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SAVANNAH RIVER PLANT

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REACTOR ROOM EXPERIMENTAL SF_6 TESTS TO DETERMINE PROBABLE STACK ACTIVITY RESPONSE TO RADIOACTIVE RELEASES (U)

INTRODUCTION AND SUMMARY

A reactor incident involving a release of radioactive nuclides to the atmosphere must be evaluated quickly to provide the data necessary to make correct emergency response decisions. A critical component in the evaluation process is an early determination of the probable magnitude of the incident based on the stack activity monitor response. The monitor response is functionally dependent on the air flow characteristics in the reactor process room and the amount of material being released. The probable stack activity monitor response has been experimentally determined based on SF_6 releases in the process room near the reactor. For a 45 ml SF_6 release, the response was consistent for one or two ventilation fans on-line. Results of these analyses are shown in Figures 2-7 for the six tests. The conclusion from these results is that a simple model can adequately represent a puff release to obtain data useful for emergency response within a few (less than 10) minutes. Furthermore, the mathematical model, as currently programmed to perform these estimates, should be revised to provide more accuracy. This revision consists of assuming a response curve of a chi-squared distribution with three degrees of freedom.

DISCUSSION

A series of tests[1] were performed in L-Area in late February by the SRL Reactor Engineering Division to determine the air flow characteristics in the process area. The occurrence of these tests provided an opportunity for the Environmental Transport Group to perform some additional experiments[2] with a minimum of additional effort. These additional experiments were performed to obtain information that could be useful for obtaining an early estimate of the probable total stack activity monitor response in the event of an accidental release of activity in the process room. If it can be shown that the stack activity monitor would exhibit a "typical" shape as the activity passes the monitor, the magnitude of an incident release may be reliably predicted for emergency response purposes long before the release to the environment is complete.

BACKGROUND INFORMATION

Computer methods developed at SRL for emergency response associated with reactor accidents have required an estimate of core damage before a source term could be defined. This was a severe restraint because estimates of the extent of core damage were based on analysis methods that were sensitive to basic, and probably unreliable, assumptions. These analyses could be accomplished only after a significant delay and could result in inappropriate emergency response action. Therefore, a program was developed to base source term estimates on the response of the total stack activity monitor located in each reactor area. Locations of these monitors are being standardized, and responses to unit releases of various isotopes have been computed[3] to develop source terms from the monitor response. This capability is offered as an option in the SRL Emergency Response Code.

The most probable incident leading to core damage is criticality following a loading error during charge-discharge operations. This is still a very low probability event and historically no unintentional criticality has ever occurred at the Savannah River Plant. Any fuel melted during such an incident is expected to remain in a molten state for only a brief period due to fuel slumping, or termination of the incident by safety system activation. Therefore, any activity release is expected to be brief also, and may be simulated as a puff release into the process room. This puff release mode has been modeled in the emergency response code to provide information pertaining to the extent of the incident as early as possible. If the release is other than brief, this will be apparent from the monitor response and could be evaluated accordingly.

A successful mathematical simulation of the monitor response to a puff release in the process room requires some knowledge of the shape of the response curve as the radioactivity is transported past the monitor. To determine this shape, puff releases of SF_6 were performed in L Area which is being re-activated for production. The SF_6 gas was used because it is easily detected, non-radioactive, non-toxic, and apparently causes no reaction detrimental to reactor components. These tests also were performed with the assistance of SRL Reactor Engineering during other ventilation and flow distribution tests being performed prior to L Area startup. The objective of the monitor response tests was to show a characteristic response that would allow simulation by a simple algorithm that would apply for the likely conditions prevailing during an incident.

SF_6 RELEASES

All SF_6 releases were made manually by the discharge of SF_6 loaded syringes being held immediately above the reactor tank in the process room. Each discharge was performed at the same location. SF_6 samples for the detector were drawn from a point within the 200 foot discharge stack at an elevation of about 148 feet. Therefore, the SF_6 gas was transported through the same filter and confinement system through which any incident radioactivity would pass. Two series of tests were performed. The first series consisted of three discharges of 10 ml SF_6 each. These tests proved to be inadequate for reliable analyses since the response from the SF_6 monitor was only about 15 to 18% of full scale on the most sensitive usable scale. However, these tests were included in the analyses (with the exception of the first test in the series in which the syringe was not adequately purged before filling). The second series consisted of four tests using 45 ml of SF_6. Two of these tests were performed with two ventilation fans running, the final two with only one fan running.

