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Small Tank Tetraphenylborate: Catalyst Influence of Selected Metals

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Summary

This study examined the differences in reaction rates observed for the decomposition of sodium tetraphenylborate between tests with radioactive waste and simulated waste. The study focused on eight transition metals that may serve as catalysts. Previous studies with simulated waste did not include these metals, although analysis identified them as present in radioactive waste in low concentrations. This study provides the following conclusions.

- The tests replicated previous experimental results in the decomposition of sodium tetraphenylborate (NaTPB) in simulated waste using the "Enhanced Comprehensive Catalyst (ECC)".
- When added as simple soluble salts to sodium tetraphenylborate slurries of approximately the same composition as used in the previous test with actual waste, these transition metals demonstrated no tendency to increase the decomposition of sodium tetraphenylborate.
- Based on recent findings by Peterson, we suspect the observed lack of reactivity may result in part from failure to reduce the transition metals to catalytically active forms.

Keywords: sodium tetraphenylborate, transition metal catalysts

Introduction

Previous studies of sodium tetraphenylborate (NaTPB) decomposition in the presence of catalytically active metals did not include eight transition metals (W, V, Au, Re, Os, Ir and Pt) identified in the High Level Waste. Here, rhenium (Re) metal is used as a surrogate for technetium. Therefore, the concentration of rhenium in the simulant reflects the concentration of both technetium and rhenium. This study attempted to measure the relative catalytic influence of the

seven metals on the decomposition rate of NaTPB using the Enhanced Comprehensive Catalyst (ECC) composition and the adjusted ECC (AECC) simulant designed to reflect the actual waste in both concentration and composition. (Since technetium and rhenium exhibit similar chemical behavior, we opted to not test technetium to avoid the safety and environmental risks of using radioactive materials). Previous studies demonstrated that ECC causes decomposition of active NaTPB in comparable fashion to reaction observed during Tank 48H processing.

Table 1 provides the list of tests using the standard ECC composition for the study of the decomposition of NaTPB, along with the various transition metals. Listed in Table 4 are the concentration of these transition metals and the other seven metals, which were normally not included in the ECC system. We adjusted the composition of the reactive slurry to match that of the actual waste system as found in Cycle 1 Batch 2 of the investigation by Hobbs et al[2]. We term this waste recipe as the Adjusted Enhanced Comprehensive Catalyst (AECC).

Experimental

Approach

The experimental approach involved the following steps.

- Reproduce previous catalytic work on the decomposition rate of NaTPB using the Enhanced Comprehensive Catalytic system. This first test serves as a quality control.
- Determine and compare the decomposition rate of NaTPB with ECC control plus all or some of the seven potential transition metal catalysts at sodium ion concentrations of 2.7 M and 4.7 M.
- Adjust the ECC composition (Adjusted ECC = AECC) so that the concentration of all reagents are comparable to those observed in the works of Hobbs et al[2]. The NaTPB decomposition rates in these AECC simulants with and without the potential catalysts provide a comparison with ECC control NaTPB decomposition rates.

This study used non-radioactive test solutions. The first test provides a quality control check for comparison of results with previous experiments. The test design purposely examines platinum reactivity independent from and combined with the other transition metals. We make this platinum differentiation due to previous studies by Yali Su at PNNL that showed catalytic activity for platinum in the decomposition of tetraphenylborate under different solution compositions.

Table 1. Test design summary

	2.7 M Na^+ concentration and analyze for NaTPB anion
1)	**ECC Control**
2)	**ECC** + Pt
3)	**ECC** + (V, W, Re[i], Os, Ir, Au)
4)	**ECC** + (V, W, Re, Os, Ir, Pt, Au)
5)	**Adjusted ECC Control:** To match concentrations in tests by Hobbs *et al.*
6)	**Adjusted ECC** + (V, W, Re, Os, Ir, Pt, Au): To match concentrations in tests by Hobbs et al.[2]
	4.7 M Na^+ concentration and analyze for boron and NaTPB anion
7)	**ECC Control**
8)	**Adjusted ECC** + (V, W, Re, Os, Ir, Pt, Au): To match concentrations in tests by Hobbs et al.[2]

Solutions used were reagent grade chemicals and all equipment used in this study were calibrated by the SRTC Standards Laboratory. The sodium tetraphenylborate ($Na[B(C_6H_5)_4]$; 99.5% purity) lot # 05711AU came from Aldrich chemical. We monitored the temperature of the oven daily and it remained at 45 ± 1 ^oC throughout the study.

