RFSP SIMULATIONS OF DARLINGTON FINCH REFUELLING TRANSIENT

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ABSTRACT

Immediately after refuelling of a channel, the fresh bundles are free of fission products. Xenon-135, the most notable of the saturating fission products, builds up to an equilibrium level in about 30 h. The channel power of the refuelled channel would therefore initially peak and then drop to a steady-state level. The RFSP code can track saturating-fission-product transients and power transients. The Fully INstrumented CHannels (FINCHs) in Darlington NGS provides channel power data on the refuelling power transients. In this paper, such data has been used to identify the physical evidence of the fission-product transient effect on channel power, and to validate RFSP fission-product-driver calculation results.

1 INTRODUCTION

Immediately after refuelling of a channel, the fresh bundles are free of fission products. But as irradiation progresses, fission products build up in these bundles. Xenon-135, the most notable of the saturating fission products, builds up to an equilibrium level in about 30 to 40 h. One would expect that the power in these fresh bundles would peak after refuelling, and then drop to the equilibrium level with a time variation characteristic of the xenon build-up. In the irradiated bundles, which have been shifted to new positions along the channel, the xenon concentration will also change and eventually settle at a new equilibrium level. The xenon concentration in these irradiated bundles may initially increase or decrease, depending on the change in power from the old to the new bundle position. The effects of these xenon transients contribute to the channel power variation, which can be further influenced by other factors such as a change in water level in a nearby zone controller.

The RFSP[1] code has the capability of tracking saturating-fission-product transients. It has been used to predict the fission-product transient effect on channel power of the refuelled channel and its neighbouring channels (see References 2 and 3) for CANDU 6 reactors, which are fuelled with an 8-bundle-shift scheme. Based on these calculations, "xenon-free correction factors" have been derived, defined as the ratio of peak transient power to the power with equilibrium saturating fission products. For a channel refuelled with an 8-bundle-shift, the correction factor is around 4 to 6%. Validation of these calculations has been handicapped by the fact that there are few direct power measurement data (at full power) to compare with.

The fully instrumented channels (FINCHs) in Darlington NGS provide channel-power data on the refuelling power transients. The FINCHs provide measured channel powers based on channel flow (accounting for boiling) and the difference between inlet and outlet temperatures. Darlington reactors are fuelled with a 4-bundle shift scheme in the inner channels and with an 8-bundle shift scheme in the outer channels. For this study, FINCH data has been used to identify the physical evidence of the xenon transient effect on the channel power, to validate RFSP fission-product-driver calculation results, and to quantify the effect of 4-bundle-shift fuelling on the xenon-free correction factors, as compared with those of the 8-bundle shift.

The study was separated into two main sections. The first task was to set up the Darlington core model and repeat the SORO[4] steady-state production runs using the RFSP code. Once this task was complete, simulation of the detailed transient from a steady state prior to FINCH channel fuelling until about 30 h after fuelling could proceed using the RFSP transient fission-product driver.

2 METHODOLOGY

The RFSP Darlington model was first verified by comparing steady-state core simulation results to SORO results. In this study a 3-month period of Darlington operation (1995 Nov. 15 to 1996 Feb. 20) was simulated. SORO production calculations are performed at site, with a minimum of 3 runs per week. The SORO Input Data File (IDF) contains information on power level, channels refuelled, as well as zone controller levels and summaries of FINCH channel powers. These files were converted to RFSP input by using a Perl[5] script, which produced 43 RFSP run input streams for duplication of the SORO runs. During the 3-month period, the reactor was maintained essentially at full power (FP). The SORO IDF indicated that any departures from full power were of short duration and very seldom went below 97% FP. Full-power operation for the entire period was assumed in the RFSP simulations and is not expected to produce any significant error. The SORO zone fills, refuelling sequence, and exact time of refuelling were used in the RFSP calculations. In both SORO and RFSP, the steady-state calculations assumed equilibrium-saturating fission-product concentrations at simulation time. Essentially, the SORO calculations were repeated using RFSP with the history-based local-parameter methodology, with the fuel irradiations incremented using the fluxes obtained by RFSP. A coolant-density axial distribution was provided by Ontario Hydro and modelled in RFSP; the same axial distribution was assumed for all channels.

Starting from a steady-state case before a FINCH channel fuelling, RFSP transient simulations are performed using the transient-fission-product driver. The simulations were extended to 30 or 40 h after refuelling of the FINCH. The Darlington spatial-control algorithm, as modelled in OHRFSP[6], was incorporated in RFSP to calculate the zone fills at each simulation step. The algorithm involves zone-control detector calibration in such a manner that the sum of the signals from the pair of detectors in the zone is made equal to the normalized zone power (obtained from the FINCH channels in the zone), while the difference of the two signals is preserved. The FINCH power and the detector signals calculated at the starting point of each refuelling transient were used as the reference values. Zone-control fill data from site were available at hourly intervals; however this interval was found to be too coarse to accurately model the transient, and the zone-fill data therefore was not used. The calculated FINCH power transient was compared with the measured data. In addition, the calculated average and individual zone-fill transients were compared with site data, which would provide confidence in the validity of the spatial-control model.

3 RESULTS AND DISCUSSION

Among the channels refuelled over the 3-month period, 11 FINCHs were refuelled, 2 with 8-bundle-shift and 9 with 4-bundle-shift. Table 1 shows the percent power increase upon refuelling and the estimated xenon-free correction factors based on measurement data for the 11 FINCHs. The xenon-free effect for the 4-bundle-shift channels varied from negligible (e.g., Channel H20) to as much as 4.7% (Channel K03). The two 8-bundle-shift channels, E05 and E20, show xenon-free corrections of 5.1 and 4.1% respectively.

For steady-state core simulations, both RFSP and SORO results on FINCH channel power agree very well with measured data, with a standard deviation typically about 1%. These results are summarized for the 11 FINCH channels in Tables 2 and 3. It is noted that the calculated power after fuelling is typically 1% higher than the measurements. Figures 1 through 4 compare the steady-state results of the two diffusion codes with the measured FINCH results for channels E05, H20, K03, and E20.

Four of the 11 FINCH refuellings (E05, E20, H20 and K03) were simulated with RFSP using the transient-fission-product-driver. The percent increase in channel power upon refuelling is overestimated in all four cases by RFSP, which was also the result found in the steady-state comparison. The channel power transient following refuelling is however very well reproduced by RFSP in all four cases, which indicates that the RFSP fission-product-driver model captures the effect of the fission-product transient accurately. Figures 5 through 8 show the transient results for each of the four channels. The calculated average zone-fill transient agrees very well with site data. The trends in individual zone-fill transients are also well reproduced, although the site zone-level changes are generally greater in magnitude than the calculated values. Figure 9 shows a comparison of the calculated and site average zone-fill transient for the refuelling of E05, and Figures 10 and 11 show the individual zone-level responses for zones 6 and 8, which are the zones in which the fuelling occurs.

