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TECHNICAL BACKGROUND FOR THE UPDATE AND EXTENSION OF THE TIME-DEPENDENT ALLOWABLE STRESSES OF TYPE 304H AND 316H STAINLESS STEELS

Michael D McMurtrey, Ting-Leung Sham

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Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Technical Background for the Update and Extension of the Time-Dependent Allowable Stresses of Type 304H and 316H Stainless Steels

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Gen IV Materials Project

- Task 6
  - Review allowable stresses for Section III, Division 1, Subsection NH Class 1 (now Section III, Division 5, Class A) components
  - Assembled expanded databases and assessed use for expanding allowable stresses from 300,000 hours to 500,000 hours
- Task 14
  - Goal to extend the allowable stresses of Types 304H and 316H stainless steels
  - Issue noted in that new allowable stresses were significantly lower than current Division 5 values (particularly for higher temperatures and longer lifetimes)
- The temperature and time dependent S_t values are determined from the lesser of the following criteria:
  - 100% of the average stress required to obtain a total (elastic, plastic, primary, and secondary creep) strain of 1% ($S_{1\%}$),
  - 80% of the minimum stress to cause initiation of tertiary creep (S_{t3})
  - 67% of the minimum stress-to-rupture (S_r)
- The lower new allowable stresses at higher temperatures and longer lifetimes was found to be largely driven by onset of tertiary creep

Onset of tertiary creep

- Limited data set – significantly less data than time to rupture
- Larger data scatter in onset of tertiary creep data as well
  - Some creep curves showed behavior that deviated from classical creep deformation (primary, secondary, tertiary)
  - May show multiple “tertiary creep” onset points
- Final recommendation by Sengupta and Nestell was to reconsider the technical basis for including time to onset of tertiary creep as a criteria for allowable stresses

Onset of tertiary creep relation to creep rupture time

- Leyda and Rowe (1969) found that onset of tertiary creep can be correlated to creep rupture time for a given material at a given temperature.
- Limited database for time to onset of tertiary creep could be overcome by using an average Leyda-Rowe correlation on the creep rupture database
- Would also remove the issue of non-classical creep behavior and misidentifying onset of tertiary creep
- This approach was used to draft new allowable stress values for Types 316H and 304H stainless steels which are being proposed for ASME Code committees' approval.

S_r Type 304 stainless steel

Temp. (°C)	100 hr. rupture stress (MPa)	S_u/1.1 (Mpa)	100 hr. S_r (MPa)
425	591.48	392.53	392.53
450	509.05	388.55	388.55
475	437.02	382.92	382.92
500	374.19	375.39	374.19
525	319.51	365.81	319.51
550	272.02	354.05	272.02
575	230.88	340.05	230.88
600	195.32	323.83	195.32
625	164.66	305.46	164.66
650	138.30	285.15	138.30
675	115.70	263.14	115.70
700	96.38	239.78	96.38
725	79.92	215.55	79.92
750	65.95	191.04	65.95
775	54.13	166.93	54.13
800	44.17	144.05	44.17
825	35.82	123.36	35.82

S_r is capped at S_u/1.1

S_r Type 304 stainless steel

Type 304H SS, S_r—Expected Minimum Stress-To-Rupture Values (MPa)												
Temp., °C	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	392.53	392.53	392.53	392.53	392.53	392.53	392.53	376.27	336.62	297.46	265.29	251.41
450	388.55	388.55	388.55	388.55	388.55	388.55	358.78	315.93	280.84	246.38	218.25	206.16
475	382.92	382.92	382.92	382.92	382.92	341.09	302.30	264.31	233.39	203.20	178.71	168.23
500	375.39	375.39	375.39	374.19	330.72	288.28	253.82	220.28	193.14	166.82	145.59	136.55
525	365.81	365.81	365.81	319.51	280.60	242.82	212.33	182.84	159.12	136.27	117.97	110.21
550	354.05	354.05	315.15	272.02	237.31	203.80	176.93	151.10	130.47	110.72	95.02	88.40
575	340.05	309.50	269.45	230.88	200.01	170.41	146.82	124.29	106.42	89.44	76.05	70.43
600	323.83	265.63	229.71	195.32	167.97	141.90	121.28	101.72	86.32	71.80	60.43	55.70
625	305.46	227.34	195.22	164.66	140.51	117.66	99.70	82.79	69.59	57.23	47.65	43.69
650	268.51	194.00	165.37	138.30	117.06	97.10	81.53	66.99	55.72	45.28	37.25	33.96
675	231.88	165.03	139.59	115.70	97.09	79.73	66.29	53.85	44.30	35.52	28.85	26.12
700	199.73	139.92	117.39	96.38	80.14	65.11	53.57	42.98	34.93	27.61	22.09	19.86
725	171.56	118.21	98.32	79.92	65.81	52.85	43.00	34.04	27.29	21.23	16.71	14.90
750	146.93	99.49	82.01	65.95	53.74	42.63	34.26	26.72	21.11	16.13	12.47	11.01
775	125.45	83.40	68.08	54.13	43.61	34.13	27.07	20.77	16.14	12.08	9.14	7.99
800	106.76	69.61	56.24	44.17	35.16	27.12	21.19	15.97	12.18	8.90	6.57	5.67
825	90.54	57.83	46.21	35.82	28.14	21.35	16.41	12.12	9.05	6.44	4.61	3.92

