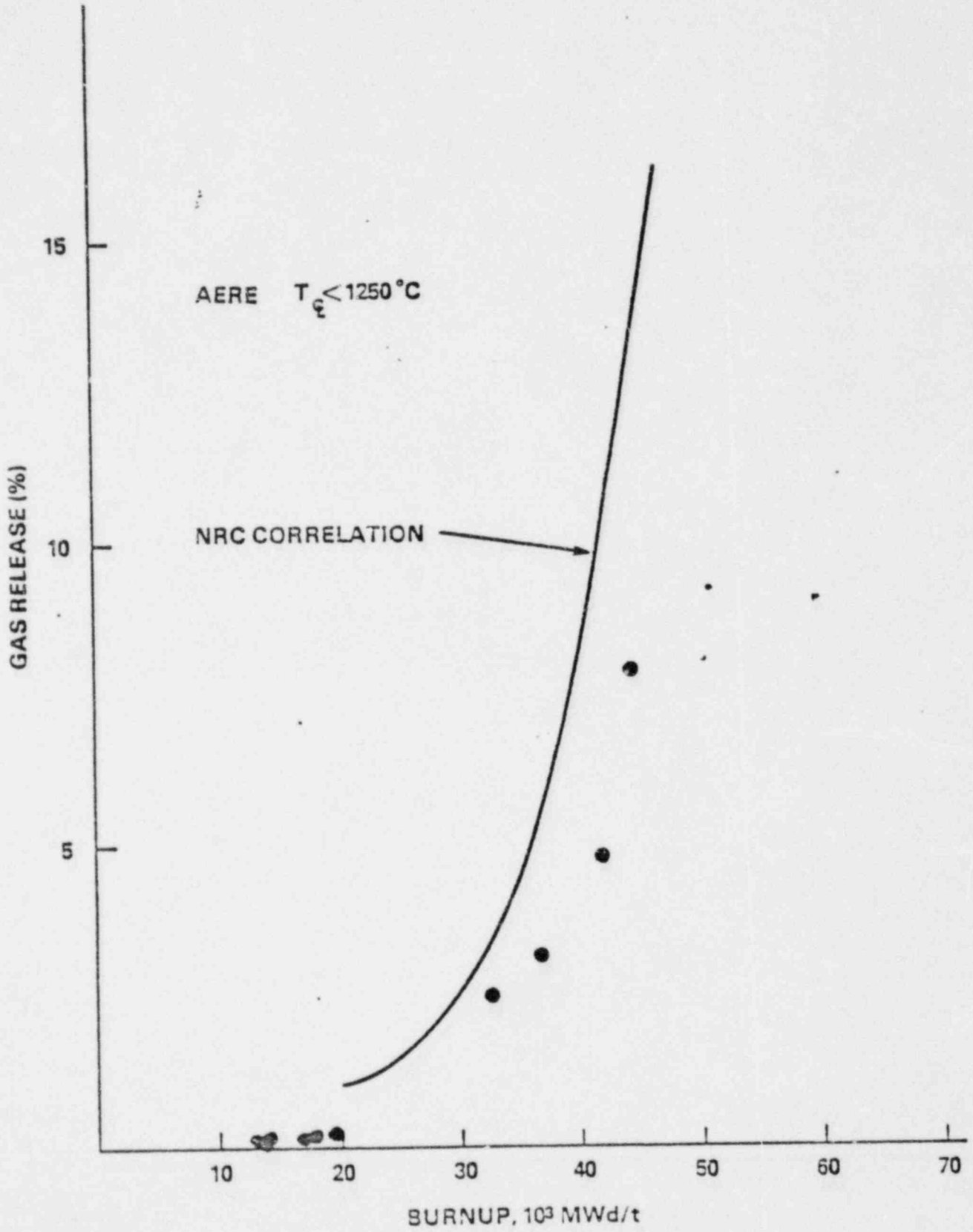

Figure 5. AERE Fission Gas Release Data (from Ref. 15).

(Dutt and Baker) correlation and of primary interest in LWR safety analysis. Both mechanisms, however, should be enhanced by high-burnup microstructural changes even though their geometric dependence might be different. A geometric difference may exist because one mechanism is a surface-related mechanism and the other is a volume-related mechanism.

Experimentally measured fission gas release from German PWR fuel rods (19) is shown in Figure 6. The data were obtained from both pressurized and unpressurized Zircaloy-clad fuel rods irradiated in the Kraftwerk Union reactor at Obrigheim. The NRC correlation is shown in this figure with the fraction F(T) at 20,000 MWd/t set at the lower limit of 1%. At 30,000 MWd/t, these results show a range of fission gas releases that are approximated, rather than bounded, by the NRC correlation.

Figure 7 shows early Babcock & Wilcox data from a paper by Baroch and Rigdon (20). For comparison with the high burnup correction method, F(T) was set equal to the B&W estimate of gas release fraction at 20,000 MWd/t. Because of uncertainties in the power levels reported on these UO-2 test pins, these data are not considered well characterized. In spite of the questionable results, the NRC correction function predicts the trend well.

Figures 8 and 9 show European LMFBR data (21), and it is apparent that the NRC correction reproduces the high burnup trend reasonably well. In each case, the value of F(T) is based on the author's estimate of gas

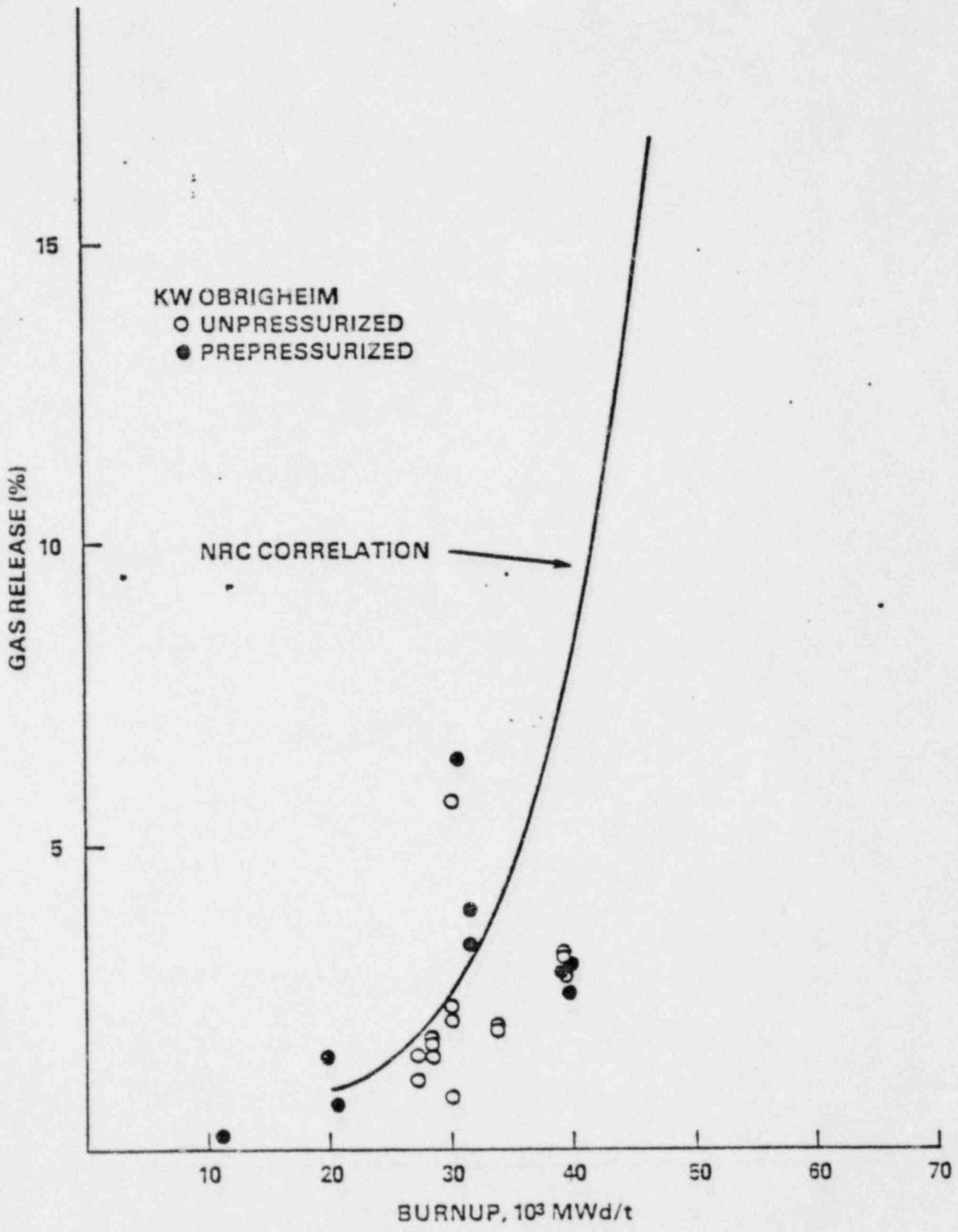

Figure 6. KW Obrigheim Fission Gas Release Data (from Ref. 19).