MATHEMATICAL MODEL

In the event of a brief release of radioactivity the stack activity monitor indication would be expected to rise rapidly to a peak value and then decrease approximately exponentially. The mathematical model that was employed was based on the chi-squared distribution which was intuitively chosen because it appeared to have the basic properties required. This distribution could be made to rise as steeply as required by adjusting the degrees of freedom, m, and the area under the curve integrates to unity which is convenient for normalization. This chi-squared distribution is shown in Figure 1[4] for several degrees of freedom. The number of degrees of freedom implemented was arbitrarily chosen as five, which is one of the curves represented in Figure 1. The error associated with the use of this curve is minimized by normalizing the curve peak value to the peak indication of the activity monitor, and also by normalizing the displacement of the peak from the y-axis (a time displacement on the x-axis) to agree with the time of the activity monitor indication. Since the peak response of the activity monitor is expected to occur very soon (minutes) after any puff release in the process room, the magnitude of this peak and the time of occurrence effectively fixes the magnitude of the incident if the mathematical model is realistic. This then allows a quick assessment of expected environmental consequences of the incident to suggest the appropriate emergency response actions. The results from the SF_6 tests were used to test the model.

The curves of Figure 1 are defined by

$$f(w) = \left[w^{(m-1)/2}\right] \div \left[2^{m/2}\,\Gamma(m/2)\right] exp\left(-w/2\right) \quad (1)$$

where $f(w)dw$ is the frequency distribution function of w, and

m is an integer referred to as the number of degrees of freedom

and $$\int_0^\infty f(w)\,dw = 1.0 \quad (2)$$

To relate Equation 1 to the experimentally determined SF_6 concentrations (and consequently to potential radioactive releases), the parameter w will be transformed to time and f(w) will therefore represent monitor response intensity. Equation 1 may be expressed more generally as

$$\phi = \alpha\, t^{\gamma} e^{(-\beta t)} \quad (3)$$

where $$\alpha = a \div \left[2^{\{(\gamma+1)/2\}}\,\Gamma(\{\gamma+1\}/2)\right]$$

a = normalization factor to adjust the peak value of f(w) to agree with the observed peak monitor response.

Equation 3 is now assumed to be the theoretical monitor response for a puff release and time is measured relative to the time of the first perceptible response. Equation 3 appears to have three free parameters that could be used for curve fitting, α , β , and γ. However, after normalization to the peak observed value it is seen that β is a function of γ which reduces the free parameters to two.

In addition to peak value normalization it is also necessary to normalize to the time at which the peak value occurs. This normalization is also referenced to the time at which a response by the monitor is first perceptible. The time value to produce a peak value of Φ in Equation 3 can be determined as follows

$$\frac{d\Phi}{dt} = \alpha\frac{d}{dt}(t^{\gamma})e^{-\beta t} + \alpha t^{\gamma}\frac{d}{dt}(e^{-\beta t})$$

$$= \alpha t^{\gamma-1}e^{-\beta t}(\gamma - \beta t)$$

and for Φ_{max}, $t = \gamma / \beta$ (5)

Now the normalization factor Ψ, required to adjust t in Equation 3 to agree with the observed value of t at the peak, can be determined.

At maximum monitor response, $t^{*}_{\Phi_{max}} = \Psi t_{obs} = (\gamma / \beta)$

as determined by Equation 5, where t is the theoretical value.

Therefore,

$$\Psi = (\gamma / \beta) / t_{obs} \quad (6)$$

Equation 3 may now be expressed as

$$\Phi = \alpha^{*} t^{\gamma} e^{-\beta^{*} t} \quad (7)$$

Where the constants α^{*} and β^{*} now include the time normalization constant Ψ.

Therefore, once a value of γ , has been chosen the values of α and β are fixed as a result of the normalization restraints.

Thus it is determined that there is only one parameter in Equation 7 that can be adjusted to force a fit to the experimental data being tested. Equation 7 represents the theoretical fit to a given experiment and comparisons may be made to determine γ for the best fit.

ANALYSIS RESULTS

In Figures 2 through 7 the results of using various values of γ to simulate the experimental data are shown. In each figure the experimental data are presented as a heavy solid line. The trial curves are as indicated in the legends appearing on each figure. Four curves are presented on each figure to show the effect of various values of γ . The error associated with each curve relative to the experimental data are also indicated in the legends.

Figures 2 and 3 are the analyses for the first series in which 10 ml of SF_6 was released. As stated earlier, this amount of SF_6 was not sufficient to obtain a satisfactory response at the detector. However, it is noted that the results from this series agreed reasonably well with the curve obtained with a value of 5/2 for γ . This is equivalent to the chi-square distribution with five degrees of freedom as programmed for emergency response before any experimental data were available.