4 CONCLUSIONS

This study demonstrated that the FINCH data is indeed suitable for the purpose of benchmarking the xenon-free effect on channel power. The most significant conclusion from this study is that, for the four channels studied, the effects on the power of the refuelled FINCH channel that are due to the fission-product transients are accurately captured by RFSP. The cases studied covered both 8-bundle-shift and 4-bundle-shift fuelling. Steady-state calculations assuming saturating fission products in the fresh fuel bundles do not necessarily reflect the higher powers shortly after refuelling.

For 8-bundle-shift channels, the present study gives a xenon-free effect on channel power of the order of 4 to 6%, which is consistent with the results from previous studies for the CANDU 6 reactors (see References 2 and 3).

For 4-bundle-shift channels, on the other hand, the present study gives a xenon-free effect from almost 0 to 4 to 5%.

The percent increase in channel power immediately after refuelling seems to be consistently overestimated in the RFSP calculation for the four FINCH refuelling transients simulated. The overestimate is partly due to the deficiencies in the spatial-control algorithm built in the simulation code, relative to the station control computer. It could also be partly due to other systematic modelling errors, such as overestimate in the H-factor for fresh fuel, or an overestimate in the burnup of the discharged bundles. The component due to modelling errors has not been isolated in this study.

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Table 1
Measured FINCH Power Increase Upon Refuelling and Xenon-Free Correction Factor

FINCH Channel	Bundle Shift *	Power Increase Upon Refuelling	Xenon-Free Correction Factor
E05	– 8	18.4%	5.1%
O14	– 4	5.1%	~0.0%
O20	– 4	8.0%	3.0%
R14	+ 4	5.8%	~0.0%
H20	– 4	4.9%	~0.0%
R05	– 4	5.3%	~0.0%
K03	+ 4	11.2%	4.7%
U17	+ 4	7.7%	2.7%
R11	– 4	6.4%	2.3%
C10	+ 4	10.8%	2.6%
E20	+ 8	18.5%	4.1%

* "+" and "–" indicate direction of fuelling

Table 2
Comparisons of FINCH Channel Powers – RFSP Steady-State Results versus Measurements

Percent Difference of RFSP minus MEASURED FINCH Channel Power

	BEFORE FUELLING				AFTER FUELLING			
FINCH CHANNEL	AVERAGE	MAXIMUM	MINIMUM	ST.DEV.	AVERAGE	MAXIMUM	MINIMUM	ST.DEV.
E05	1.8	5.7	0.3	1.3	2.7	4.8	0.2	1.1
O14	1.3	3.0	0.0	0.8	2.8	4.0	1.7	0.7
O20	-1.1	1.3	-2.6	1.0	1.8	3.7	-1.3	1.1
R14	-0.6	0.6	-1.8	0.7	0.3	1.2	-0.7	0.5
H20	-0.5	1.1	-2.0	0.9	0.0	1.6	-2.2	1.0
R05	-0.7	1.7	-1.6	0.8	0.2	2.3	-1.2	1.1
K03	-0.3	3.1	-1.6	1.1	-0.1	1.8	-2.2	1.2
U17	-3.7	-1.7	-5.1	0.8	-2.9	-1.9	-6.0	0.9
R11	1.3	2.5	0.1	0.6	2.5	3.5	1.1	0.7
C10	2.5	4.5	1.1	0.9	1.6	3.0	0.3	0.7
E20	0.1	1.7	-2.3	1.1	1.1	2.6	-2.7	1.3
Average	0.01	2.1	-1.4	0.9	0.9	2.4	-1.1	0.9

Table 3
Comparisons of FINCH Channel Powers – SORO Results versus Measurements

Percent Difference of SORO minus MEASURED FINCH Channel Power

	BEFORE FUELLING				AFTER FUELLING			
FINCH CHANNEL	AVERAGE	MAXIMUM	MINIMUM	ST.DEV.	AVERAGE	MAXIMUM	MINIMUM	ST.DEV.
E05	-1.8	-0.1	-2.7	0.9	2.0	3.8	-0.4	1.0
O14	-0.3	0.8	-1.4	0.6	2.2	3.6	0.4	0.8
O20	-0.6	1.9	-1.9	1.1	2.7	4.2	0.5	1.0
R14	-1.6	-0.6	-2.4	0.5	-0.2	1.2	-1.8	0.6
H20	-1.0	1.4	-2.3	0.9	0.6	2.6	-1.5	1.2
R05	-0.7	0.4	-2.2	0.7	0.4	2.2	-0.9	0.9
K03	-1.2	1.0	-3.6	1.2	-0.4	1.6	-2.1	1.0
U17	-3.2	-2.1	-5.2	0.8	-2.1	-0.2	-4.1	1.0
R11	1.0	2.2	-0.4	0.7	2.4	3.8	1.0	0.8
C10	0.4	2.1	-0.8	0.7	1.3	3.0	-0.4	0.8
E20	-2.9	-0.6	-4.4	1.0	1.4	2.8	-3.2	1.5
Average	-1.1	0.6	-2.5	0.8	0.9	2.6	-1.1	1.0

Figure 1 Channel E05 (8) RFSP & SORO Calculated, FINCH Measured Channel Power (kW)