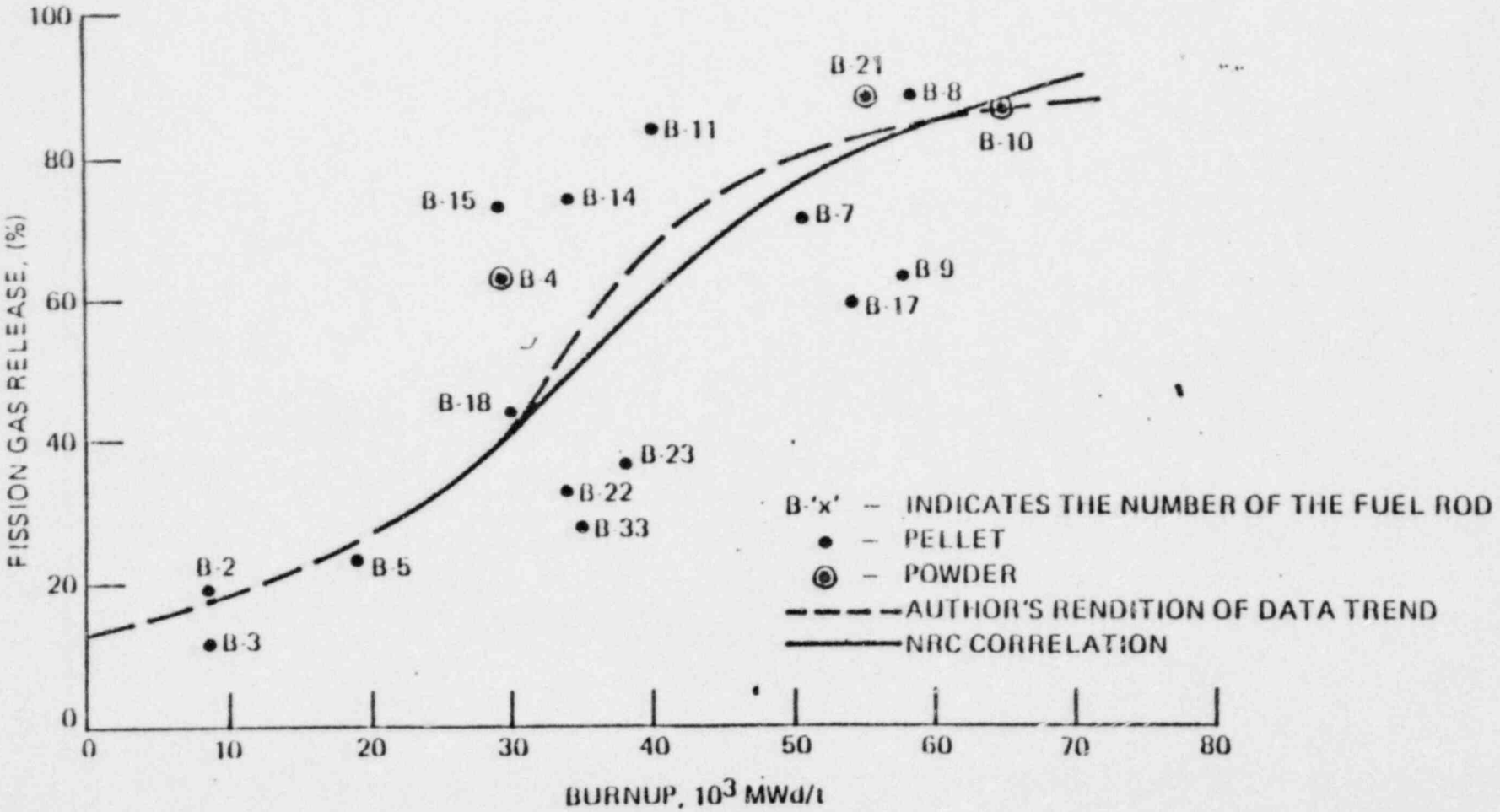

Figure 7. Babcock & Wilcox Fission Gas Release Data (from Ref. 20).

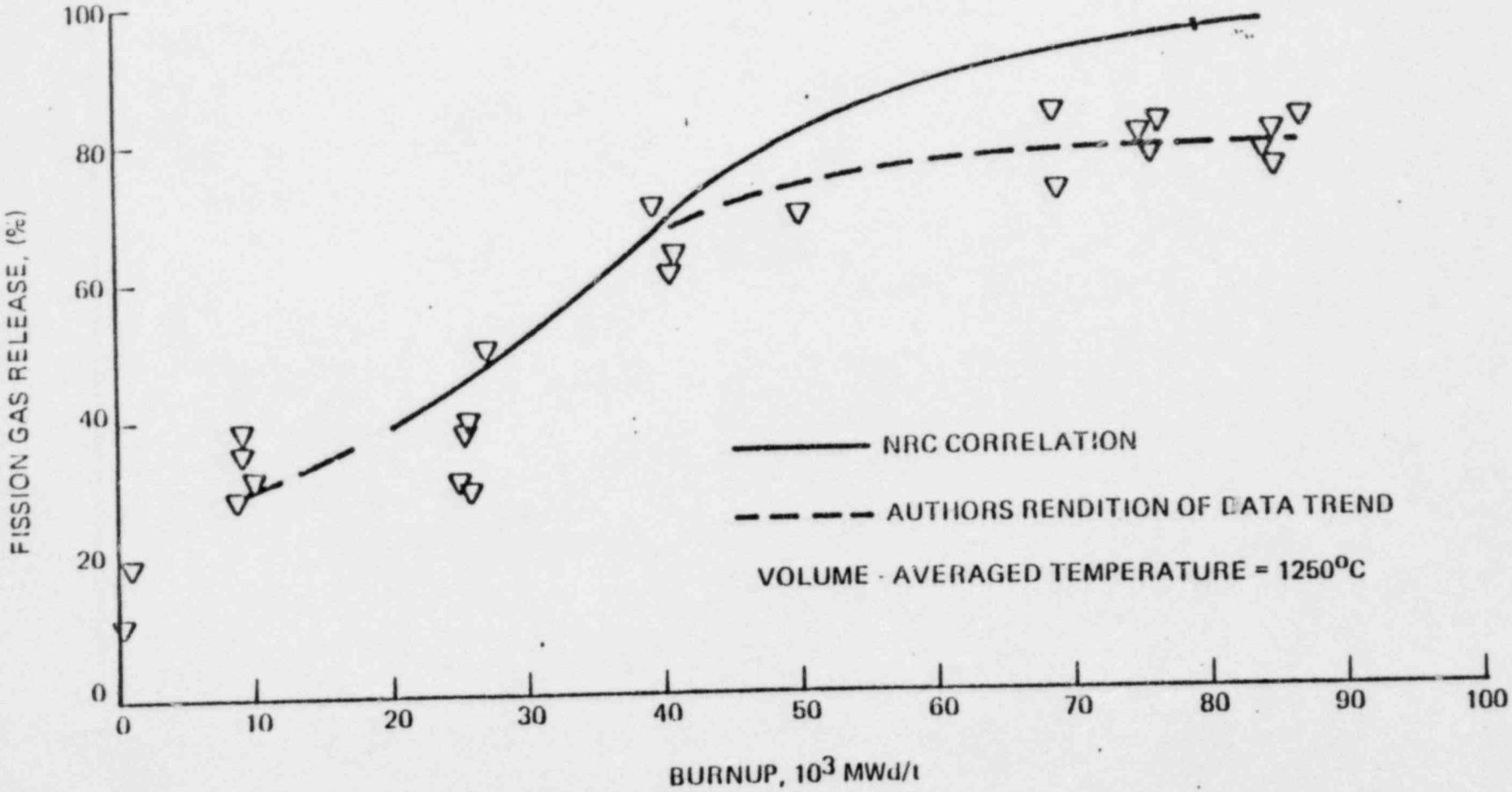

Figure 8. European LMFBR Fission Gas Release Data (from Ref. 21).