Figures 4 and 5 are results from the second series of tests in which 45 ml SF_6 were released. This amount was sufficient to overrange the most sensitive usable range on the SF_6 monitor, however this was compensated by switching to the next higher attenuation during the high response period. In these two tests there were two ventilation fans in operation which is normal for normal reactor operations. In the next two tests, Figures 6 and 7, there was only one fan operating. This is a more likely configuration that would prevail during a radioactive release since operating procedures specify this condition for an emergency situation. One fan, however, will deliver about 65 to 70% of the ventilation flow that two fans deliver. These four tests, Figures 4 through 7, show results that are consistent and significantly different from the first series. As shown, a value of 5/2 for γ over-estimates the integral release by 50-60%. The best-fit curves in this series required a value of γ in the range of 0.4 to 0.6 which is more closely associated with a chi-square distribution with three degrees of freedom, i.e., $\gamma = 3/2$.

The results from the tests releasing 10 ml SF_6 indicated the chi-square distribution with five degrees of freedom as programmed is adequate for estimating source terms for emergency response to short term releases. However, these results were not corroborated at higher releases (45 ml) that should have been more accurate. The possibility of the SF_6 reacting with the reactor confinement system has not been determined. This would probably influence these results more at low level releases since a higher percentage of the relesed material would be involved. The results using 45 ml releases were consistent but there was an unexpected flat region at the peaks. The cause is currently speculative and also is probably associated with the confinement system.

CONCLUSIONS

The distribution curve for estimating source terms currently in use is too conservative based on the 45 ml releases. Since the 45 ml results are held to be more indicative of system response these results will be used as a basis for using a distribution curve that is more representative of these results. A response curve more closely related to a chi-square distribution with three degrees of freedom ($\gamma = 3/2$) should be used to provide early and more realistic estimates of integral source terms.