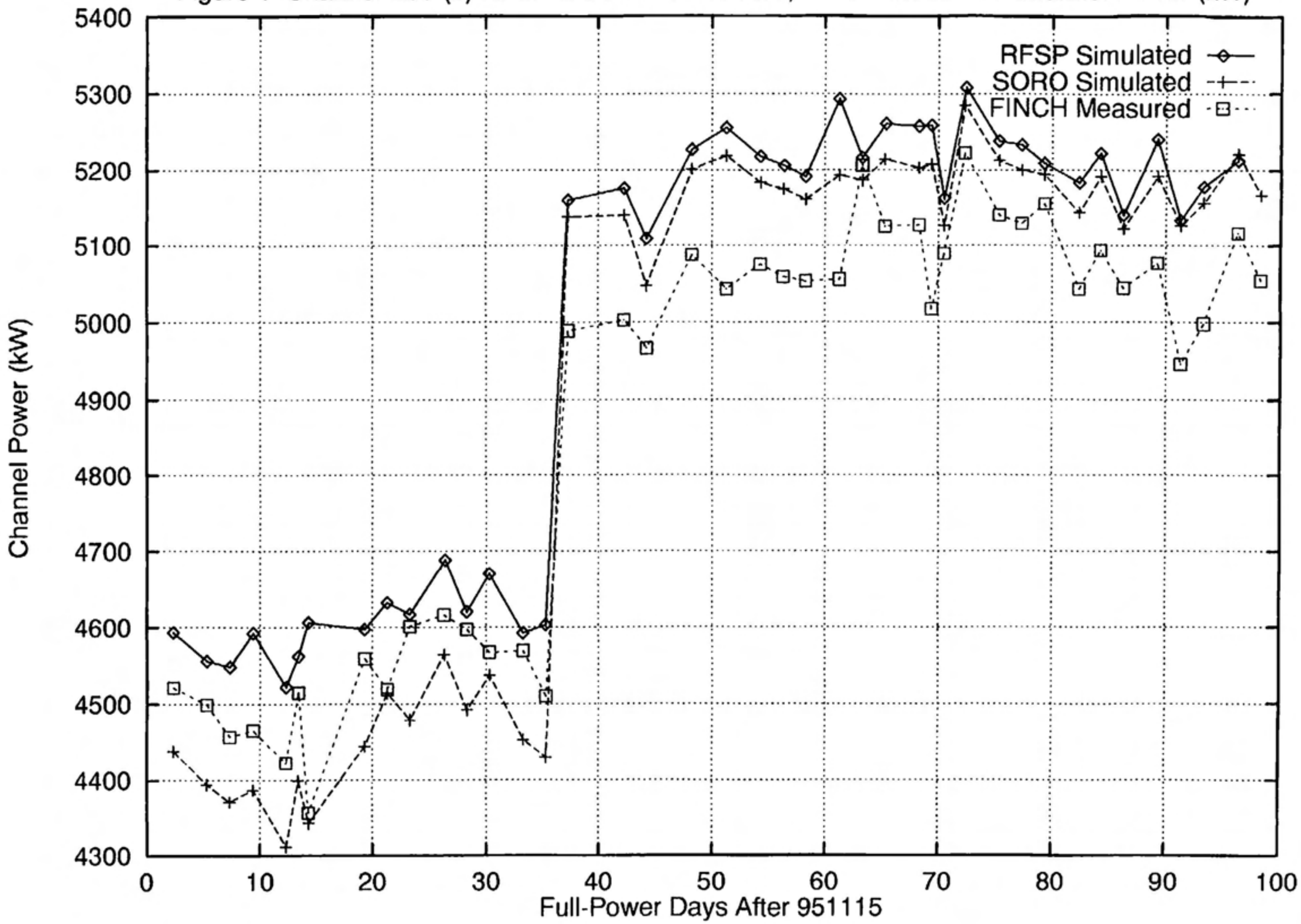

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Figure 2 Channel H20 (4) RFSP & SORO Calculated, FINCH Measured Channel Power (kW)

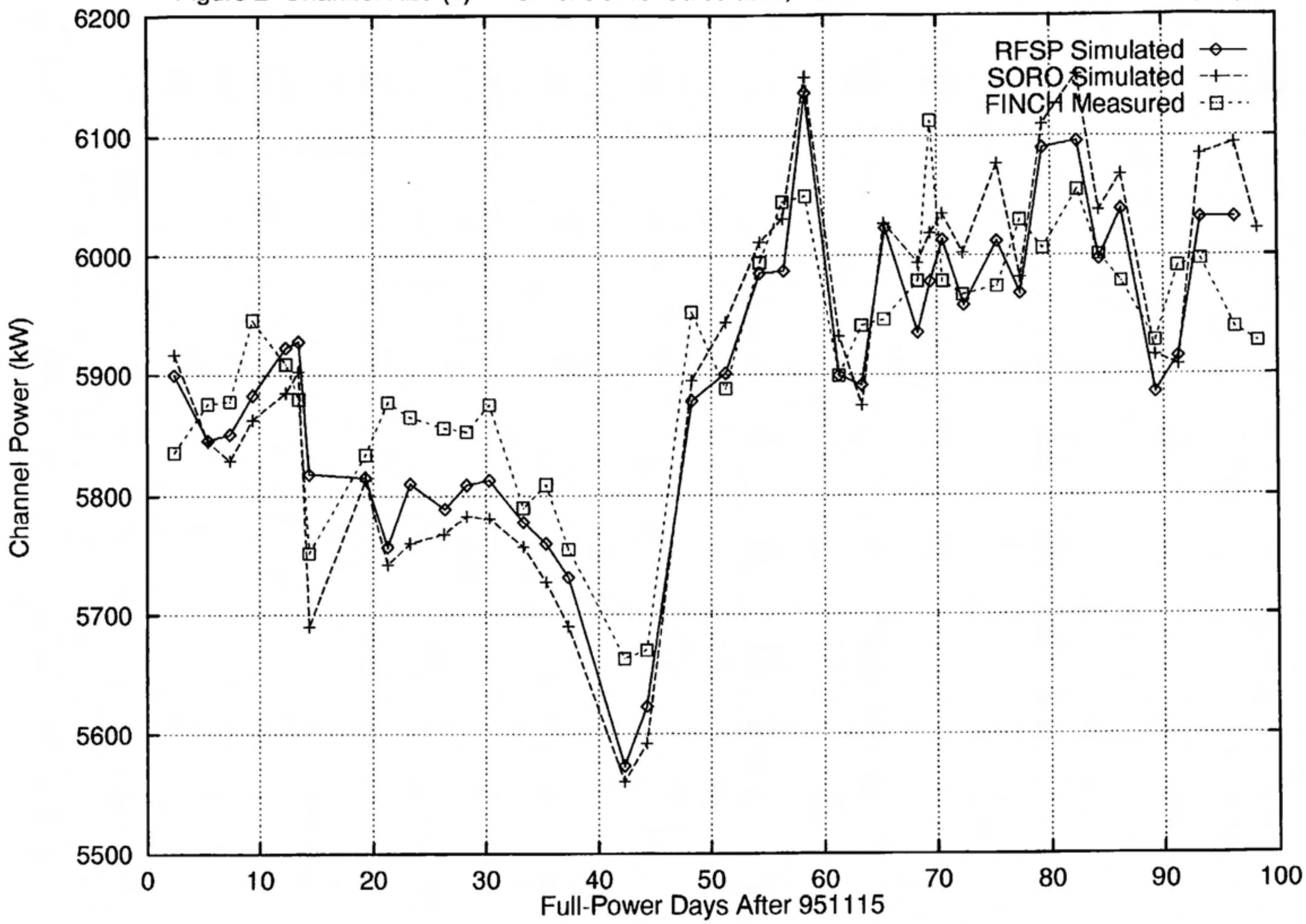

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Figure 3 Channel K03 (4) RFSP & SORO Calculated, FINCH Measured Channel Power (kW)