We observed the tests for more than four weeks. We used 250-mL Teflonâ reaction vessels equipped with Teflonâ lined rubber septa for sampling and nitrogen purging of the vessel before and after sampling. We saturated the headspace in each vessel with nitrogen by purging for five minutes before and after sampling. We also wrapped high temperature tape around the cap of each reaction vessel to further reduce the chances for air leaks (Figures 1a and 1b). We did not provide stirring of the vessel contents during reaction. Table 2 summarizes the test conditions.

[1] Due to chemical similarities between rhenium and technetium, we set the rhenium concentrations used in all tests equal to combined concentrations of rhenium and technetium ([Re] = [Re] + [Tc]) from the work of Hobbs et al[2].

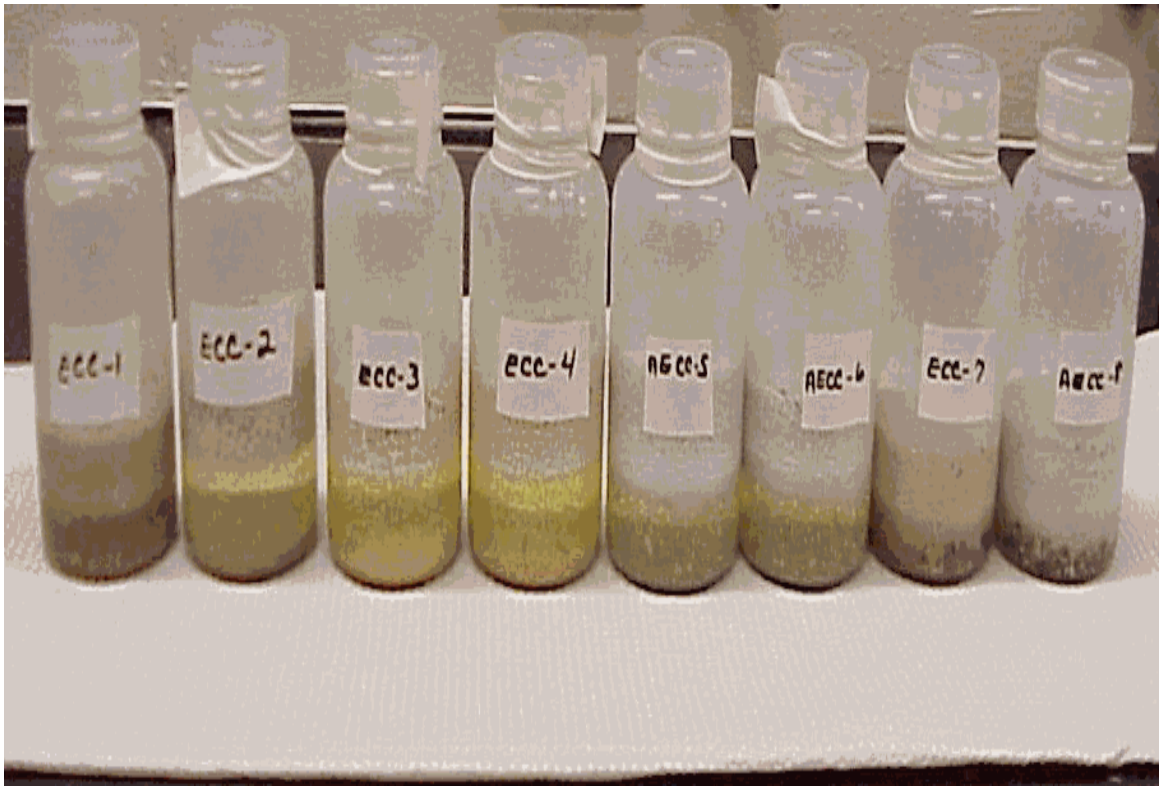

Figure 1a. Picture of all reaction vessels after 1000 hours of reaction time.