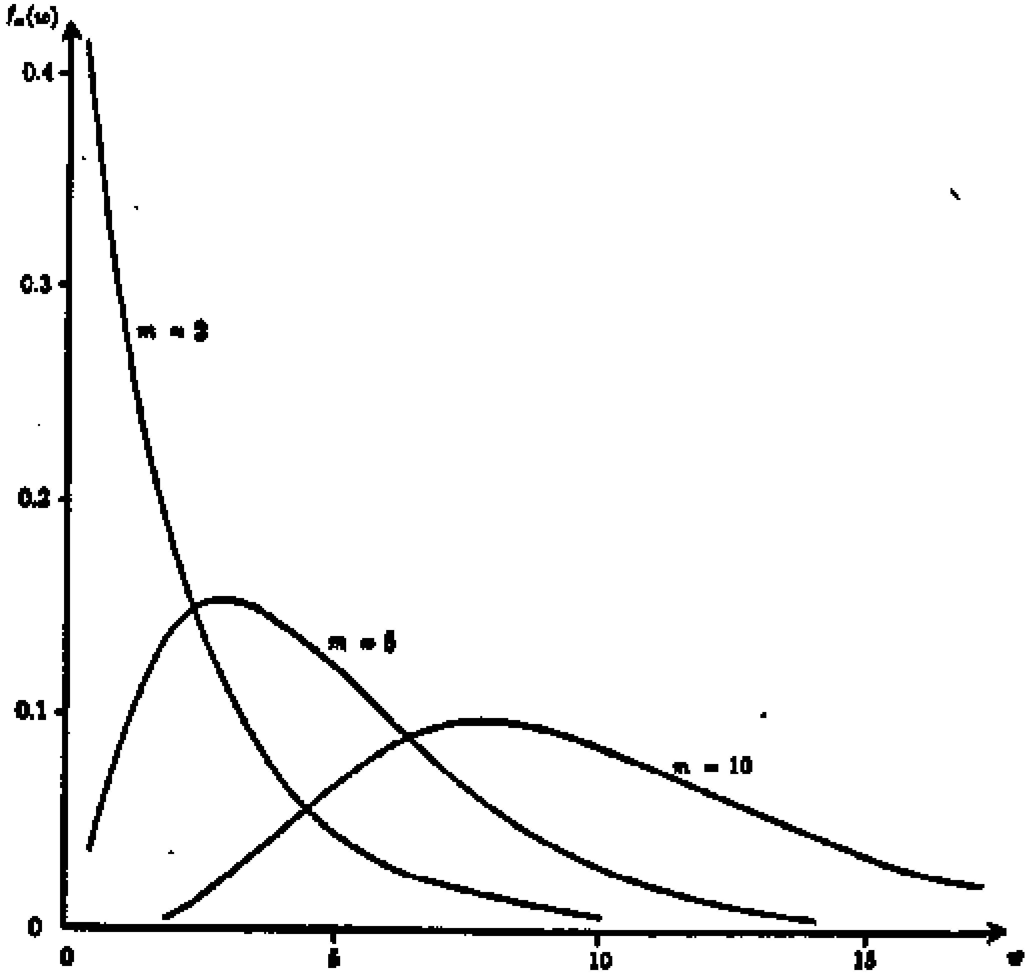
REFERENCES

1. S. F. Petry, et. al., L-Area Ventilation Tests - 1984, DPST-85-336, Mar. 1, 1985.

2. R. C. Milham and R. E. Cooper, SF_6 Measurements To Determine Probable Stack Activity Response To Radioactive Releases From The Reactor Room, DPST-85-802, Sept., 1985.

3. R. E. Grove, Total Stack Activity Monitor Response To Fission Product Noble Gas And Halogen Isotopes, RTR-2234, May, 1985.

4. R. S. Burington and D. C. May, "Handbook Of Probability And Statistics", McGraw-Hill Book Col., 1970.



χ^2-*Distribution Density Function* $f_m(w)$.