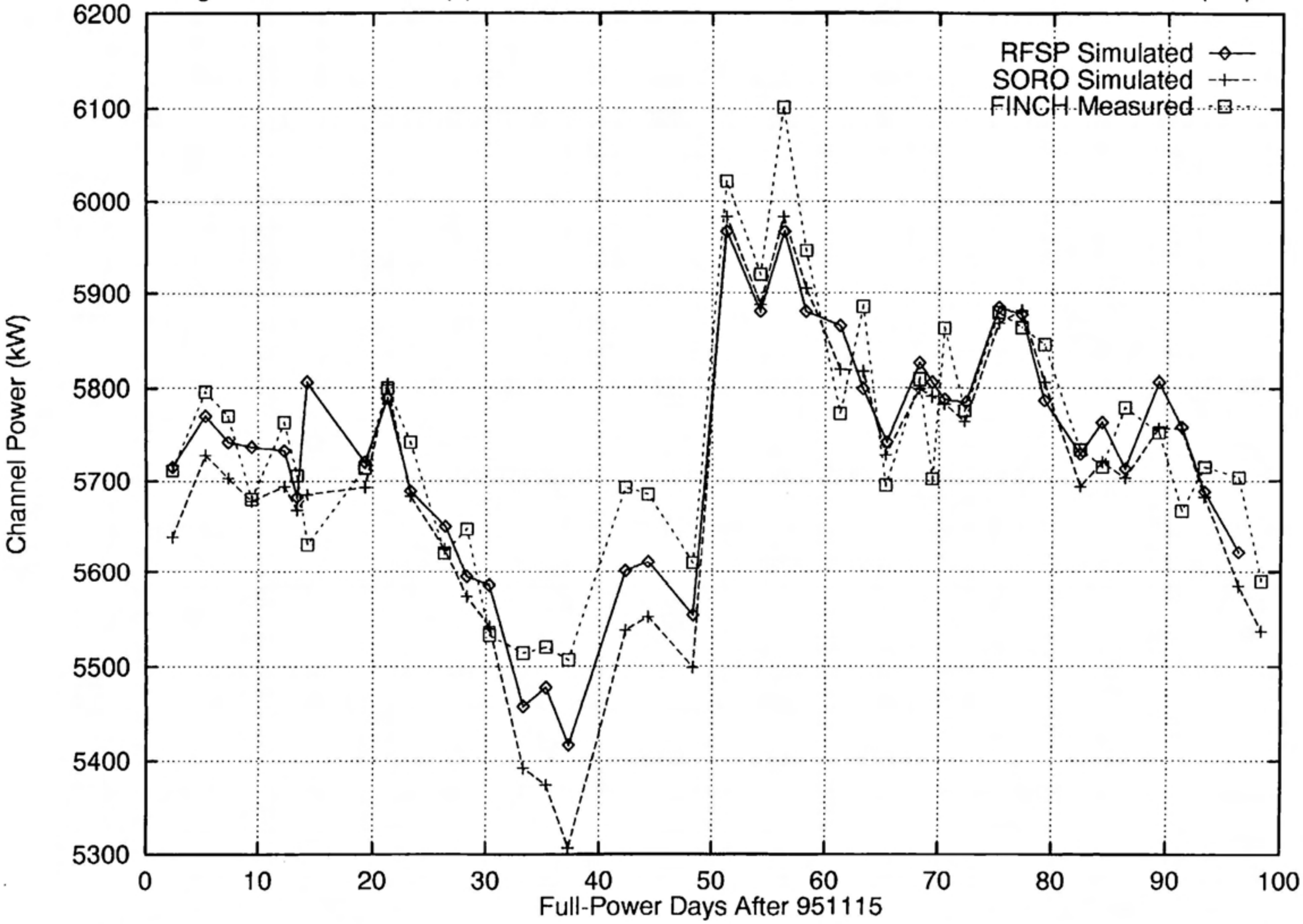

Figure 4 Channel E20 (8) RFSP & SORO Calculated, FINCH Measured Channel Power (kW)

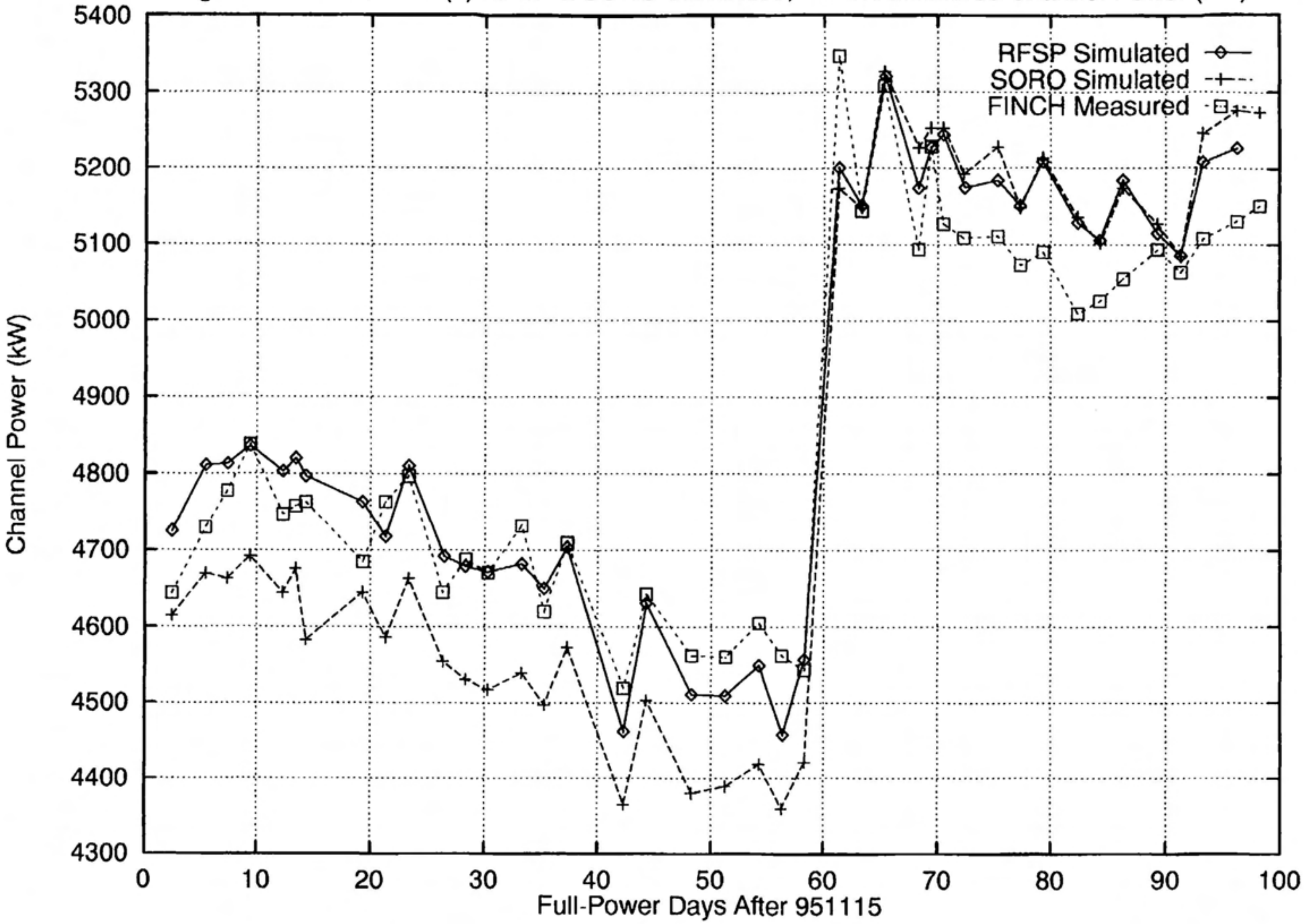

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Figure 5 Channel Power Transient - Channel E05