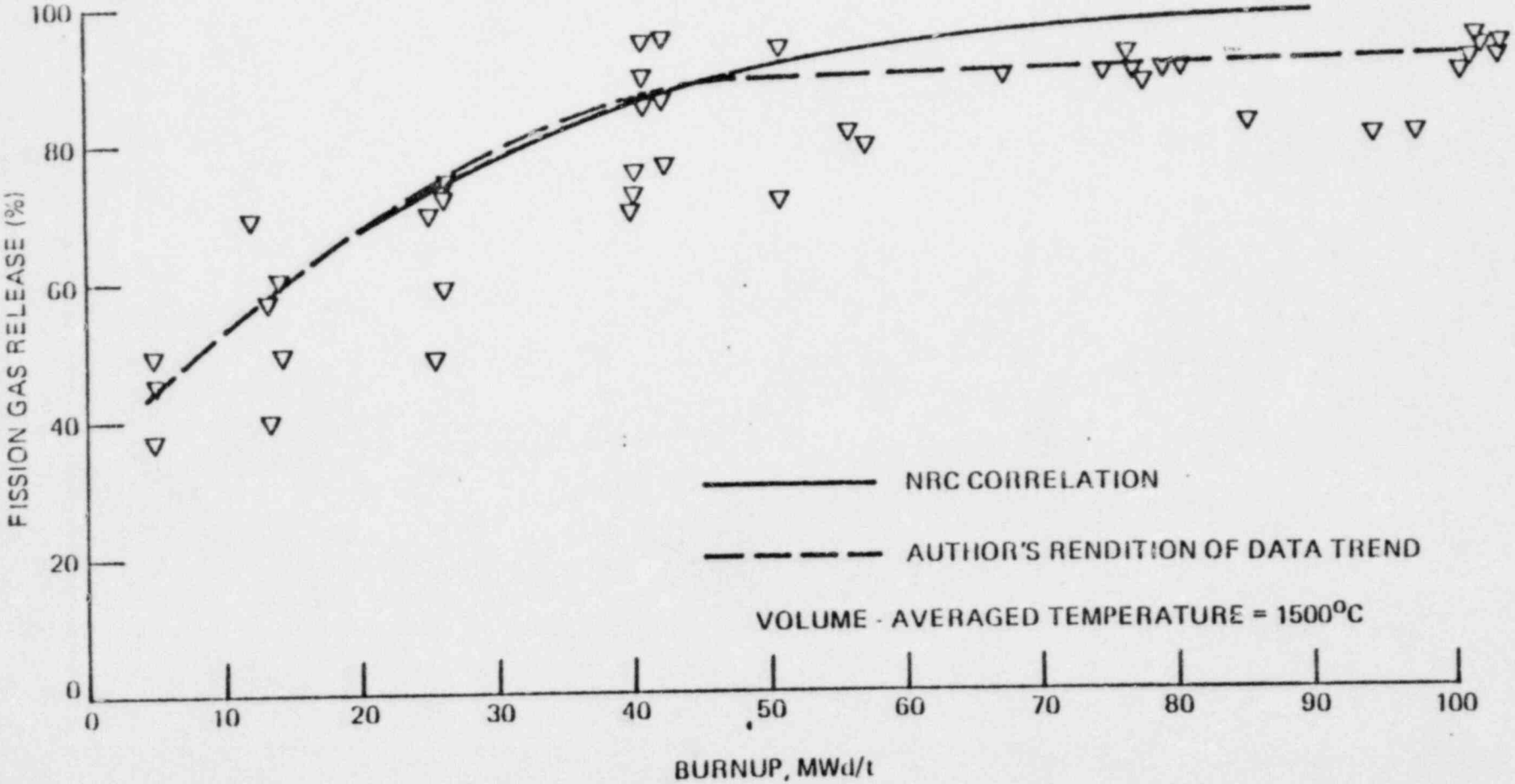

Figure 9. European LMFBR Fission Gas Release Data (from Ref. 21).

release fraction at 20,000 MWd/t. Again it should be emphasized that these data were not included in the derivation of the correction method and thus serve as an independent check. Questions regarding the relevance of LMFBR data will be discussed in the next section.

Several state-of-the-art theoretical models predict a strong burn-up dependence of gas release. Although we have not reviewed these models carefully, both GRASS (22,23) and the British model of Hargreaves and Collins (24) are based on grain-boundary gas-bubble saturation. In sample calculations, Hargreaves and Collins predict saturation in the 10,000 to 30,000 MWd/t range, whereas GRASS did not predict saturation (and hence would not indicate enhanced release) for H. B. Robinson fuels at 28,000 MWd/t. The onset of saturation and enhanced release in these models depends on the accumulated quantity of gas and thus on the early life release rate. The NRC correction method is in qualitative agreement with these theories except that the correction method has a fixed (20,000 MWd/t) threshold corresponding to saturation. This is a limitation of the correction method that is acknowledged, and this limitation could only be remedied by substantial developmental effort.

VI. DISCUSSION

Several comments have been made critizing the NRC high burnup correction method described above. These comments will be discussed below in a question-and-answer format.

Q1. Is it inappropriate to "correct" a fuel design model by simply modifying one portion of the model?

A1. In a thermal performance code it is true that the various fuel behavior models are interrelated. But it is also true that in almost all cases the models for fission gas release are developed empirically outside of a thermal performance code. Some adjustments may be made to other parts of the code to improve overall agreement with data, but this calibration is done in the low burnup range (<20,000 MWd/t) since few high-burnup data are available (the new Westinghouse code PAD-3.3 (2) is a possible exception to this statement since it appears to utilize high-burnup Saxton data). In all cases except PAD-3.3, which has a strong burnup dependence, it is assumed that release rates at high burnup are the same as at low burnup; or, in the case of the Combustion Engineering code FATES (25) and the earlier Westinghouse code PAD-3.1, that the weak burnup dependence exhibited at low burnup is continued at high-burnups. These assumptions are incorrect, and it is more correct to assume that gas release is enhanced in the manner we have suggested. In general, this will have no effect on code calibration since that was accomplished in the unaltered low burnup range.

Q2. Is there any double penalty taken because of implicit temperature effects in the EBR-II (Dutt and Baker) data?

A2. Some measure of double penalty is taken because of our implicit assumption that constant power corresponds to constant temperature at high exposures in EBR-II fuel. This effect, however, is probably unimportant. This point was raised because some fuels (in BWRs) experience a marked decrease in gap conductance with burnup as a result of helium dilution in the gap. The EBR-II plenum volume was about 10 times the BWR fuel plenum volume per unit of fuel. Therefore, gas dilution effects in the EBR-II rods was reduced.

Q3. Does the correction function overpredict LWR release because it was derived from LMFBR fuels which run hotter?

A3. No, it does not. In the Dutt and Baker figure (Fig. 1), each curve has been identified by the LMFBR linear heat rating, and it is well known that, for example, a 7 kW/ft LMFBR fuel will operate at higher temperatures than a 7 kW/ft LWR fuel. But in transforming the Dutt and Baker correlation to a correction function F'(Bu,T), no equivalence of heat ratings was assumed. An LWR case that follows the 7kW/ft LMFBR curve (above 20,000 MWd/t) will undoubtedly be operating at a higher power -- a power that would give a 13% release at 20,000 MWd/t as calculated by a vendor's existing model.

Q4. Are there errors in the correction function that result from errors in GAPCON or the Beyer-Hann gas release model?

A4. No. The correction function is entirely empirical and neither GAPCON nor the Beyer-Hann model was used in its derivation. Determination of coefficients was accomplished with a standard regression procedure.

Q5. Does the correction function grossly overpredict low temperature releases?

A5. Possibly, but probably not. Some low temperature fission gas release data show reasonable agreement with the correction function(see Figs. 5 and 6). However, it has been pointed out that the H.B. Robinson data at 28,000 MWd/t (16) show no enhancement with burnup. The H.B. Robinson releases were small (<1%), and in such cases the corrected value would be no more than 3.5% at 33,000 MWd/t. While such a correction is large on a relative basis (i.e., 3.5 times the uncorrected value), an overprediction of several percent in gas release is a small absolute error. Westhouse also has critically stated that we would overpredict small releases by 5 times (24), but they failed to acknowledge that their new proposed model does the same. Such overpredictions are explainable in terms of the proposed mechanism for enhancement, viz., grain-boundary saturation. This mechanism predicts that a greater burnup would be required for lower temperature fuels in order to produce saturation and its resultant release enhancement. This level of detail is not present in the Dutt and Baker model (nor in our correction function) because low temperature data were not readily available at the time this function was developed. The industry may wish to address this shortcoming in future modeling work. For the present, however, the error is small, conservative, and probably unimportant since it is usually the hot rod (not a low-temperature rod) that is analyzed in the safety analysis.

Q6. Does the use of mixed-oxide (MOX) data lead to overprediction of gas release?

A6. We concluded in GESMO that MOX and UO-2 releases were not significantly different. Statements by Westinghouse (5) support that conclusion. It has been suggested that local temperatures are high in MOX fissile particulates, but calculations (5) show insignificant temperature rises on the order of 11°F. It has also been suggested (27) that local exposures are high in MOX fuel particulates and that this exaggerates the burnup enhancement. This hypothesis, however, depends on particle size and fuel enrichment and would not predict a significant effect for 20-25 w/o PuO-2 EBR-II fuels. The hypothesis has also been challenged because fuel particulates are homogenized in high-temperature regions, which dominate gas release.

Q7. What are the implications of the poor agreement with Saxton high-burnup data of some GAPCON predictions (28) using the NRC burnup correction?

A7. The failure of GAPCON predictions to match the Saxton data when the NRC high-burnup fission gas correction was applied was not a failure of the correction function. The exercise indicated that (a) the unpressurized, small-plenum (~30% smaller than commercial rods per unit of fuel) Saxton rod temperatures are very sensitive to small changes in the fuel behavior models (including gas release) and therefore provide a poor example for this comparison, and (b) that GAPCON is not well verified for high-burnup work. This latter point is illustrated by the large (~800°F) changes in fuel temperature that result from small model changes at moderate burnups (17,000 MWd/t). The Saxton data have also been criticized recently by Ritzman (8).

VII. SUMMARY

A high burnup enhancement of fission gas release has been recognized in the range of LWR fuel burnups, and licensing actions have been taken to include this effect in plant safety analyses. These actions included the development by NRC of a method for correcting existing models, which do not describe releases adequately at high burnup.

The NRC correction method was developed because no other method was available and a safety assessment was required. The method was derived in an approximate manner from LMFBR data. No claim was made for great accuracy in the correction method and several specific shortcomings are noted; however the correction method produces surprisingly good agreement with most of the available high burnup gas release data. Derivation of the correction method, its application, and evidence that supports its validity have been discussed in detail.

Further refinements in gas release modeling are indicated and that burden of development lies with the commercial segment of the industry. To assist in this effort, several sources of unpublished data, which were made available to the NRC during its safety assessment, have been included as appendicies to this report.

VIII. REFERENCES

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APPENDIX A

LMFBR GAS RELEASE DATA

Hanford Engineering
Development Laboratory

P O BOX 1970 RICHLAND, WA 99352

June 21, 1977

7752741

Director, FFTF Project Office (5)
U. S. Energy Research and
Development Administration
Richland, Washington 99352

TRANSMITTAL OF FISSION GAS RELEASE DATA FOR LMFBR MIXED OXIDE FUEL PINS IRRADIATED IN EBR-II

References (1) Telecon, D. S. Dutt (HEDL) with M. Mendonca (US/NRC), "Request for Fission Gas Release Data Used in SIEX Correlation," February 28, 1977.