$$f_m(w)\,dw = [(w^{(m/2)-1})/(2^{m/2}\Gamma(m/2))]\exp(-w/2)\,dw,\ w > 0,$$

Figure 1

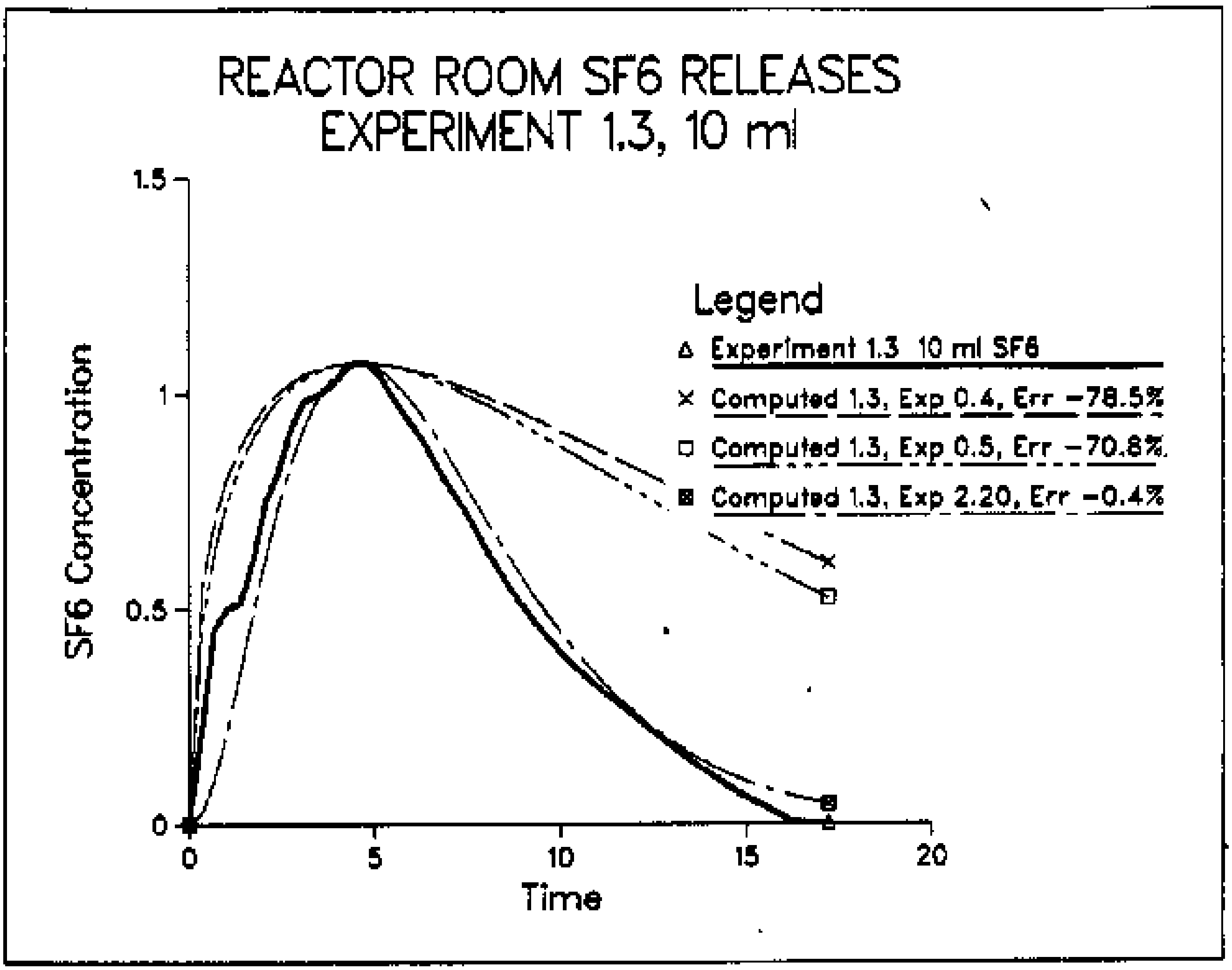

REACTOR ROOM SF6 RELEASES
EXPERIMENT 1.3, 10 ml
SF6 Concentration
Time
1.5
1
0.5
0
0
5
10
15
20
Legend
Experiment 1.3 10 ml SF6
Computed 1.3, Exp 0.4, Err -78.5%
Computed 1.3, Exp 0.5, Err -70.8%
Computed 1.3, Exp 2.20, Err -0.4%