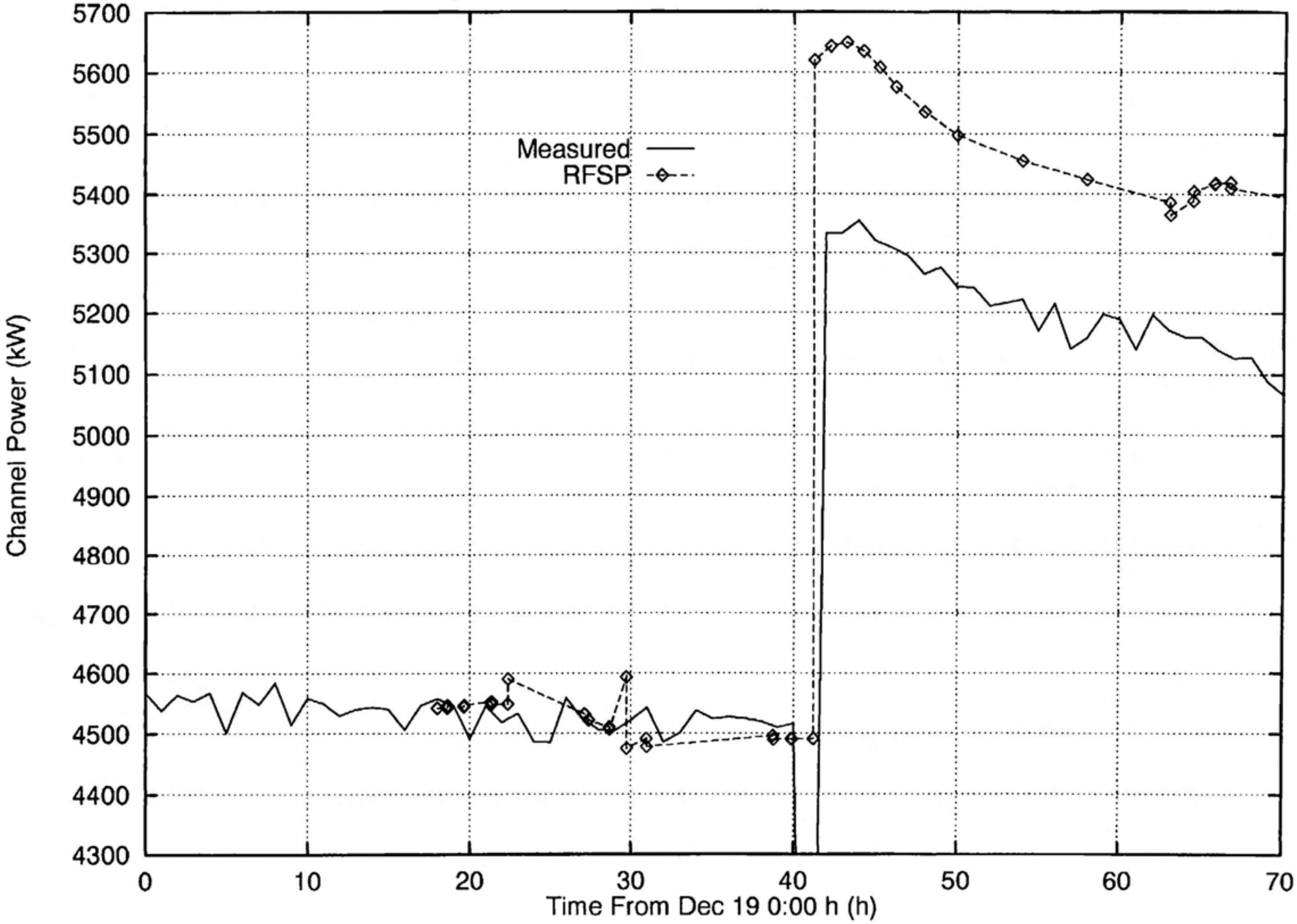

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Figure 6 Channel Power Transient - Channel H20