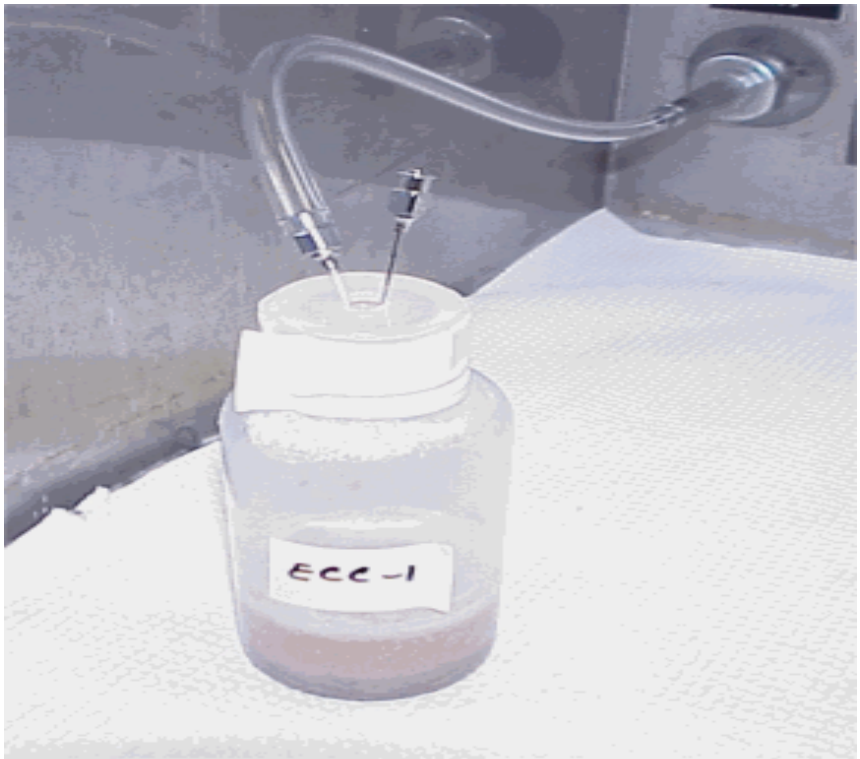

Figure 1b. Nitrogen purging set up for the 250-mL Teflon reaction vessel showing the syringe system through the rubber septa.

Each of the eight reaction vessels were first charged with 100-mL portions of NaTPB slurry, using 2.7 M Na^+ slurry for tests 1 through 6 and 4.7 M Na^+ for tests 7 and 8 (Tables 1 and 3). We then added the required amount of each catalyst or reagents to the vessels, by spiking each vessel with 0.1 mL of stock solutions to meet the prescribed amounts of each reagent as summarized in Table 4 and Appendix A.

Table 2. Summary of test conditions

Molar sodium ion concentration	= 2.7 for tests 1-6; 4.7 for test 7 and 8.
Reaction temperature	= 45 ^{0}C
NaTPB target concentration	= 5000 mg/L (soluble concentration)
Reaction atmosphere	= Nitrogen gas
Reaction vessel container	= 250 m L Teflon®bottles
Total reaction volume	= 100 mL portion
Reaction time duration	= >4 weeks for each test
Sampling frequency	= At least twice per week
Analysis	= Analysis for TPB anion and soluble boron for test 7 and 8.

No agitation of reaction mixtures occurred during the course of reaction.

Slurry density and estimated weight percent of sludge in each vessel determined the composition of insoluble solids in the reaction mixtures. As described in Table 5, ECC sludge is mostly iron while adjusted ECC (AECC) sludge is rich in aluminum, with very little iron. Each ECC test vessels received 1.540 grams of sludge and each AECC tests vessel received 1.106 grams of sludge. See Table 5 for sludge composition and concentrations. The soluble organic components of each test vessel (i.e., triphenylborane (3PB), diphenylborinic acid (2PB) and phenylboronic acid (1PB)), phenol, isopropanol and methanol from alkaline stock solutions, copper, benzene, monosodium titanate (MST), diphenylmercury and biphenyl were added last into each vessel. For the ECC experiments, we added 1.54 and 0.015 grams of MST and biphenyl, respectively. For the AECC experiments, we added 1.11 and 0.015 grams of MST and biphenyl, respectively.

After adding all the reagents including the potential catalysts, each reaction vessel was sealed and the headspace purged with nitrogen for five minutes before sampling for initial compositions. We put the samples into equilibrated oven at 45 ^{o}C. Twice a week we retrieved samples from the sealed reaction vessels for analysis. After three weeks, we changed the sampling frequency to once every two weeks for all AECC runs due to the slow observed reaction.