(2) Personal Communication, C. M. Cox.(HEDL) with E. C. Norman (ERDA/RDD-HQ), May 9, 1977.

By copy of this letter, we are transmitting a tabulation of the subject information and comparison to SIEX predictions (Table 1). Figures 1 and 2 and Table 2 are included to assist in the evaluation of the "quality of fit" as requested in Reference 1 and concurred with in Reference 2. This table contains information on fuel conditions (restructuring etc.) necessary for interpretation of the results.

C. M. Cox

C. M. Cox, Manager

tsm

Enclosures:
Table 1 - Data Used for the Correlation of SIEX
Table 2 - Summary of the Analysis of Variance for the SIEX Fission Gas Release Correlation
Figure 1 - Power-Burnup Range of Data Used in the Fission Gas Release Correlation
Figure 2 - Predicted vs Measured Fission Gas Release

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TABLE 1 - DATA USED FOR CORRELATION OF SIEX AND PREDICTED FISSION GAS RELEASE

PIN-SECTION IDENT.	NUMBER REACTOR CYCLES	CLADDING TYPE	FAB. PIN OD INCHES	PELLET GEOMETRY	PELLET TYPE	FISSION GAS RELEASE MEAS %	FISSION GAS RELEASE PRED %	DISTANCE FROM FUEL BOT. INCHES	FAB. DIAM GAP INCHES	LOCAL POWER (DEP.) KW/FT	LOCAL BURNUP MWD/KG	POST-IRR. DIAM. GAP INCHES	COLUMNAR RADIUS INCHES	EQUIAXED RADIUS INCHES
PNL-X-6 SECTION	>5	SS304	.250	SOLID	PRESSED	10.8	*****	5.5	.0060	7.98	7.01	.0029	.0525	.0695
PNL-X-7 SECTION	>5	SS304	.250	SOLID	PRESSED	25.0	16.5	5.5	.0088	8.96	8.49	.0027	.0585	.0715
PNL 1-5 SECTION F	>5	SS304	.250	SOLID	PRESSED	13.9	10.3	7.4	.0068	8.85	8.17	.0039	.0615	.0677
PNL 1-6 SECTION F	>5	SS304	.250	SOLID	PRESSED	12.9	9.7	7.4	.0060	8.14	8.07	.0023	.0582	.0684
PNL 1-10 SECTION D	>5	SS304	.238	SOLID	PRESSED	8.2	9.6	5.9	.0060	8.43	8.18	*******	.0248	.0474
PNL 1-17 SECTION F	>5	SS304	.238	SOLID	PRESSED	15.1	13.7	7.3	.0058	9.95	8.68	*******	.0371	.0558
PNL 1-18 SECTION F	>5	SS304	.238	SOLID	PRESSED	18.1	15.2	6.5	.0058	9.28	8.95	*******	.0498	.0709
PNL 1-19 SECTION F	>5	SS304	.238	SOLID	PRESSED	29.9	21.5	7.3	.0078	9.20	9.09	*******	.0568	.0767
SECTION CS								4.4	.0078	9.12	9.01	*******	.0431	.0658
SECTION CA								4.4	.0078	9.12	9.01	.0028	.0436	.0603
PNL 3-8 SECTION F	>5	SS304	.250	SOLID	PRESSED	10.7	5.7	7.0	.0061	5.19	23.82	.0029	0.0000	.0467
PNL 3-20 SECTION H	>5	SS304	.250	ANNULAR	PRESSED	39.1	43.9	5.0	.0056	8.96	85.65	.0018	0.0000	.0751
PNL 3-21 SECTION F	>5	SS304	.250	ANNULAR	PRESSED	1.8	*****	7.0	.0057	5.09	27.97	.0044	0.0000	.0448
PNL 3-27 SECTION F	>5	SS304	.250	SOLID	PRESSED	12.5	40.6	7.9	.0056	8.72	82.99	.0057	0.0000	.0288
PNL 3-33 SECTION F	>5	SS304	.250	SOLID	PRESSED	13.1	*****	7.0	.0076	5.05	27.62	.0061	0.0000	.0368
PNL 4-1 SECTION F	>5	SS304	.250	SOLID	PRESSED	62.2	52.8	7.0	.0057	8.96	82.59	.0028	.0413	.0707
PNL 4-20 SECTION F	>5	SS304	.250	ANNULAR	PRESSED	61.8	45.4	7.0	.0058	8.33	81.67	.0023	0.0000	.0756
PNL 4-24	>5	SS304	.250	SOLID	PRESSED	64.9	54.2	7.0	.0060	8.51	81.77	.0024	.0488	.0732

TABLE 1 (Cont'd)

PNLA-10	>5	88308	.250	SOLID	PRESSED	65.4	58.5						
SECTION F								7.0	.0077	8.20	48.54	.0024	.0534	.0751
PNLS-5	>5	55308	.250	SOLID	PRESSED	80.3	72.8						
SECTION F								7.0	.0059	12.98	67.95	.0010	.0756	.0924
PNLS-A	>5	55308	.250	SOLID	PRESSED	100.7	91.7						
SECTION A								1.0	.0059	10.30	52.73	.0024	.0565	.0708
SECTION F								6.9	.0059	12.27	62.79	*******	.0660	*******
SECTION H								10.9	.0059	10.59	54.19	*******	.0606	.0871
SECTION I								11.4	.0059	10.28	52.62	*******	.0647	.0841
PNLS-15	>5	55308	.250	SOLID	PRESSED	97.6	92.8						
SECTION A								1.0	.0058	10.66	53.86	.0038	.0704	*******
SECTION I								7.0	.0058	12.61	63.85	.0062	.0855	*******
SECTION I								11.4	.0058	10.40	53.57	.0032	.0809	*******
PNLS-22	>5	88308	.250	ANNULAR	PRESSED	93.5	78.8						
SECTION D								1.0	.0059	10.74	80.99	.0024	.0547	.0768
SECTION I								7.0	.0059	12.78	68.77	0.0000	.0855	*******
SECTION N								12.6	.0059	9.97	58.83	*******	.0679	.0841
PNLS-25	>5	88308	.250	ANNULAR	PRESSED	99.7	94.9						
SECTION C								1.0	.0057	10.39	55.77	*******	.0756	.0858
SECTION H								7.0	.0057	12.29	66.08	.0027	.0868	*******
SECTION J								12.5	.0057	9.56	51.33	.0021	.0706	.0855
PNL-S-31	>5	88308	.250	SOLID	PRESSED	82.7	78.0						
SECTION G								7.9	.0060	13.81	68.96	0.0000	.0860	*******
PNLS-35	>5	88308	.250	SOLID	PRESSED	73.3	76.0						
SECTION F								7.0	.0077	13.88	68.85	.0015	.0788	*******
PNLS-41	>5	88308	.250	SOLID	PRESSED	83.4	79.6						
SECTION I								11.4	.0056	10.41	15.27	.0015	.0623	.0695
SECTION F								7.0	.0056	12.48	18.25	.0015	.0737	.0782
PNLS-71	>5	55308	.250	ANNULAR	PRESSED	55.2	18.6						
SECTION C								1.0	.0053	10.11	15.82	.0021	.0519	.0755
SECTION H								7.0	.0053	11.99	18.75	.0016	.0686	.0783
SECTION J								12.5	.0053	9.57	14.66	.0031	.0607	.0779
PNL7-10	>5	88316	.250	SOLID	PRESSED	38.1	35.6						
SECTION F1								6.8	.0062	8.90	24.98	.0027	.0867	.0782
SECTION F2								7.5	.0062	8.83	24.78	.0038	.0528	*******
PNLA-11	>5	55316	.250	SOLID	PRESSED	92.2	86.6						
SECTION A								1.0	.0062	9.90	48.03	.0025	.0466	*******
SECTION I								7.0	.0062	11.78	56.91	.0042	.0803	*******
SECTION I								11.4	.0062	9.84	47.74	.0038	.0488	.0802
PNLA-25	>5	55316	.250	SOLID	PRESSED	98.3	87.9						
SECTION A								1.0	.0057	9.79	47.62	*******	.0572	.0752
SECTION I								7.0	.0061	11.61	56.43	.0042	.0822	*******
SECTION I								11.4	.0061	9.71	47.22	.0027	.0489	.0807

TABLE 1 (Cont'd)