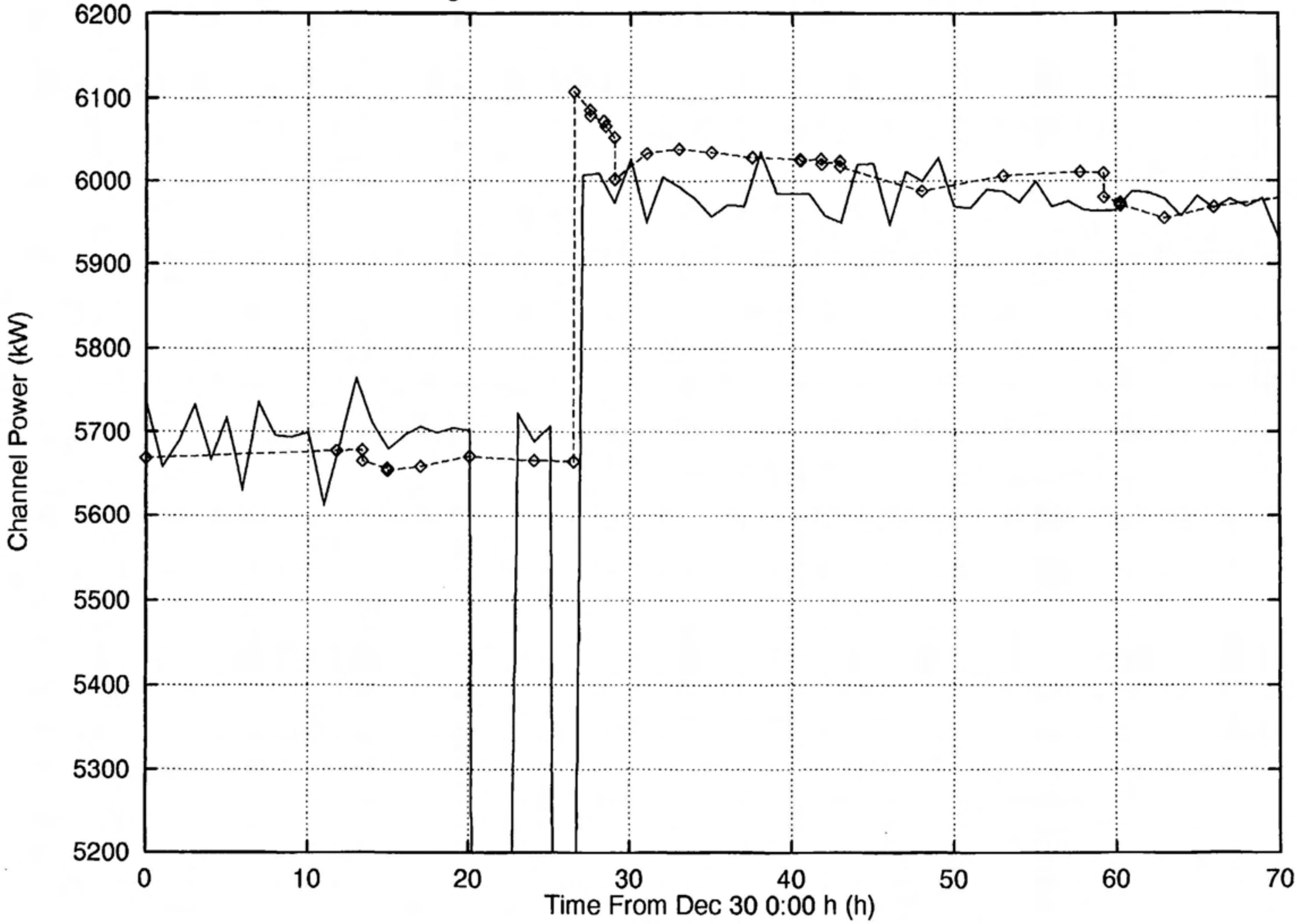

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Figure 7   Channel Power Transient - Channel K03

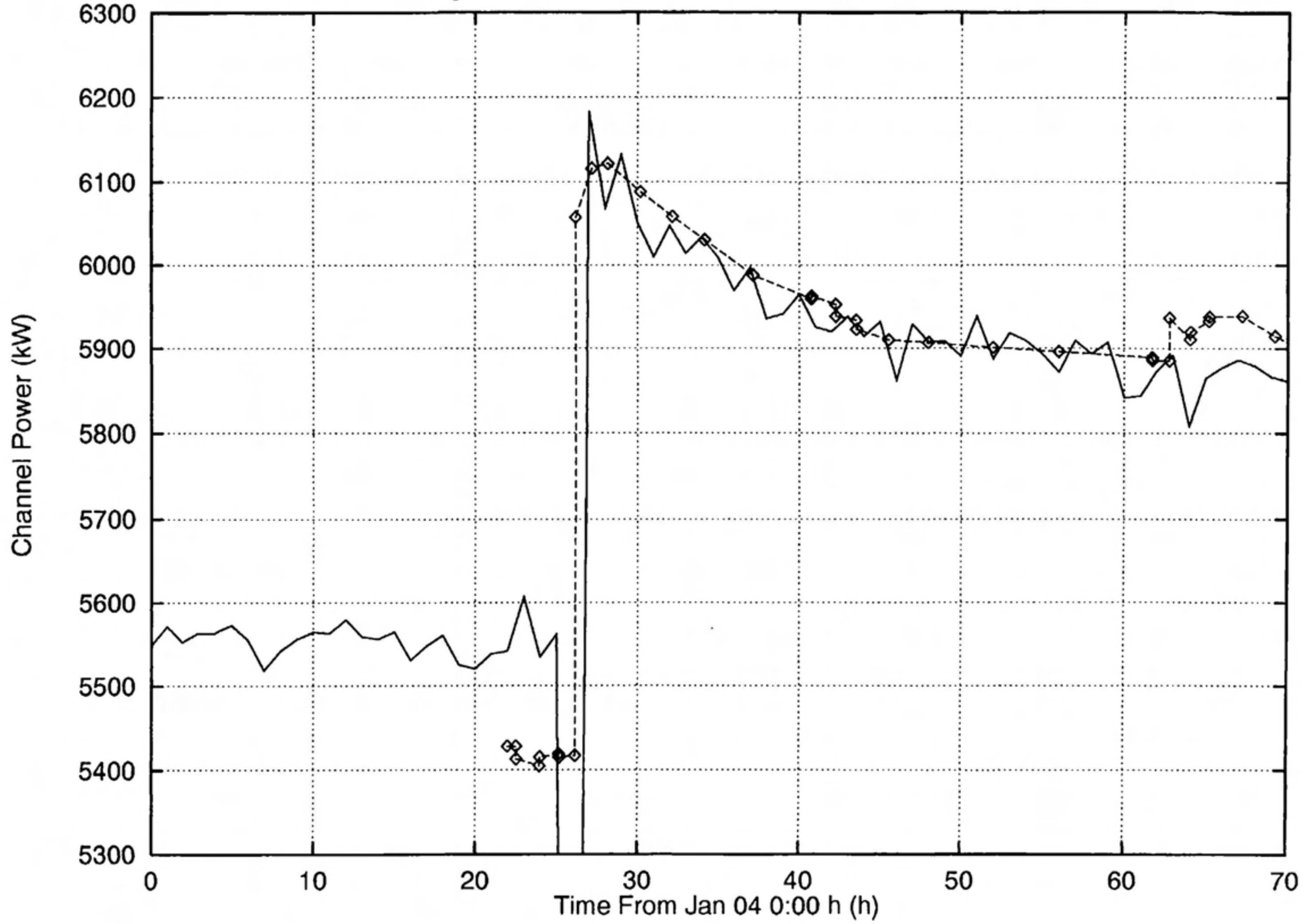

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Figure 8 Channel Power Transient - Channel E20