Table 3. Target slurry compositions (2.7 and 4.7 M Na^+)

4.7 M Na^+ Slurry					*2.7 M Na^+ Slurry*
Chemical		**Mol.Wt**	**mole/L**		**mole/L**
NaOH		40.0	3.24		1.86
$Al(NO_3)_3 \bullet 9H_2O$		375.14	0.17		0.10
$NaNO_3$		84.99	0.18		0.10
$NaNO_2$		69.01	0.70		0.40
$Na_2CO_3 \bullet H_2O$		124.02	0.19		0.11
Na_2SO_4		142.05	0.01		0.006
NaCl		58.44	0.02		0.008
NaF		41.99	0.01		0.005
$Na_3PO_4 \bullet 12H_2O$		380.12	0.01		0.004
NaTPB		342.23	0.19		0.109
Total Na^+, M			**4.72**		**2.702**
KNO_3		101.10	0.134		0.08

Analysis

In all tests, initial liquid samples were collected and analyzed by High Performance Liquid Chromatography (HPLC) to establish initial concentrations of tetraphenylborate, triphenylborane (3PB), diphenylborinic acid (2PB), and soluble boron. Boron analysis was carried out for the 4.7 Molar Na^+ tests only (ECC-7 and AECC-8) due to the much lower solubility of NaTPB. Periodic filtrate sampling of the reaction mixtures occurred during the remainder of the testing period. This syringe-based sampling involved periodic withdrawing of 5-mL sample portions followed by filtering. ADS analyzed the filtrate by HPLC for 3PB, 2PB and other products of interest. After sampling from each vessel, technicians purged headspace with nitrogen for five minutes before putting it back into the oven. Technicians also logged the reaction time in the oven for all the samples.

Results and Discussion

Table 6 contains the collected concentration data for NaTPB, 3PB and 2PB for up to 1600 hours of elapsed time for all tests. Table 7 contains soluble boron data for tests 7 and 8. Figure 2 shows a general plot for the variation of NaTPB concentration with time for the first six test designs in Table 1. Concentration data for test runs 7 and are shown in Figure 3.

$$\text{Rate} = -d[NaTPB]/d\tau = k[NaTPB][catalyst]^n = k'[NaTPB]$$

$$\text{Where } k' = k[catalyst]^n \text{ ---------- } 1$$

The solution to equation 1 above is

$$\text{Ln}\,([NaTPB]_0/[NaTPB]_\tau) = k'\tau \text{ ---------- } 2$$

Table 4. Target ECC and AECC Reagent Compositions and Concentrations.

Species	ECC	AECC[ii]	Species	ECC	AECC[ii]
Cu	3.7	3.4	Ce	0.3	0.26
Mo	12	20.4	Ru	5.4	0.09
Cr	60	29.1	Rh	1.4	0.44
Si	16	19.6	Pd	2.6	0.26
Se	1	9.1	Ag	6.8	9.9
As	0.04	34.2	3PB	125	125
Zn	8.8	10.1	2PB	125	125
Pb	1.2	5.7	1PB	125	125
Fe	2.6	166	phenol	125	125
Sn	2.1	2.7	isopropanol	50	50
Hg	2.2	0.53	methanol	5	5
Ca	12.2	206	diphenylHg	720	720
Sr	0.1	13.2	biphenyl	150	150
La	0.05	2.8	benzene	150	150
Co	0.04	0.14	Pt	-	0.0096[iii]
Mg	2.0	0.24	V	-	2.75 [iii]
Al	96	4810	W	-	0.74 [iii]
Ti	960	172	Re	-	0.0021 [iii]
Ni	50	11.7	Os	-	0.0023 [iii]
Zr	50	2.3	Ir	-	0.00071 [iii]
Cd	0.4	3.9	Au	-	0.0016 [iii]

All concentrations are in units of mg/L

$[NaTPB]_0$ is the initial concentration and [NaTPB]t is the concentration at time, t . The data summarized in Table 6 including changes in concentration of sodium tetraphenylborate and boron with time Table 7, can be used to analyze the kinetics of decomposition by applying equation 2 above or a data regression analysis using Microsoftâ Excel 5.0.

The left-hand side of equation 2 is plotted against time, t , with the slope of the curve representing the pseudo first-order rate constant for the decomposition of sodium tetraphenylborate. Figure 4 shows a typical application of equation 2 to determine the pseudo first -order decomposition rate constant for tetraphenylborate.