Figure 3

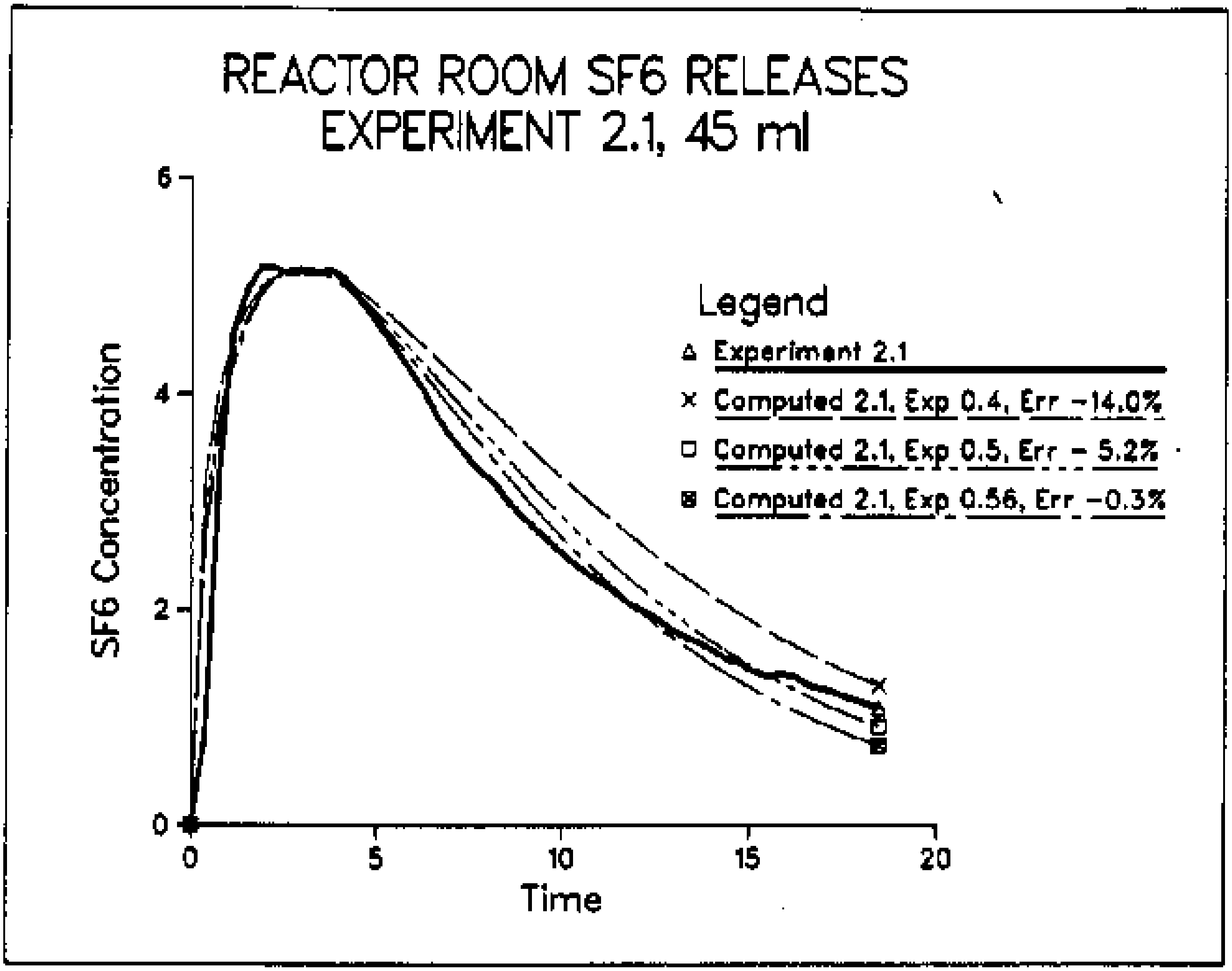

REACTOR ROOM SF6 RELEASES
EXPERIMENT 2.1, 45 ml
SF6 Concentration
Time
0
2
4
6
0
5
10
15
20
Legend
Experiment 2.1
Computed 2.1, Exp 0.4, Err -14.0%
Computed 2.1, Exp 0.5, Err - 5.2%
Computed 2.1, Exp 0.56, Err -0.3%