PNL 8-2A	>5	SS316	.250	SOLID	PRESSED	62.6	63.4						
SECTION B								1.0	.0058	9.52	86.7A	.0007	.0551	.0619
SECTION G								7.0	.0058	11.26	55.33	.0011	.0718	*******
SECTION J								11.4	.0058	9.81	46.25	.0018	.0633	.0688
PNL 8-3A	>5	SS316	.250	SOLID	PRESSED	65.2	61.9							
SECTION B								1.0	.0058	9.85	45.88	.0007	.0548	.0626
SECTION G								7.0	.0058	11.28	58.38	.0016	.0852	*******
SECTION J								11.4	.0058	9.36	45.81	.0017	.0469	.0737
PNL 8-3A	>5	SS316	.250	SOLID	PRESSED	53.6	52.1							
SECTION E								6.9	.0058	11.46	28.25	.0015	.0451	.0766
SECTION F2								11.9	.0058	9.61	22.88	.0022	.0548	.0788
PNL 9-3A	>5	SS316	.250	SOLID	PRESLUG.	53.8	48.5	6.9	.0055	5.51	48.21	.0029	0.0000	.0557
SECTION I														
PNL 10-2A	>5	SS316	.250	SOLID	PRESLUG.	67.5	66.6							
SECTION E								1.0	.0052	6.94	81.18	.0021	0.0000	.0561
SECTION H								7.0	.0052	8.40	49.85	.0011	.0524	.0491
SECTION C								12.9	.0052	6.58	39.09	.0021	0.0000	.0628
PNL 10-3A	>5	SS316	.250	SOLID	PRESLUG.	71.5	72.5	6.9	.0051	8.51	51.82	.0018	.0559	.0699
SECTION H														
PNL 11-1A	>5	SS316	.250	SOLID	PRESLUG.	59.8	60.8							
SECTION J								7.0	.0059	12.08	29.91	.0012	.0499	.0754
SECTION K								12.8	.0059	9.51	23.54	.0018	.0855	.0758
PNL 11-2A	>5	SS316	.250	SOLID	PRESLUG.	59.6	62.7	7.0	.0060	12.22	30.32	.0011	.0708	.0727
SECTION J														
PNL 11-2A	1	SS316	.250	SOLID	PRESLUG.	29.7	18.9							
SECTION D								1.0	.0057	10.15	1.85	.0046	.0468	.0728
SECTION F								7.0	.0057	7.82	2.10	.0022	.0719	.0713
SECTION I								12.8	.0057	9.42	1.71	.0024	.0581	.0688
PNL 11-2A	1	SS316	.250	SOLID	PRESLUG.	33.9	17.6							
SECTION D								1.0	.0057	9.81	1.79	.0039	.0558	.0669
SECTION F								7.0	.0057	11.43	2.12	.0048	.0892	*******
SECTION I								12.8	.0057	9.11	1.66	.0054	.0541	.0615
PNL 11-3A	1	SS316	.250	SOLID	PRESLUG.	29.7	18.9							
SECTION F								7.0	.0057	12.06	2.20	.0029	.0727	.0737
SECTION D								1.0	.0057	10.18	1.85	.0053	.0406	.0670
SECTION F1								2.0	.0057	10.81	1.97	.0037	.0637	.0687
SECTION I								12.8	.0057	9.45	1.72	.0033	.0592	.0688
PNL 17-6	>5	SS316	.250	SOLID	PRESLUG.	58.1	51.8	7.3	.0058	9.88	31.98	.0015	.0813	.0813
SECTION G														
P17A-5	4	SS316	.250	SOLID	PRESLUG.	32.8	22.6							
SECTION B								8.2	.0058	18.91	3.29	.0021	.0787	*******
SECTION D								6.0	.0058	11.28	3.81	.0016	.0753	*******
								7.9	.3058	11.17	3.37	.0013	.0767	*******

TABLE 1* (Con't'd)

P17A-16	4	SS316	.250	SOLID	PRESSING.	33.7	22.9	4,2	.0054	11.17	3.38	.0023	.0813	*******
SECTION B								6,0	.0100	11.10	3.53	.0023	.0848	.0887
SECTION E								7.9	.0058	11.59	3.91	.0822	.0733	.0760
SECTION H														
P17A-17	4	SS316	.250	SOLID	PRESSING.	32.5	27.1	4,2	.0058	10.75	3.24	.0815	.0733	.0787
SECTION B								7,9	.0058	11.17	3.37	.0808	.0760	.0813
SECTION I								6.0	.0080	10.98	3.48	.0822	.0807	.0867
SECTION F														
P17A-18	4	SS316	.250	SOLID	PRESSING.	31.7	22.7	4,2	.0058	10.59	3.21	.0820	.0741	.0778
SECTION B								6,0	.0060	10.92	3.33	.0823	.0788	.0848
SECTION E								7.9	.0058	10.91	3.38	.0815	.0779	.0808
SECTION H														
P17A-19	4	SS316	.250	SOLID	PRESSING.	30.4	17.0	4,2	.0058	10.28	3.11	.0807	.0782	.0793
SECTION B								6,0	.0080	10.76	3.21	.0806	.0800	.0808
SECTION E								7.9	.0058	10.52	3.18	.0811	.0787	.0867
SECTION I														
P17A-20	4	SS316	.250	ANNULAR	PRESSED	15.5	11.7	6.1	.0100	10.79	3.72	.0838	.0573	.0787
SECTION D														
P17A-26	4	SS316	.250	ANNULAR	PRESSED	11.9	13.2	6.1	.0080	11.01	3.53	.0826	0.0000	.0808
SECTION E														
P17A-27	4	SS316	.250	ANNULAR	PRESSED	10.5	12.0	6.1	.0080	10.80	3.46	.0815	0.0000	.0709
SECTION D														
P17A-29	4	SS316	.250	ANNULAR	PRESSED	20.0	32.5	6.1	.0100	10.99	3.77	.0825	.0807	.0808
SECTION D														
P17A-31	4	SS316	.250	ANNULAR	PRESSED	17.7	21.8	6.1	.0081	10.97	3.68	.0817	.0813	.0787
SECTION D														
P17A-33	4	SS316	.250	ANNULAR	PRESSED	14.1	27.0	6.1	.0099	11.09	3.65	.0821	0.0000	.0787
SECTION E														
P20-5	>5	SS316	.250	SOLID	PRESSING.	37.8	34.8	1,4	.0074	11.92	6.12	.0811	.0792	.0848
SECTION D								6,0	.0076	13.98	7.16	.0811	.0833	.0867
SECTION G								11.9	.0076	11.79	6.05	.0812	.0753	.0808
SECTION L														
P20-12	>5	SS316	.250	SOLID	PRESSING.	25.5	19.8	1,5	.0075	11.65	5,98	.0813	.0827	.0848
SECTION D								6,1	.0075	13.58	6,97	.0808	.0847	.0847
SECTION G								11.9	.0075	11.56	5.98	.0810	.0827	.0827
SECTION I														
P20-15	>5	SS316	.250	SOLID	PRESSED	32.9	38.8	1,4	.0077	12.40	6,09	.0815	.0787	.0793
SECTION D								6,1	.0077	14.04	7,07	.0810	.0793	.0847
SECTION G								11.9	.0077	11.79	5.98	*******	.0733	.0813
SECTION I														
P20-24	>5	SS316	.250	SOLID	PRESSING.	39.8	39.8	1,5	.0054	11.92	5,90	.0813	.0713	.0844
SECTION D								4,2	.0054	13.89	6,88	.0807	.0787	.0854

TABLE 1 (Cont'd)

P20-3A	>5	55316	.230	SOLID	PRESLUG.	38.3	28.1						
SECTION D								1.6	.0035	11.98	5.83	.0011	.0478	.0823
SECTION G								6.1	.0035	13.97	6.83	.0009	.0778	.0867
SECTION I								11.9	.0035	11.77	5.78	.0007	.0715	.0833
P20P191	>5	55316	.230	SOLID	PRESLUG.	34.3	28.8						
SECTION BB								1.6	.0095	11.48	6.02	.0021	.0773	0.00##
SECTION BD								6.2	.0095	13.58	6.98	.0013	.0813	.0967
SECTION BG								12.1	.0095	11.28	5.79	.0025	.0757	*******
P20P1918	>5	88316	.230	SOLID	PRESLUG.	65.8	28.1							
SECTION B								1.6	.0037	12.07	5.85	.0010	.0473	.0827
SECTION D								6.2	.0037	13.99	6.78	.0010	.0733	.0890
SECTION G								12.1	.0037	11.78	5.69	.0009	.0708	.0813
P23A-2I	>5	55316	.230	SOLID	PRESLUG.	58.5	29.2							
SECTION I								2.1	.0069	9.87	17.58	.0021	.0628	.0882
SECTION P								6.1	.0069	11.16	88.25	.0015	.0667	.0719
SECTION S								7.0	.0069	11.58	85.75	.0011	.0725	.0[illegible]
SECTION U								10.3	.0069	10.52	81.69	.0030	.0548	.0708
SECTION X								13.3	.0069	9.18	36.21	.0013	.0632	.0789
P23A-2S	>5	55316	.230	SOLID	PRESLUG.	78.7	27.3							
SECTION I								2.3	.0052	9.66	17.87	.0022	.0578	.0781
SECTION P								6.0	.0052	11.38	84.87	.0022	.0667	.0729
SECTION S								7.0	.0052	11.76	86.17	.0028	.0708	*******
SECTION AA								10.3	.0052	10.70	82.28	.0028	.0673	.0717
SECTION BB								13.8	.0052	9.47	37.18	.0026	.0686	.0789
P23A-2A	>5	55316	.230	SOLID	PRESLUG.	53.5	31.7							
SECTION J								1.8	.0051	9.81	18.88	.0032	.0578	.0781
SECTION L								3.8	.0051	11.38	21.72	.0019	.0672	.0723
SECTION P								6.8	.0051	11.81	22.68	.0018	.0701	.0723
SECTION T								10.4	.0051	10.68	20.68	.0024	.0667	.0699
SECTION V								12.9	.0051	9.29	17.81	.0018	.0589	.0697
SECTION X								12.8	.0051	9.35	17.92	.0021	.0618	.0723
SECTION Z1								13.8	.0051	9.22	17.68	.0023	.0538	.0699
SECTION BB								12.7	.0051	9.48	18.81	.0024	.0621	.0[illegible]
P23A-2P	>5	55316	.230	SOLID	PRESLUG.	61.5	32.2							
SECTION G								1.8	.0050	9.83	8.53	.0036	.0588	.0719
SECTION I								3.8	.0050	10.58	8.98	.0028	.0665	.0692
SECTION L								6.8	.0050	10.98	10.28	.0023	.0687	.0722
SECTION N								10.8	.0050	9.68	9.13	.0037	.0616	.0681
SECTION P1								13.8	.0050	8.76	7.79	.0042	.0568	.0738
P23A-3I	>5	55316	.230	SOLID	PRESLUG.	51.9	31.8							
SECTION I								1.8	.0052	9.83	18.87	.0035	.0582	.0684
SECTION K								3.5	.0052	11.26	21.56	.0018	.0698	.0719
SECTION N								6.5	.0052	11.85	22.89	.0019	.0687	.0724
SECTION P								10.8	.0052	10.86	20.88	.0017	.0695	.0727
SECTION V								13.8	.0052	9.22	17.65	.0023	.0621	.0748
P23A-3J	>5	55316	.230	SOLID	PRESLUG.	68.6	36.8							
SECTION I								1.8	.0070	9.55	18.51	.0027	.0608	.0693
SECTION K								3.6	.0070	10.96	21.24	.0023	.0699	.0724
								6.6	.0070	11.49	22.28	.0021	.0727	*******