The observed rate constants for test designs 7 and 8 (ECC-7 and AECC-8), Table 8 and Figure 3, were not based on the decomposition of tetraphenylborate but rather on the active production of soluble boron during the entire course of the reaction. This approach

is required for calculating the rate constant because test design 7 and 8 contained excess insoluble tetraphenylborate, and as the reaction proceeds additional tetraphenylborate dissolves to replace any tetraphenylborate that may have reacted.

[ii] D. T. Hobbs, *et al*. (WSRC-TR-98-00070) - Cycle 1 Batch 2 average concentrations.

[iii] D. T. Hobbs, *et al*. (WSRC-TR-98-00070) - Cycle 1 Batch 4A average concentrations

Table 5. Target Sludge composition for ECC and AECC.

	AECC sludge	ECC Sludge
Component	Mass, g/L	Mass, g/L
$Mn(NO_3)_2 \cdot xH_2O$	16.782	16.782
NaOH	52.5	52.5

KMnO4	4.338	4.338
$Fe(NO_3)_3 \bullet 9H_2O$	1.016	127.6
$Ni(NO_3)_2 6H_2O$	0.0579	8.376
$CaCO_3$	0.453	3.01
$Al(OH)_3$	13.895	13.323
$BaSO_4$	0.3226	0.3226
$Ca_3(PO_4)_2 \bullet xH_2O$	0.0957	0.158
$CaSO_4$	0.042	0.234
Cr_2O_3	0.0851	0.276
$CsNO_3$	0.01	0.01
KOH	0.356	0.356
MgO	0.0004	0.26
$Na_2CO_3 \bullet H_2O$	0.106	0.106
Anhyd. Na_2SO_4	0.378	0.378
Anhyd. Na_3PO_4	0.018	0.018
NaCl	0.916	0.916
NaF	0.218	0.218
NaI	0.014	0.014
$NaNO_2$	2.385	2.385
$NaNO_3$	0.556	0.556
NaOH	1.018	1.018
Nd_2O_3	0.866	0.866
$Pb(NO_3)_2$	0.00741	0.346
SiO_2	0.042	3.657
$SrCO_3$	0.0224	0.146
Zeolite	3.741	3.741
ZnO	0.0126	0.184
ZrO_2	0.00311	2.502

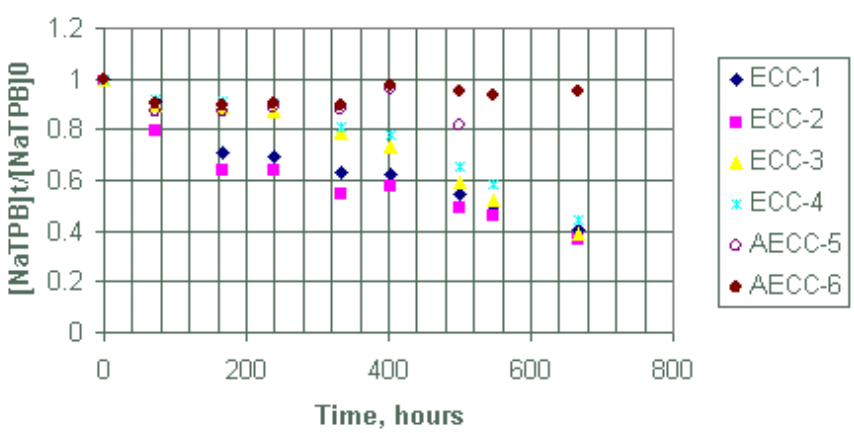

Figure 1. Changes in NaTPB concentration with time for the first 6-test desi

Where,

ECC-1 = Enhance Comprehensive Catalyst Control (2.7 M Na^+)
ECC-2 = Control + Pt
ECC-3 = Control + all other 7 seven transition metals
ECC-4 = Control + all 7 transition metals
AECC-5 = Simulated cycle 1
AECC-6 = Simulated cycle 1 + all 7 transition metals