Su/1.1 limit

Rupture stress

S_r Type 316 stainless steel

Type 316H SS, S_r – Expected Minimum Stress-To-Rupture Values (MPa), SI Units												
Temp., °C	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	444.08	444.08	444.08	444.08	444.08	444.08	444.08	444.08	444.08	413.26	367.07	347.19
450	438.25	438.25	438.25	438.25	438.25	438.25	438.25	438.25	389.31	339.94	299.79	282.59
475	430.69	430.69	430.69	430.69	430.69	430.69	420.09	365.54	321.32	278.34	243.61	228.80
500	421.15	421.15	421.15	421.15	421.15	399.86	350.46	302.58	264.01	226.77	196.89	184.21
525	409.43	409.43	409.43	409.43	388.77	334.68	291.22	249.37	215.89	183.77	158.19	147.39
550	395.40	395.40	395.40	376.41	326.75	279.05	240.98	204.56	175.62	148.07	126.29	117.15
575	378.97	378.97	372.66	317.52	273.62	231.72	198.50	166.95	142.06	118.55	100.12	92.42
600	360.12	360.12	315.80	266.91	228.24	191.57	162.72	135.51	114.22	94.27	78.76	72.33
625	338.85	312.38	266.73	223.53	189.59	157.64	132.69	109.34	91.23	74.40	61.43	56.10
650	315.25	264.95	224.48	186.45	156.78	129.06	107.59	87.66	72.33	58.23	47.47	43.07
675	289.44	223.97	188.22	154.86	129.03	105.09	86.69	69.78	56.89	45.15	36.29	32.69
700	261.59	188.65	157.18	128.03	105.64	85.06	69.39	55.11	44.35	34.64	27.40	24.50
725	231.95	158.30	130.69	105.32	86.00	68.40	55.12	43.15	34.22	26.27	20.41	18.08
750	198.41	132.28	108.16	86.18	69.58	54.61	43.43	33.46	26.11	19.65	14.96	13.11
775	168.33	110.06	89.07	70.10	55.92	43.26	33.91	25.66	19.66	14.46	10.75	9.31
800	135.34	91.14	72.94	56.66	44.61	33.97	26.20	19.44	14.59	10.45	7.55	6.44
825	101.87	75.08	59.39	45.48	35.30	26.41	20.00	14.51	10.63	7.38	5.15	4.31

Su/1.1 limit

Rupture stress

S_3 from S_r using the Leyda-Rowe correlation

- t_3 calculated using the Leyda-Rowe correlation as $t_3 = A \times t_r$ with A being a fitting parameter

Leyda-Rowe Coefficient: A	
Type 304 Stainless Steel	5.7951459582E-01
Type 316 Stainless Steel	-2.3693562130E-01

Type 304H Stainless Steel: LM Parameters for t_r, $n = 2$	
	SI
a_0	2.6425818477E+04
a_1	-2.2913459635E+03
a_2	-9.0077040205E+02
C	1.6009230631E+01
SEE	5.0350040055E-01

- Larson-Miller representation of t_r can be used to express t_3
  - $log_{10}t_3 = \left(\frac{1}{T_a}\sum_{p=0}^{n} a_p \Sigma^p\right) - (C - log_{10}A) - h \times SEE$
  - a_p, C, and SEE are same as those for t_r

For 100 hours			
Temp. (°C)	S_r (MPa)	Leyda-Rowe Correlation	S_3 (MPa)
425	591.48		561.27
450	509.05		481.71
475	437.02		412.35
500	374.19		352.01
525	319.51		299.63
550	272.02		254.26
575	230.88		215.07
600	195.32		181.28
625	164.66		152.25
650	138.30		127.37
675	115.70		106.10
700	96.38		87.99
725	79.92		72.62
750	65.95		59.62
775	54.13		48.67
800	44.17		39.48
825	35.82		31.81