Figure 4

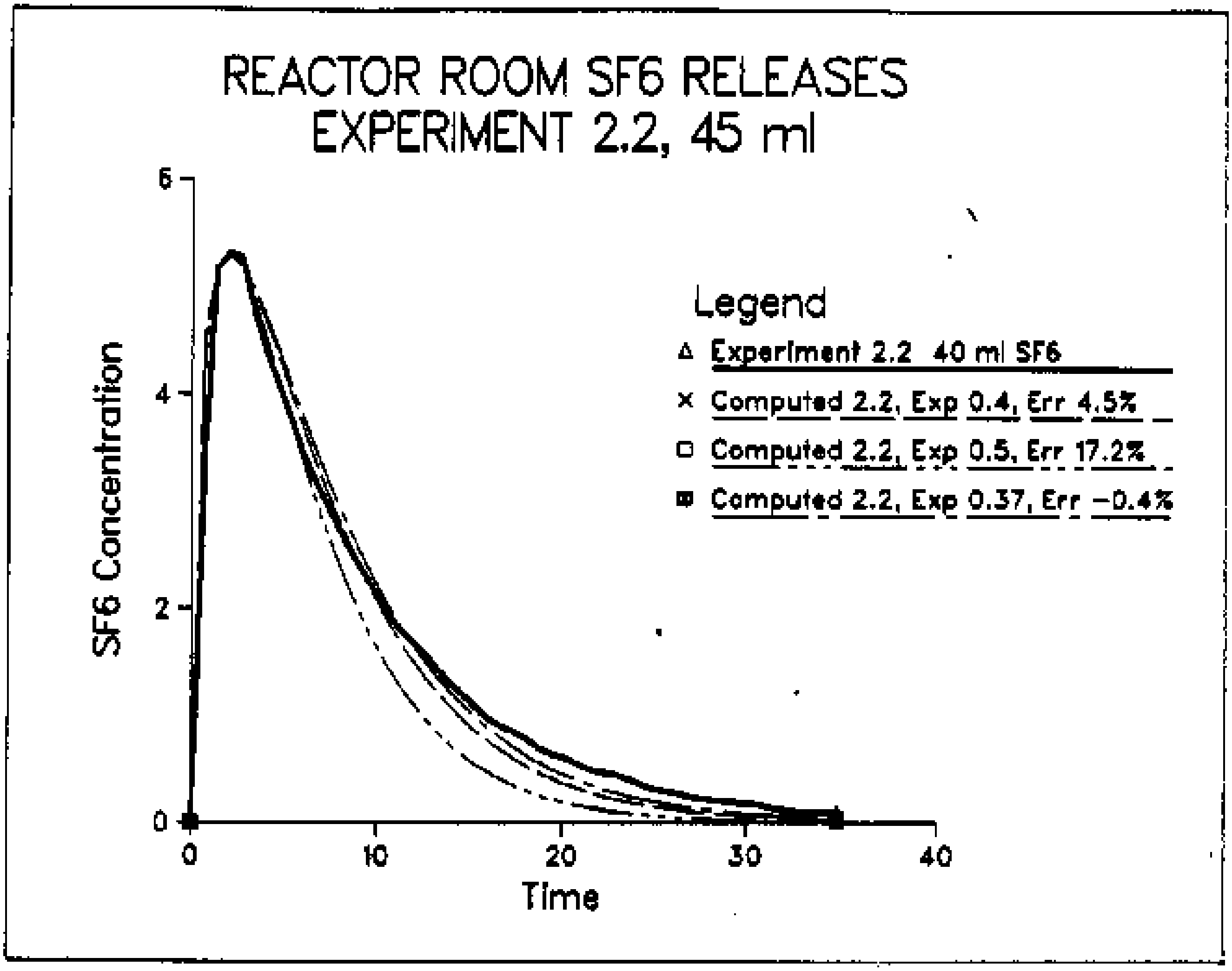
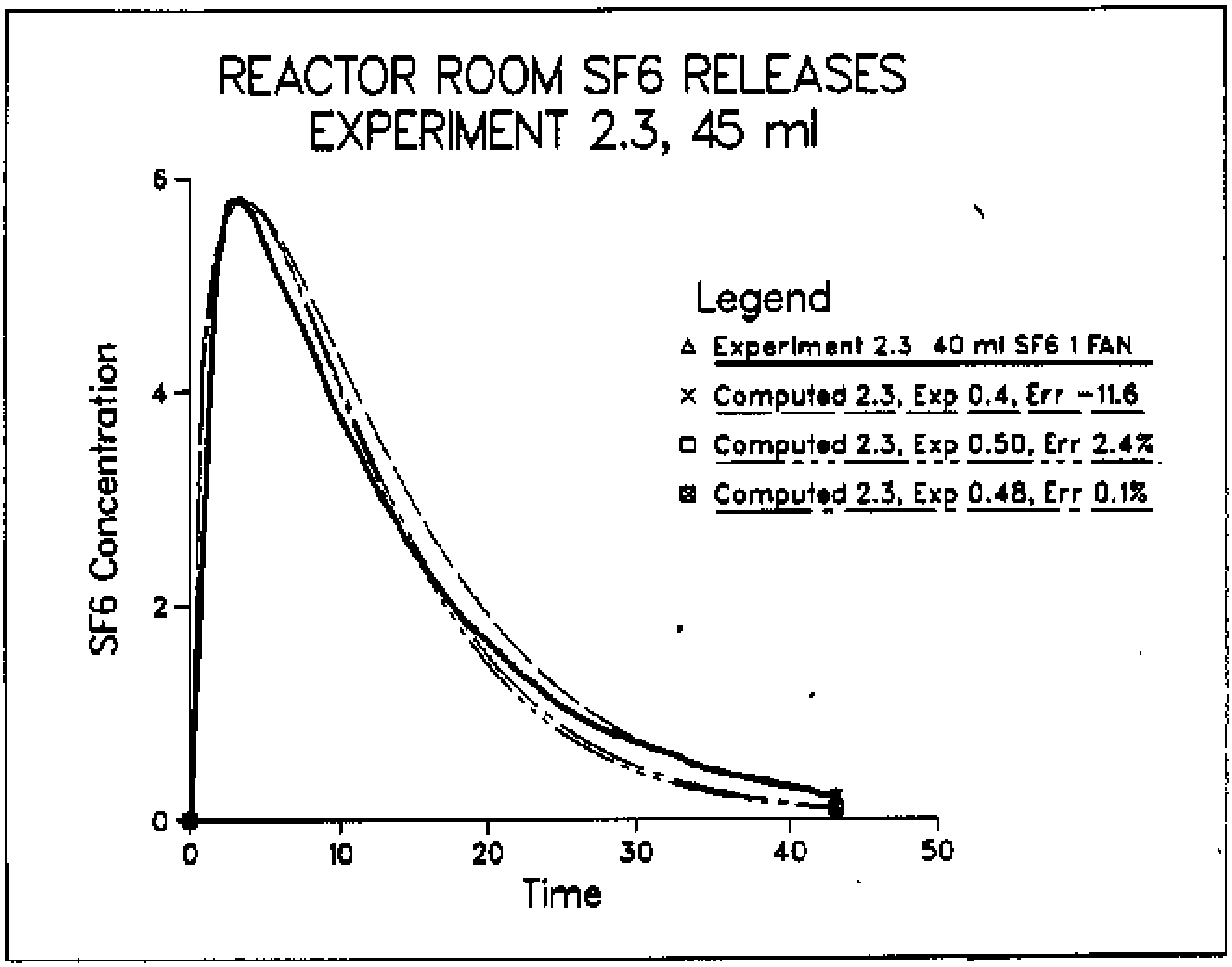

REACTOR ROOM SF6 RELEASES
EXPERIMENT 2.2, 45 ml
SF6 Concentration
Time
Legend
Experiment 2.2 40 ml SF6
Computed 2.2, Exp 0.4, Err 4.5%
Computed 2.2, Exp 0.5, Err 17.2%
Computed 2.2, Exp 0.37, Err -0.4%
0
2
4
6
0
10
20
30
40