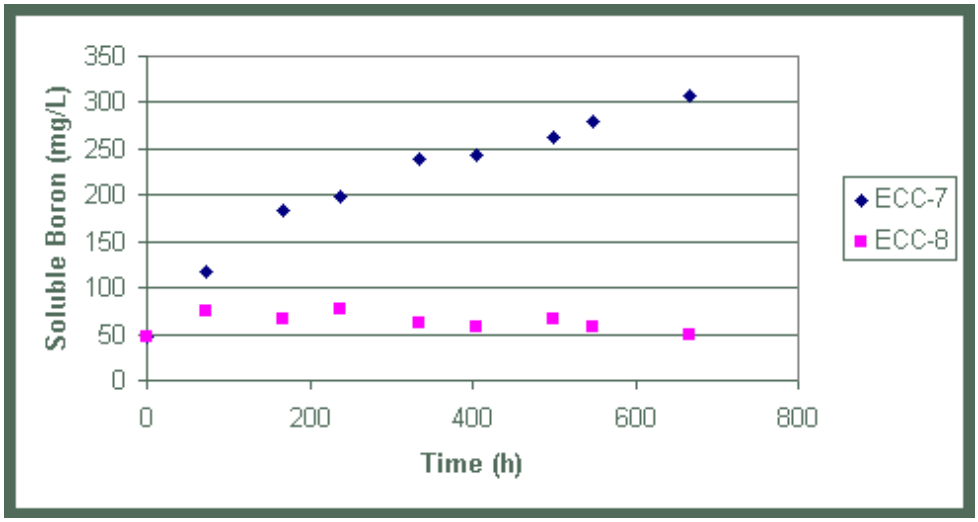

Figure 2. Overlay plot of variation of boron concentration with time (ECC-7 & AECC-8).

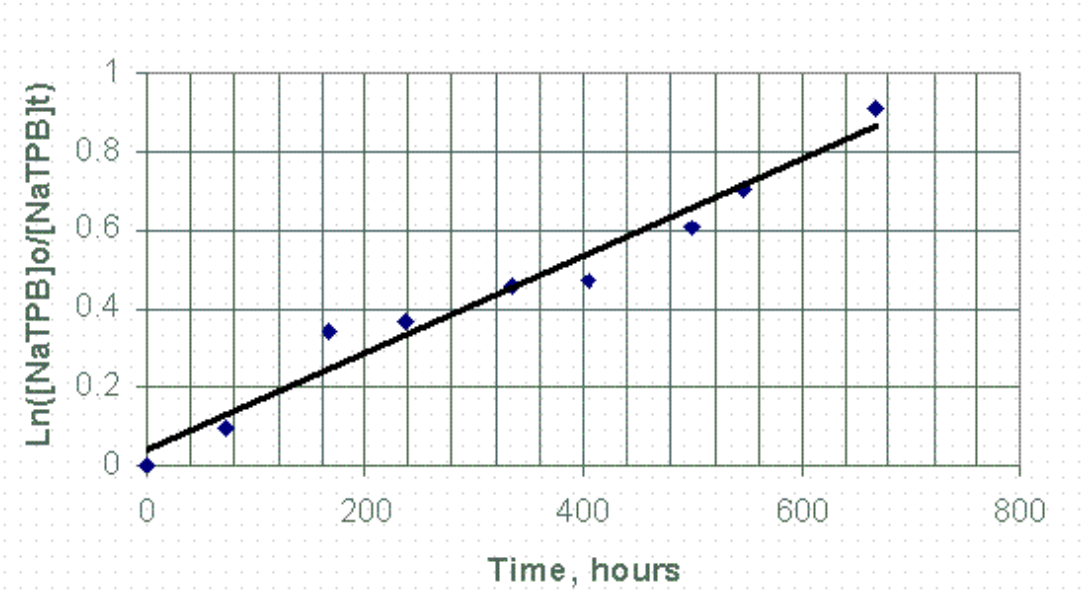

Figure 3. A typical plot per equation 2 for the decomposition NaTPB

The magnitude of the sodium tetraphenylborate pseudo first-order decomposition rate constant determined in this study (17 E-04 h^{-1}) for the ECC-1 control run (Table 8) is at the low end of the range of literature reported values. Literature reported values [2] carried out under identical experimental condition range from 13.1 to 26.7 E-04 h^{-1}, with and average value of 22 ± 5 E-04 h^{-1}.