S_3 Type 304 stainless steel

Type 304H SS, S_3 – Expected Onset of Tertiary Creep Values, (MPa), SI Units												
Temp. (°C)	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	865.98	698.90	629.87	561.27	504.57	448.34	401.97	356.09	318.34	281.08	250.49	237.30
450	760.03	606.76	543.88	481.71	430.58	380.14	338.76	298.05	264.73	232.04	205.36	193.90
475	665.83	525.62	468.52	412.35	366.40	321.31	284.52	248.53	219.25	190.69	167.54	157.64
500	582.22	454.30	402.60	352.01	310.85	270.68	238.10	206.41	180.79	155.96	135.96	127.45
525	508.10	391.71	345.05	299.63	262.88	227.23	198.49	170.70	148.38	126.89	109.70	102.43
550	442.51	336.91	294.91	254.26	221.57	190.04	164.78	140.52	121.17	102.66	87.97	81.78
575	384.56	289.00	251.32	215.07	186.08	158.31	136.20	115.11	98.41	82.55	70.06	64.84
600	333.44	247.22	213.52	181.28	155.68	131.31	112.04	93.80	79.45	65.94	55.39	51.00
625	288.44	210.85	180.81	152.25	129.72	108.41	91.70	75.99	63.73	52.29	43.43	39.77
650	248.89	179.28	152.58	127.37	107.61	89.07	74.63	61.17	50.76	41.13	33.74	30.71
675	214.20	151.93	128.28	106.10	88.85	72.79	60.38	48.91	40.12	32.06	25.94	23.45
700	183.83	128.30	107.42	87.99	72.99	59.14	48.53	38.81	31.43	24.74	19.72	17.69
725	157.31	107.94	89.58	72.62	59.64	47.74	38.72	30.53	24.39	18.87	14.79	13.15
750	134.20	90.44	74.36	59.62	48.43	38.28	30.65	23.80	18.71	14.21	10.92	9.62
775	114.11	75.46	61.42	48.67	39.07	30.45	24.04	18.35	14.18	10.54	7.92	6.89
800	96.69	62.67	50.46	39.48	31.30	24.02	18.67	13.98	10.59	7.68	5.61	4.82
825	81.62	51.78	41.22	31.81	24.87	18.77	14.34	10.51	7.78	5.47	3.87	3.26

S_3 Type 316 stainless steel

Type 316H SS, S_3 – Expected Onset of Tertiary Creep Values, (MPa), SI Units												
Temp. (°C)	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	1238.76	992.66	891.48	791.27	708.74	627.18	560.16	494.09	439.93	386.68	343.14	324.41
450	1082.07	857.33	765.62	675.26	601.23	528.46	469.00	410.72	363.22	316.80	279.09	262.94
475	943.39	738.74	655.87	574.65	508.47	443.79	391.24	340.04	298.57	258.30	225.80	211.94
500	820.82	635.00	560.35	487.59	428.64	371.36	325.10	280.31	244.27	209.50	181.64	169.82
525	712.68	544.43	477.39	412.43	360.10	309.57	269.02	230.01	198.83	168.97	145.21	135.19
550	617.43	465.52	405.52	347.71	301.43	257.02	221.62	187.80	160.96	135.45	115.30	106.85
575	533.67	396.92	343.38	292.11	251.34	212.47	181.70	152.52	129.53	107.85	90.87	83.80
600	460.16	337.41	289.80	244.50	208.71	174.83	148.21	123.15	103.57	85.25	71.04	65.15
625	395.76	285.91	243.71	203.83	172.54	143.14	120.21	98.80	82.22	66.84	55.03	50.17
650	339.47	241.46	204.18	169.21	141.97	116.56	96.92	78.73	64.76	51.94	42.19	38.21
675	290.35	203.19	170.38	139.82	116.21	94.37	77.62	62.25	50.57	39.96	31.98	28.75
700	247.60	170.33	141.56	114.97	94.59	75.91	61.71	48.81	39.11	30.40	23.92	21.32
725	210.48	142.20	117.07	94.04	76.53	60.63	48.67	37.91	29.92	22.82	17.62	15.56
750	178.32	118.19	96.34	76.47	61.51	48.06	38.04	29.14	22.60	16.88	12.75	11.13
775	150.53	97.78	78.84	61.79	49.08	37.76	29.43	22.13	16.83	12.27	9.03	7.77
800	126.58	80.47	64.15	49.59	38.84	29.39	22.52	16.57	12.32	8.73	6.22	5.27
825	106.01	65.87	51.86	39.49	30.47	22.62	17.00	12.21	8.84	6.05	4.15	3.44