TABLE 1 (Cont'd)

P234-55	>5	55316	.250	SOLID	PRESSING.	51.0	59.1						
SECTION G								.0	.0048	9.12	8.78	.0038	.0638	.0788
SECTION I								3.0	.0048	10.43	10.18	.0019	.0788	.0788
SECTION L								6.0	.0048	10.99	10.88	.0013	.0738	*******
SECTION N								10.0	.0048	9.76	9.58	.0028	.0719	.0818
SECTION P1								12.9	.0048	8.42	8.83	.0038	.0648	.0778
P234-58	>5	55316	.250	SOLID	PRESSING.	48.2	52.8						
SECTION G								.0	.0047	9.54	9.08	.0039	.0628	.0788
SECTION I								3.0	.0047	11.12	10.58	.0028	.0692	.0718
SECTION L								6.0	.0047	11.47	10.87	.0019	.0777	.0811
SECTION N								10.0	.0047	10.11	9.59	.0028	.0729	.0778
SECTION P8								12.9	.0047	8.76	8.31	.0037	.0667	.0762
P234-59	>5	55316	.250	SOLID	PRESSING.	53.0	62.5						
SECTION I								.0	.0047	9.97	8.98	.0034	.0652	.0727
SECTION K								3.0	.0047	11.00	10.47	.0018	.0718	.07
SECTION N								6.0	.0047	11.00	10.81	.0016	.0729	.08
SECTION P								10.7	.0047	9.91	9.08	.0028	.0718	.0767
SECTION R								12.1	.0047	9.86	8.68	.0024	.0718	.0761
SECTION T								12.7	.0047	8.78	8.33	.0028	.0658	.0786
P234-60	>5	55316	.250	SOLID	PRESSING.	53.9	67.8						
SECTION P								.0	.0047	10.56	10.33	.0024	.0598	.0708
SECTION M								6.0	.0047	12.39	12.12	.0018	.0709	.0728
SECTION P								6.0	.0047	12.73	12.45	.0012	.0765	*******
SECTION R								10.2	.0047	11.38	11.08	.0018	.0707	.0779
SECTION T								13.3	.0047	9.62	9.81	.0023	.0695	.0753
ANLA	>5	55316	.250	SOLID	PRESSING.	45.6	25.9						
SECTION EM								1.0	.0050	8.53	6.13	.0042	.0532	.0723
SECTION EN								7.0	.0050	10.15	7.24	.0016	.0718	.0787
ANLB	>5	55316	.250	SOLID	PRESSING.	94.5	98.1						
SECTION EM								7.0	.0053	12.11	59.68	.0027	.0487	*******
E-N029	>5	58316	.250	SOLID	PRESSED	48.8	52.6						
SECTION C								.5	.0051	10.26	10.98	.0018	.0508	.0525
SECTION G								7.0	.0051	12.68	24.27	.0005	.0649	.0782
SECTION J								9.4	.0051	11.68	22.58	.0008	.0441	.07
SECTION L								12.6	.0051	9.98	19.23	.0017	.0499	.05
E-N089	>5	55316	.250	SOLID	PRESSED	50.2	50.7						
SECTION J								4.8	.0052	11.75	22.75	.0005	.0628	.0839
SECTION G								7.8	.0052	12.21	23.69	.0007	.0668	.0717
E-N078	>5	58316	.250	SOLID	PRESSED	61.9	68.3						
SECTION H								5.8	.0054	9.89	39.38	0.0000	.0424	.0488
SECTION L								11.9	.0054	7.92	31.56	.0018	.0438	.0457
E-N159	>5	58316	.250	SOLID	PRESSED	63.3	66.8						
SECTION G								6.9	.0055	10.12	68.42	.0018	.0629	.0669
SECTION K								13.1	.0055	7.65	30.58	.0014	.0597	.0654
SECTION L								13.1	.0055	7.65	30.58	.0018	.0617	.0737
E-N035	>5	55316	.250	SOLID	PRESSED	48.0	49.4						
SECTION G								12.4	.0053	8.31	32.81	.0009	.0598	.0658