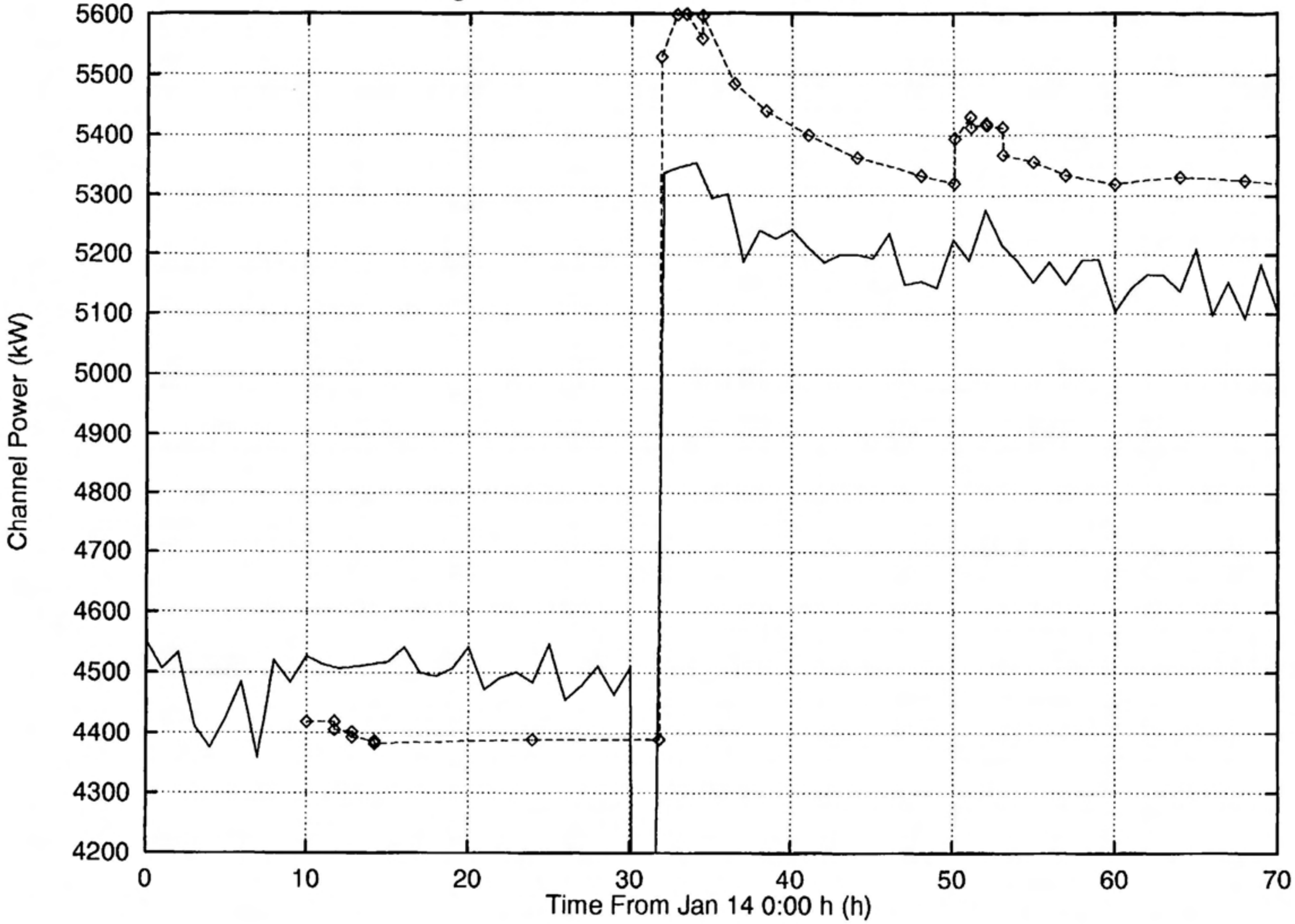

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Figure 9 Channel E05 - Zone Level Transient - Average Zone Fill