S_t Type 304 stainless steel

Type 304H SS, S_t—Allowable Stress Intensity Values (MPa), SI Units												
Temp. (°C)	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	175.83	175.83	175.83	175.83	175.83	175.83	175.83	175.83	175.83	175.83	175.83	168.44
450	172.67	172.67	172.67	172.67	172.67	172.67	172.67	172.67	172.67	165.07	146.23	138.13
475	169.50	169.50	169.50	169.50	169.50	169.50	169.50	169.50	156.37	136.14	119.74	112.71
500	166.34	166.34	166.34	166.34	166.34	166.34	166.34	147.59	129.40	111.77	97.55	91.49
525	163.18	163.18	163.18	163.18	163.18	162.69	142.26	122.50	106.61	91.30	79.04	73.84
550	160.02	160.02	160.02	160.02	159.00	136.55	118.54	101.24	87.41	74.18	63.66	59.23
575	156.85	156.85	156.85	154.69	134.01	114.17	98.37	83.27	71.30	59.92	50.95	47.19
600	153.69	153.69	153.69	130.86	112.54	95.07	81.26	68.15	57.83	48.11	40.49	37.32
625	150.53	150.53	130.80	110.32	94.14	78.83	66.80	55.47	46.63	38.34	31.93	29.27
650	147.36	129.98	110.80	92.66	78.43	65.06	54.63	44.88	37.33	30.34	24.96	22.75
675	144.20	110.57	93.53	77.52	65.05	53.42	44.41	36.08	29.68	23.80	19.33	17.50
700	133.82	93.75	78.65	64.57	53.69	43.62	35.89	28.80	23.40	18.50	14.80	13.31
725	114.95	79.20	65.87	53.55	44.09	35.41	28.81	22.81	18.28	14.22	11.20	9.98
750	98.44	66.66	54.95	44.19	36.01	28.56	22.95	17.90	14.14	10.81	8.35	7.38
775	84.05	55.88	45.61	36.27	29.22	22.87	18.14	13.92	10.81	8.09	6.12	5.35
800	71.53	46.64	37.68	29.59	23.56	18.17	14.20	10.70	8.16	5.96	4.40	3.80
825	60.66	38.75	30.96	24.00	18.85	14.30	10.99	8.12	6.06	4.31	3.09	2.61

Color indicates criteria controlling S_t limit

1% strain

Rupture

Onset of tertiary

S_t Type 316 stainless steel

Type 316H SS, S_t—Allowable Stress Intensity Values (MPa), SI Units												
Temp. (°C)	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38	180.38
450	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38	178.38
475	176.38	176.38	176.38	176.38	176.38	176.38	176.38	176.38	176.38	176.38	163.22	153.30
500	174.39	174.39	174.39	174.39	174.39	174.39	174.39	174.39	174.39	151.94	131.92	123.42
525	172.39	172.39	172.39	172.39	172.39	172.39	172.39	167.08	144.65	123.13	105.99	98.75
550	170.39	170.39	170.39	170.39	170.39	170.39	161.46	137.06	117.67	99.21	84.61	78.49
575	168.40	168.40	168.40	168.40	168.40	155.25	133.00	111.86	95.18	79.43	67.08	61.92
600	166.40	166.40	166.40	166.40	152.92	128.35	109.02	90.79	76.53	63.16	52.77	48.46
625	164.40	164.40	164.40	147.70	127.03	105.62	88.90	73.26	61.12	49.85	41.16	37.59
650	162.41	161.99	143.43	124.92	105.04	86.47	72.09	58.73	48.46	39.01	31.80	28.86
675	160.41	138.60	121.99	103.76	86.45	70.41	58.08	46.75	38.12	30.25	24.31	21.90
700	155.31	118.20	103.38	85.78	70.78	56.99	46.49	36.92	29.71	23.21	18.36	16.42
725	133.70	100.44	87.26	70.56	57.62	45.83	36.93	28.91	22.93	17.60	13.67	12.11
750	114.75	85.03	72.47	57.74	46.62	36.59	29.10	22.42	17.49	13.17	10.02	8.78
775	98.16	71.68	59.68	46.97	37.47	28.98	22.72	17.19	13.17	9.69	7.20	6.22
800	83.68	60.17	48.87	37.96	29.89	22.76	17.55	13.02	9.78	6.98	4.98	4.22
825	68.25	50.26	39.79	30.47	23.65	17.69	13.40	9.72	7.07	4.84	3.32	2.75