FIGURE 1

GAS RELEASE DATA-BURNUP VS. POWER

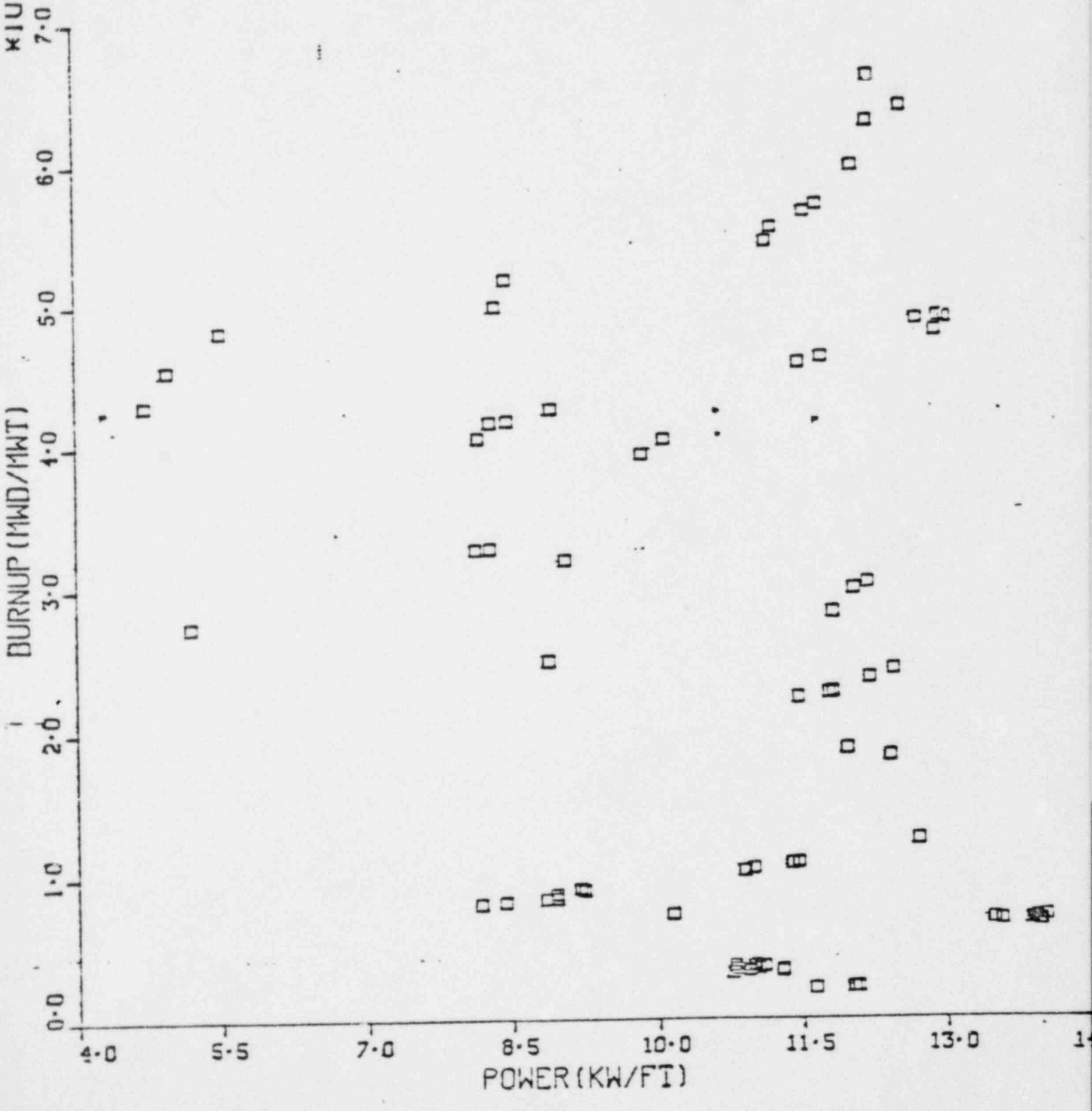

FIGURE 2

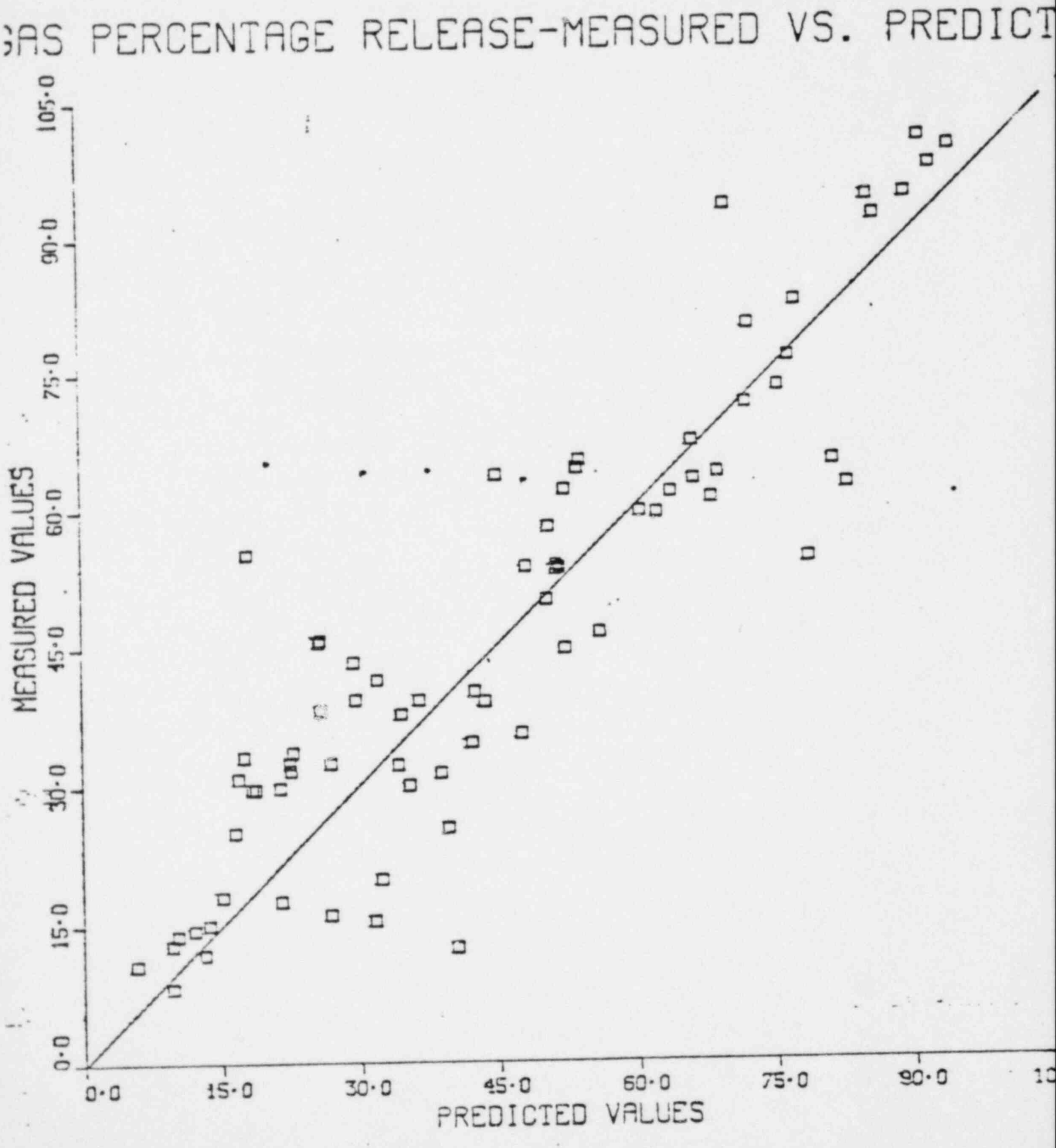
GAS PERCENTAGE RELEASE-MEASURED VS. PREDICT
MEASURED VALUES
PREDICTED VALUES
0·0
15·0
30·0
45·0
60·0
75·0
90·0
105·0

TABLE 2

ANALYSIS OF VARIANCE TABLE FOR FISSION GAS RELEASE RESIDUALS

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	EXPECTED MEAN SQUARE
Between Assemblies	3345	18	185.8	$\sigma_1^2 + 3.76\,\sigma_2^2$
Within Assemblies	5345	55	97.2	σ_1^2
TOTAL	8680	73	119.0	

From the Expected Mean Squares:

Within Assembly Standard Deviation, σ^1, is . . . 9.86%

Between Assembly Standard Deviation, σ^2, is . . . 4.86%

Total Standard Deviation 10.91%

APPENDIX B

CORRECTIONS FOR LMFBR GAS RELEASE DATA

CORRECTIONS FOR LMFBR GAS RELEASE DATA

The following corrections should be made to the gas release data given in Table 1 of the Appendix A:

PNL-3-23, 27 and 33 should have predicted percent releases of 6.74, 6.4 and 5.92, respectively;

PNL-3-27 should have a burnup of 27.6 MWd/KG instead of 42.93 MWd/KG.

APPENDIX C

KERNKRAFTWERK UNION OBRIGHEIM GAS RELEASE DATA

Measured Fission Gas Release Data from FWR Fuel Rods

Techn. Bericht Nr. RB 21/RB 31/172/77
Verfasser: Dr. Hering RB 21
R. Manzel RB 31

Technischer Bericht

RB 21/RB 31/172/77
Numerierung (Dokumentstelle/lfd. Nr./Jahr)

Titel

Erlangen, 28.09.1977
Ort, Datum

Measured Fission Gas Release Data from PWR Fuel Rods

Bezug (z.B. Projekt, F+E-Vorhaben)

Dr. Hering RB 21 3083
R. Manzel RB 31 2368
Verfasser Dokumentstelle Tel.

Stichworte (max. 12) zur Kennzeichnung des Berichtsinhaltes

I Fuchs 28.9.77
Klassen Unterschrift/Klassifizierer

Aktenzeichen, Ordnungszahl bzw. Sachgruppennummer

Zusammenfassung | Textseiten 3 | Bilder — | Schaltpläne — | Diagr./Oszgr. — | Tabellen 1 | Quellenverz.

Summary:

This paper presents fission gas release data measured on fuel rods from the Obrigheim pressurized water reactor. These rods include:
(1) standard fuel rods (one to four reactor cycles),
(2) high-power test rods,
(3) fuel rods of a cycling experiment.

Dunderlich 27.9.77
Gegenzeichnung

W. Hering
D. Manzel 27.9
Unterschrift Verfasser

Verteiler (falls nur Zusammenfassung zur Kenntnisnahme: „z.K." anfügen):
2× KWU/PSW 2 Ffm.

RB Hr. Knödler
RB 2 Hr. Holzer
RB 3 Hr. Dr. Stehle
RB 21 Hr. Fuchs
RB 31 Hr. Knaab
RB 31 Hr. Schlemmer

Thema, Anlaß Measured Fission Gas Release Data from Kraftwerk Union Fuel Rods

This report describes the results of fission gas release measurements performed by Kraftwerk Union. The results presented have been obtained from the Obrigheim pressurized water reactor and refer to standard fuel rods, high-power experimental rods and fuel rods from a cycling experiment. All fuel rods had Zircaloy claddings.

The fuel rods with standard fuel have been irradiated during one to four reactor cycles. Fuel rods from the first core were unpressurized (fuel assembly 83, 104 and 120) whereas all reload pins were prepressurized.

The prepressurized high-power rods from the fuel assembly 247 had non-standard fuel (experimental fuel with smaller grain size, higher porosity and higher enrichment).

Also the fuel rods of the cycling experiment (see table) had non-standard fuel with a higher enrichment. With the exception of the fuel rods 7-22 and 8-22 all rods were prepressurized.

Description of the measuring method: The fuel rods were pierced at a point within the upper gas plenum inside an evacuated container. The overflowing gas was pumped out and the quantity of gas at N.T.P. was calculated from the system pressure rise. Subsequently a gas sample was taken for mass spectrometric analysis. The detection efficiencies of the measuring device are:

Kr	0.01 % vol.	He	0.03 % vol.
Xe	0.02 % vol.	H_2	0.06 % vol.
		N_2	0.09 % vol.
		O_2	0.03 % vol.
		CO_2	0.3 % vol.
		CO	0.2 % vol.
		Ar	0.01 % vol.

In the following table the measured fission gas release data is shown including data characterizing the power history. $\bar{q}'$ is the LHGR averaged over the pin length and the irradiation time. q'^{max}_{local} is the maximum local LHGR having occurred at the specified average burnup of the fuel rod. The value q'^{max}_{local} has not been calculated for all fuel rods.

The data characterizing the power history is based on in-core instrumentation measurements and neutron-physics calculations. For the calculation of the fractional fission gas release the fission gas produced is calculated on the basis of an energy generation of 200 MeV per fission and a yield of 30 noble gas atoms per 100 fissions.