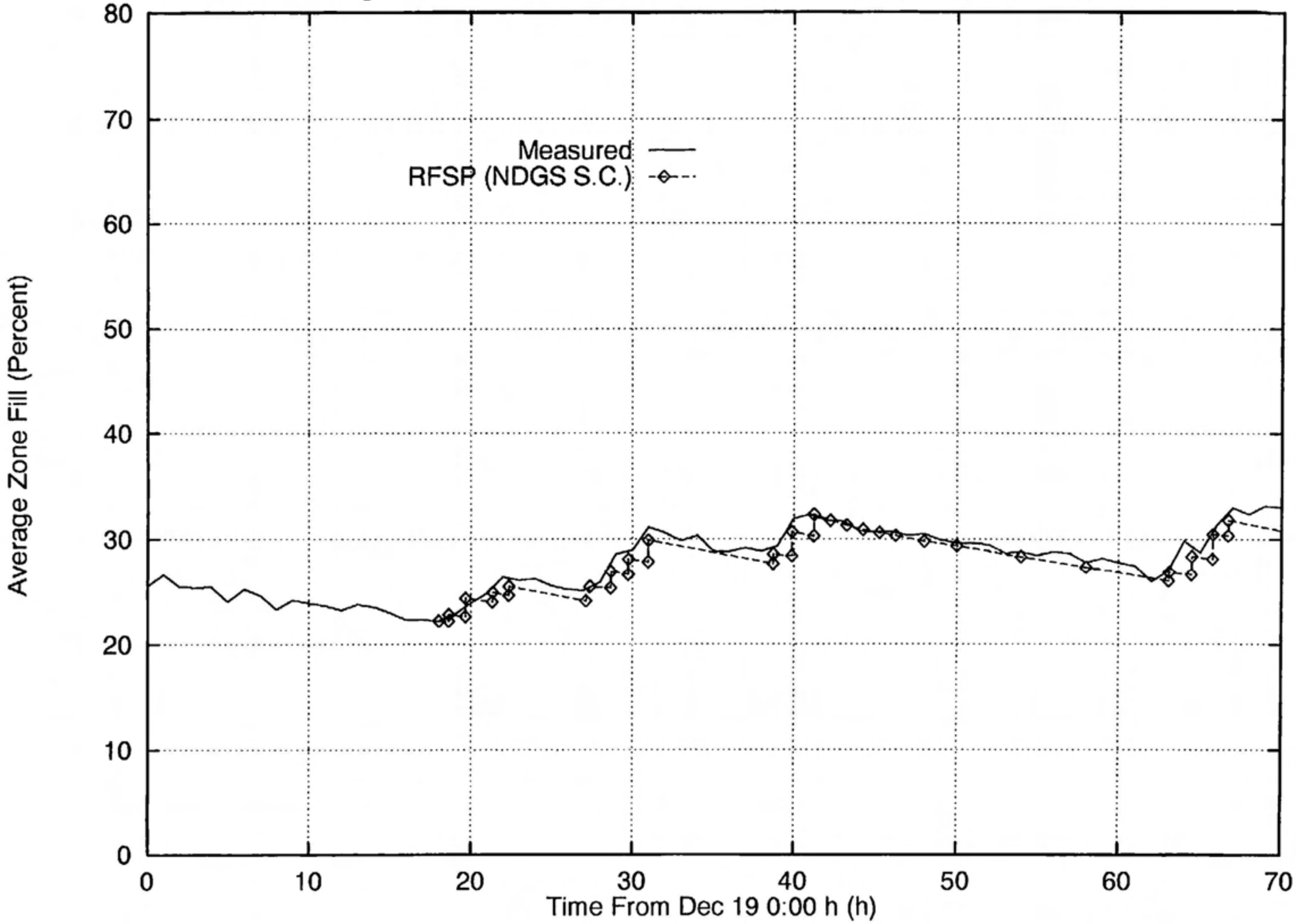

Figure 10 Channel E05 - Zone Level Transient - ZCR06

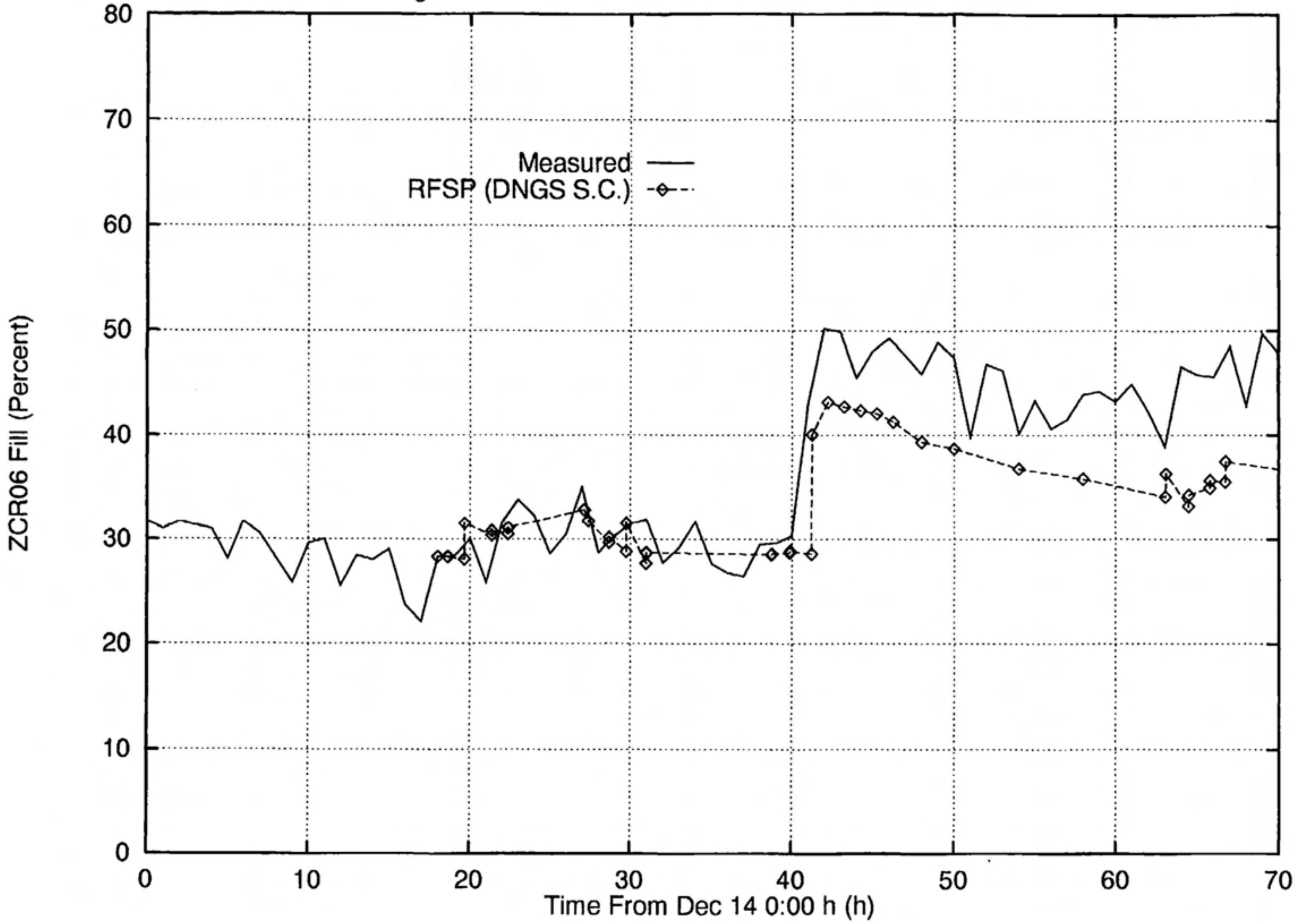

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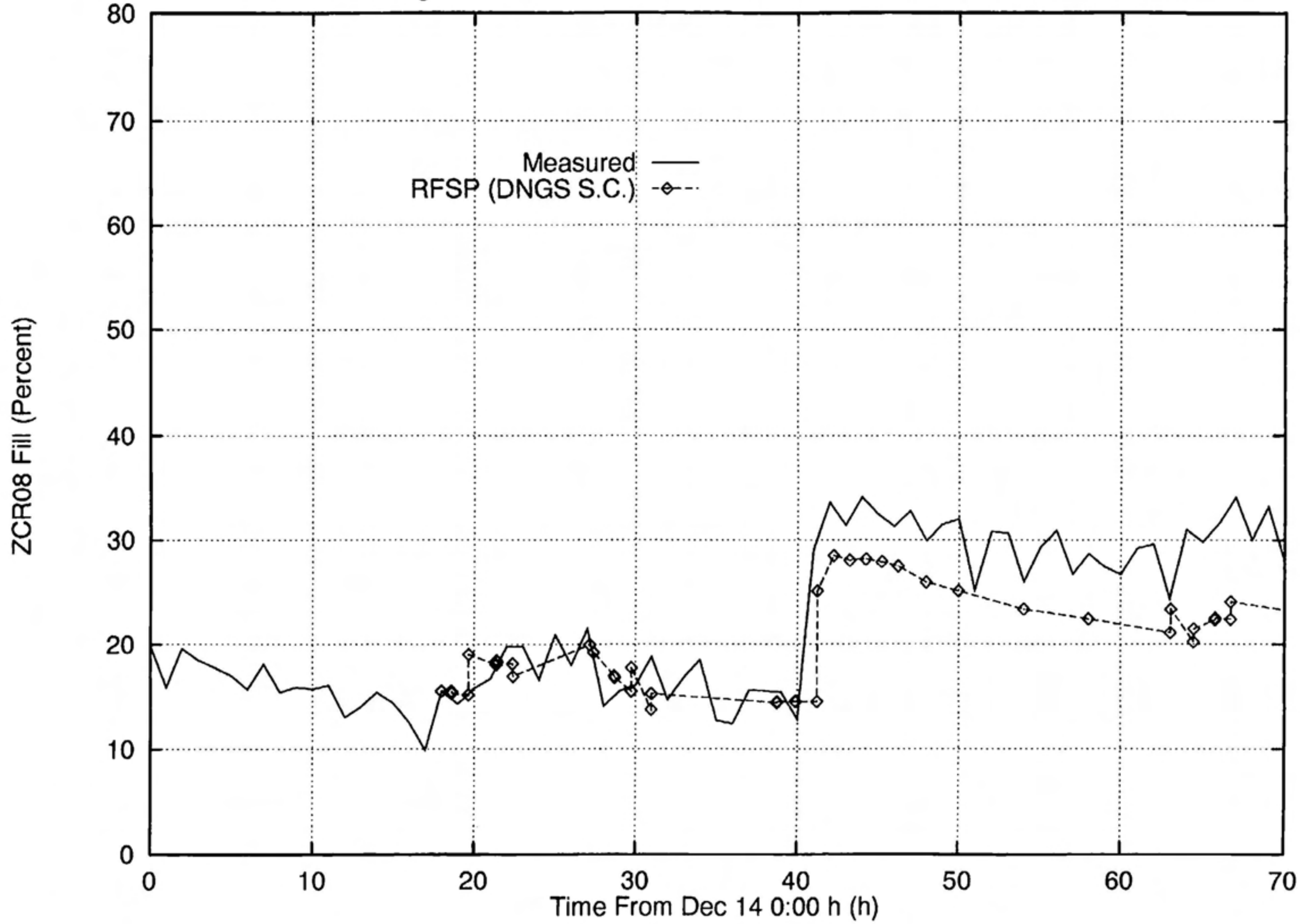
Figure 11 Channel E05 - Zone Level Transient - ZCR08



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