Color indicates criteria controlling S_t limit

- 1% strain
- Rupture
- Onset of tertiary

S_{mt} Type 304 stainless steel

Type 304H SS, S_{mt}—Allowable Stress Intensity Values (MPa), SI Units												
Temp. (°C)	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05	105.05
450	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99	102.99
475	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95	100.95
500	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	98.96	97.55	91.49
525	97.02	97.02	97.02	97.02	97.02	97.02	97.02	97.02	97.02	91.30	79.04	73.84
550	95.11	95.11	95.11	95.11	95.11	95.11	95.11	95.11	87.41	74.18	63.66	59.23
575	93.22	93.22	93.22	93.22	93.22	93.22	93.22	83.27	71.30	59.92	50.95	47.19
600	91.32	91.32	91.32	91.32	91.32	91.32	81.26	68.15	57.83	48.11	40.49	37.32
625	89.35	89.35	89.35	89.35	89.35	78.83	66.80	55.47	46.63	38.34	31.93	29.27
650	87.22	87.22	87.22	87.22	78.43	65.06	54.63	44.88	37.33	30.34	24.96	22.75
675	84.83	84.83	84.83	77.52	65.05	53.42	44.41	36.08	29.68	23.80	19.33	17.50
700	82.01	82.01	78.65	64.57	53.69	43.62	35.89	28.80	23.40	18.50	14.80	13.31
725	78.58	78.58	65.87	53.55	44.09	35.41	28.81	22.81	18.28	14.22	11.20	9.98
750	70.05	66.66	54.95	44.19	36.01	28.56	22.95	17.90	14.14	10.81	8.35	7.38
775	61.21	55.88	45.61	36.27	29.22	22.87	18.14	13.92	10.81	8.09	6.12	5.35
800	52.82	46.64	37.68	29.59	23.56	18.17	14.20	10.70	8.16	5.96	4.40	3.80
825	45.23	38.75	30.96	24.00	18.85	14.30	10.99	8.12	6.06	4.31	3.09	2.61

S_m controlling

S_t controlling

S_{mt} Type 316 stainless steel

Type 316H SS, S_{mt}—Allowable Stress Intensity Values (MPa), SI Units												
Temp. (°C)	1 h	10 h	30 h	100 h	300 h	1,000 h	3,000 h	10,000 h	30,000 h	100,000 h	300,000 h	500,000 h
425	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01	110.01
450	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03	109.03
475	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13	108.13
500	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23	107.23
525	106.27	106.27	106.27	106.27	106.27	106.27	106.27	106.27	106.27	106.27	105.99	98.75
550	105.19	105.19	105.19	105.19	105.19	105.19	105.19	105.19	105.19	99.21	84.61	78.49
575	103.92	103.92	103.92	103.92	103.92	103.92	103.92	103.92	95.18	79.43	67.08	61.92
600	102.40	102.40	102.40	102.40	102.40	102.40	102.40	90.79	76.53	63.16	52.77	48.46
625	100.55	100.55	100.55	100.55	100.55	100.55	88.90	73.26	61.12	49.85	41.16	37.59
650	98.31	98.31	98.31	98.31	98.31	86.47	72.09	58.73	48.46	39.01	31.80	28.86
675	95.61	95.61	95.61	95.61	86.45	70.41	58.08	46.75	38.12	30.25	24.31	21.90
700	92.39	92.39	92.39	85.78	70.78	56.99	46.49	36.92	29.71	23.21	18.36	16.42
725	85.05	85.05	85.05	70.56	57.62	45.83	36.93	28.91	22.93	17.60	13.67	12.11
750	73.62	73.62	72.47	57.74	46.62	36.59	29.10	22.42	17.49	13.17	10.02	8.78
775	61.77	61.77	59.68	46.97	37.47	28.98	22.72	17.19	13.17	9.69	7.20	6.22
800	49.62	49.62	48.87	37.96	29.89	22.76	17.55	13.02	9.78	6.98	4.98	4.22
825	37.35	37.35	37.35	30.47	23.65	17.69	13.40	9.72	7.07	4.84	3.32	2.75

S_m controlling

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Summary

- Onset of tertiary creep can be a problematic criteria due to small datasets and deviations from classical creep curves
- The Leyda-Rowe correlation provides a means approximate onset of tertiary creep from the much larger creep rupture database
- The formulas and the numerical values of the corresponding coefficients that are required to determine the time-dependent allowable stress values of Type 304H and 316H stainless steels are documented in this presentation and the associated paper.
- These updates and extensions are being recommended to the ASME Code committees for approval, and are subject to change upon feedback from ASME Section III Code committees.

Idaho National Laboratory

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