KWO Fission Gas Release Data

Fuel Assembly	Rod	Burnup (rod av.) MWd/t(U)	Full Power Days	Linear Rod Power $\bar{q}$' W/cm	$q'_{max\ local}$ W/cm	at Burnup (rod av.) MWd/t(U)	Fission Gas Krypton cm^3(NTP)	Xenon cm^3(NTP)	Total cm^3(NTP)	Release %	
83	0224	38 520	1331	162			3.3	54.7	58.0	3.11	Standard Fuel Rods
	0206	38 630		163	250	21 200	3.4	49.4	52.8	2.83	
	0392	33 600		141			2.3	31.2	33.5	2.08	
	0447	38 520		162	246	11 900	3.9	56.3	60.2	3.24	
104	7307	28 160	1091	150	258	7 900	1.9	23.7	25.6	1.88	
	7321	33 880		160	244	14 500	2.2	29.3	31.5	1.92	
	6025	28 160		150			1.5	19.0	20.5	1.51	
	5747	28 160		150			1.8	22.4	24.2	1.78	
126	8382	27 110	1074	147			1.5	19.2	20.7	1.59	
	8610	30 080		163	248	22 000	2.3	31.6	33.9	2.34	
	8663	27 110		147	273	6 400	1.3	14.1	15.4	1.18	
	5348	30 080		163	247	21 600	2.4	28.2	30.6	2.11	
	8613	30 060		163	248	22 000	0.9	11.5	12.4	0.85	
	9492	30 080		163			6.4	77.6	84.0	5.77	
127	1295	31 550	869	210	292	8 500	3.9	53.1	57.0	3.91	
	1240	30 580		203	291	8 500	6.5	86.4	92.9	6.47	
	2879	31 550		210	274	10 000	3.5	45.7	49.2	3.37	
133	2736	20 500	562	211	267	0	0.5	6.4	6.9	0.73	
	2784	19 700		202	274	8 400	1.1	12.9	14.0	1.53	
154	4176	39 560	1169	195			3.9	43.3	47.2	2.59	
	4613	39 560		195			4.6	50.7	55.3	3.03	
	4798	38.890		192			4.4	47.3	51.7	2.87	
212	11159	11 080	290	221	279	0	0.4	0.7	1.1	0.21	
247	150	19 350	307	364	468	19 800	18.4	186.9	205.4	25.86	High Power Fuel Rods
	45	39 140	607	353	459	27 600	79.8	781.5	860.3	55.48	
	79	40 000		370			61.1	497.0	558.1	34.80	
	98	31 350		290	365	15 600	46.0	369.5	414.5	33.20	
	1 D22	30 100	Irradiation time 600 days,				0.46	2.11	2.57	1.66	Cycling Experiment
	2 D22	30 100	880 cycles,				0.33	1.74	2.07	1.34	
	3 D14	30 600	lower power level				0.27	1.04	1.31	0.83	
	4 D14	30 600	150...300 W/cm (gradient				0.38	1.64	2.02	1.27	
	5 D05	31 600	along the rod),				1.12	5.97	7.09	4.67	
	6 D05	31 600	upper power level				0.87	4.48	5.35	3.55	
	7 - 22	30 100	about 400 W/cm.				1.66	9.30	10.96	6.94	
	8 - 22	30 100					1.68	8.92	10.60	6.75	

APPENDIX D

AEC MEMORANDUM FROM STODDART TO TEDESCO

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

APR 16 1974

Robert Tedesco, Assistant Director for Containment Safety, L
THRU: V. Benaroya, Chief, Effluent Treatment Systems Branch, L

NOBLE GAS RELEASE FROM MIXED OXIDE FUEL

On March 22, 1974, I attended a meeting held at East-West Towers to discuss the ETSB input to the draft Generic Environmental Statement on the Use of Mixed Oxide Fuels (GESMO). A list of attendees is enclosed.

Max Freshley of BNWL expressed concern that the gaseous source term for GESMO was too low with respect to our calculated releases of noble gases. According to information from Combustion Engineering, mixed oxide fuels release substantially more noble gases than are released from uranium oxide fuels because of increased temperature related diffusion of gases held in the fuel matrix. Mr. Freshley made reference to experimental work performed by Carroll and Sisman at Oak Ridge National Laboratory, showing increased release rates for mixed oxide fuels. Based on this work, the noble gas release rate from mixed oxide fuel specimens would be approximately an order of magnitude higher than that expected from comparable uranium oxide fuels.

Mr. Freshley also stated that his own earlier work in this area showed essentially no difference in noble gas releases between uranium oxide and mixed oxide fuels, but that he was no longer convinced of the validity of his own work.

We reviewed the report by Carroll and Sisman, ORNL, published in Nuclear Technology, Vol. II, August 1971, and find that the data contained in this report have no direct relevance to Mr. Freshley's position in that the burnup parameters and gaseous fractional releases are substantially lower than those used in our calculations of the GESMO source term. However, the temperatures of the fuel were in the same general range (800 to 1100°C) as anticipated for GESMO. Carroll and Sisman reported Kr-88 fractional release rates on the order of 10^{-4} at 0.23% burnup and "about one order of magnitude" greater at higher burnups; these

correspond to fractional release rates on the order of 0.01% and 0.1% ("Fractional release rate" is the ratio of release rate to birth rate). As expected, releases were largely temperature dependent. Carroll and Sisman also stated that the observed rates were about an order of magnitude higher than those expected from comparable specimens of uranium oxide.

We calculated the release of noble gases for the GESMO source term on the assumption that the escape rates for noble gases would be essentially the same for mixed oxide fuels as have been observed for uranium oxide fuels. This assumption was based on operating data from plants using mixed oxide fuels. It is expected that the temperatures of mixed oxide fuels will essentially be the same as present generation uranium oxide fuels. A review of the literature concerning noble gas releases confirms this assumption.

A. Olsen, in ORNL-4901, Part 5 (Fast Breeder Reactor Oxide Fuels Development, 1973) presented data on the percentage of Kr-85 released for a wide range of burnups for uranium oxide and mixed oxide fuels. In the range of burnups and linear heat rates which are anticipated for GESMO, integrated fractional releases were as follows:

Fuel Type	% Burnup (Avg. % FIMA)*	Peak Linear Heat Rate (kw/ft)	Fission Gas Release % Kr-85
Oxide	3.8	16.4	30
Oxide	4.4	25.9	47
Oxide	4.9	21.6	44
Oxide	4.0	17.9	41
Mixed Oxide	6.2	18	31
Oxide	5.8	17.0	47
Mixed Oxide	5.0	20.6	44
Mixed	4.1	13.4	38

*FIMA: Fissions per Initial Actinide Metal atom

J. Hoffman and D. Coplin, in GEAP-4596, "The Release of Fission Gases from Uranium Dioxide Pellet Fuel Operated at High Temperatures", General Electric Co., Atomic Power Equipment Department, San Jose, (1964), reporting on uranium oxide fission gas release studies, report that in the range of 800° to 1400°C (volumetric average temperature), most of the observed fractional releases were in the range of 2% to 30%, with no data showing releases greater than 50%. Furthermore, the level of burnup appeared to have no effect on the fractional noble gas release.

J. Rallin and D. McClintock, reporting in "Interim Postirradiation Examination of SAXTON PuO_2-UO_2 Fuel Rods", Trans. Am. Nucl. Soc., Vol. 10, No. 1 (1967), showed that approximately 2% of the available Kr and Xe gas was released from pelletized mixed oxide fuel at a peak burnup of 6,100 MWD/Tonne.

Mr. Freshley, in BNWL-366, "The Irradiation Behavior of UO_2-PuO_2 Fuels in PRTR" (1967), reports on the fractional noble gas release, in percentage of Xe+Kr release versus volumetric average fuel temperature, for mixed oxide fuel with burnups ranging from 100 to 5,000 MWD/tonne. In the temperature range from 800° to 1400°C, the data were within a range of 15% to 30%. M. Freshley also reported data in the range from 1400 to 2200°C, with fractional releases increasing to 90% at 2200°C.

The Carroll and Sisman data show fractional release rates for Kr-88, while the measurements reported in the other cited references are given in terms of integrated fractional releases of either Kr-85 or total noble gases. The assumption of Carroll and Sisman, i.e., noble gas fractional release rates for mixed oxide fuels will be on the order of a factor of ten higher than for uranium oxide fuels, if valid, should show a corresponding increase in the integrated fractional release of noble gases from mixed oxide fuels. The cited data demonstrate that this is not the case.

The Olsen data show no significant difference in the quantity of noble gas released in either uranium oxide or mixed oxide fuels at burnups and temperatures applicable to GESMO. Statistically, Olsen's data show that slightly more noble gas is released from uranium fuel than from mixed oxide fuel; this corresponds to the slightly higher fission product yield for noble gases calculated for uranium oxide fuel.

A comparison of Hoffman and Coplin's data for uranium oxide fuels with that of Freshley for mixed oxide fuels shows close correlation in the 800 to 1400°C temperature range. The data of Rollin and McClintock for mixed oxide fuel is within the same order of magnitude but the fuel temperatures were not specified.

In summary, all of the cited data, with the exception of that of Carroll and Sisman, show that the observed fractional release of noble gases, within the range of anticipated operating temperatures for GESMO, will be on the order of 2% to 30% for both uranium oxide fuels and mixed oxide fuels and that the fraction released is temperature dependent. We have found no information in the literature to substantiate any difference in noble gas fractional releases between mixed oxide fuels and uranium oxide fuels.

Based on our evaluation of available data, we conclude that there are no information available at present that warrants a change in our gaseous source term as presented in our memorandum of 1/28/74. We will continue our review of ongoing programs and literature publications in this area.

J. T. Collins
for
P. Stoddart
Effluent Treatment Systems Branch
Directorate of Licensing

Enclosure:
List of attendees

cc: A. Giambusso
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J. Glynn
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J. Austin
A. Clark
W. Thompson
G. Kligfield
L. Rubenstein
J. Shea
J. Collins
P. Stoddart

ATTENDANCE LIST
GESMO SOURCE TERM DISCUSSION

March 22, 1974

AEC	BNWL
R. Odegaarden	R. Widrig
J. Austin	S. Goldsmith
A. Clark	M. Freshley
W. Thompson	J. Burnum
G. Kligfield	
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