Figure 5



REACTOR ROOM SF6 RELEASES
EXPERIMENT 2.3, 45 ml
SF6 Concentration
Time
Legend
Experiment 2.3 40 ml SF6 1 FAN
Computed 2.3, Exp 0.4, Err -11.6
Computed 2.3, Exp 0.50, Err 2.4%
Computed 2.3, Exp 0.48, Err 0.1%

Figure 6

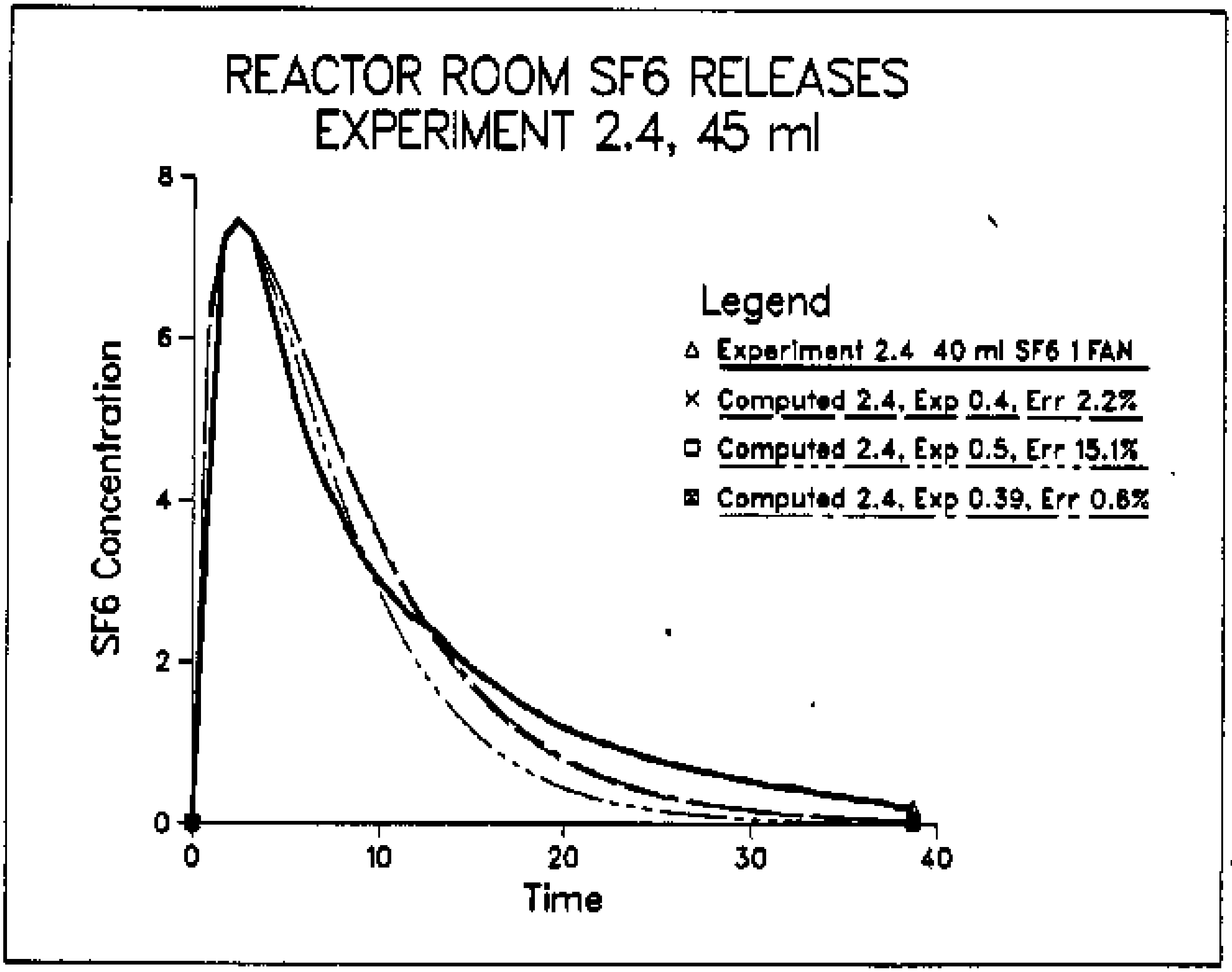

REACTOR ROOM SF6 RELEASES
EXPERIMENT 2.4, 45 ml
SF6 Concentration
Time
Legend
Experiment 2.4 40 ml SF6 1 FAN
Computed 2.4, Exp 0.4, Err 2.2%
Computed 2.4, Exp 0.5, Err 15.1%
Computed 2.4, Exp 0.39, Err 0.8%
0
2
4
6
8
0
10
20
30
40

Figure 7