With the addition of a platinum catalyst to the ECC control reaction mixture (ECC-2 test) there is no corresponding increase in the NaTPB decomposition rate. Parallel work by Peterson and Barnes[1] show that platinum, when present as the reduced metal species on alumina substrate, does increase the decomposition rate for the NaTPB. Apparently, the

platinum added in these tests (ECC-2 test) failed to reduce to the active catalytic form. When all the potential catalysts but platinum is added (ECC-3 test design) the increase in the NaTPB decomposition rate is still within the range of values for the decomposition rate constant reported in literature. The NaTPB decomposition rate with all seven potential catalysts included is comparable to the reaction rate for the ECC-3 test design without platinum as a potential catalyst.

All the simulated Cycle 1 Batch 2 test (AECC-5, AECC-6 and AECC-8) showed no measurable NaTPB decomposition rates even with an extension of the reaction time to 1600 hours. Test design 7 (control with 4.7 M Na^+) showed a measurable reaction rate in terms of soluble boron production (0.072 h^{-1}).

Uncertainties in the NaTPB decomposition rate constants are not ascertained, because we did not carry out the tests and analyses in duplicate due to analytical costs and time constraints.

Additionally, the use of mainly chloride transition metal precursors for the seven potential catalysts may pose another problem; one dealing with the extent to which these metals could be reduced as catalysts (APPENDIX A). One can argue that the simulated Cycle 1 Batch 2 tests did not show any signs of NaTPB decomposition because the catalysts did not reduce during the course of the reactions or that these metals do not show significant catalytic activity at the temperature and conditions tested.

Table 6. Summary of analytical results for NaTPB, 3PB, and 2PB concentration variation with time.

Sample ID	[NaTPB] mg/L	[3PB] mg/L	[2PB] mg/L	Reaction Time, h
ECC-1-0	6577	106	<100	0
ECC-1-1	5977	684	206	72.0
ECC-1-2	4672	1858	739	166.9
ECC-1-3	4539	1945	932	238.10
ECC-1-4	4154	1824	1211	333.80
ECC-1-5	4101	1880	1236	403.90
ECC-1-6	3576	1759	1339	500.50
ECC-1-7	3261	1696	1344	546.70
ECC-1-8	2652	1645	1498	667.21
ECC-2-0	7144	100	<100	0
ECC-2-1	5741	834	155	72.0
ECC-2-2	4613	1748	732	166.9
ECC-2-3	4644	2085	965	238.10
ECC-2-4	3980	2055	1300	333.80
ECC-2-5	4191	2075	1578	403.90
ECC-2-6	3557	1967	1534	500.50
ECC-2-7	3335	1877	1652	546.70
ECC-2-8	2652	1669	1417	667.21
ECC-3-0	7268	<100	<100	0
ECC-3-1	6527	<100	<100	72.0
ECC-3-2	6455	119	<100	166.9
ECC-3-3	6369	319	210	238.10
ECC-3-4	5704	813	524	333.80
ECC-3-5	5325	1455	795	403.90
ECC-3-6	4298	2058	1078	500.50
ECC-3-7	3807	2084	1170	546.70
ECC-3-8	2860	2434	1171	667.21

ECC-4-0	7065	<100	<100	0
ECC-4-1	6485	<100	<100	72.0
ECC-4-2	6439	119	<100	166.9
ECC-4-3	6371	323	184	238.10
ECC-4-4	5699	813	439	333.80
ECC-4-5	5514	1382	1035	403.90
ECC-4-6	4605	2001	998	500.50
ECC-4-7	4128	2013	1110	546.70
ECC-4-8	3111	2365	1125	667.21
AECC-5-0	7157	86	<100	0
AECC-5-1	6251	<100	<100	72.0
AECC-5-2	6246	<100	<100	166.9
AECC-5-3	6368	<100	<100	238.10
AECC-5-4	6282	84	<100	333.80
AECC-5-5	6859	69	144	403.90
AECC-5-6	5838		92	500.50
AECC-5-7	6706	91	117	546.70
AECC-5-8	6810	146	126	667.21
AECC-5-9	5981	130	72	1002.60
AECC-5-10	5913	177	205	1362.06
AECC-5-11	6502	294	95	1674.31
AECC-6-0	7223	84	<100	0
AECC-6-1	6519	<100	<100	72.0
AECC-6-2	6476	<100	<100	166.90
AECC-6-3	6528	<100	<100	238.05
AECC-6-4	6455	74	122	333.80
AECC-6-5	7061	80	218	403.90
AECC-6-6	6843	121	118	500.50
AECC-6-7	6727	95	153	546.70
AECC-6-8	6873	134	201	667.21
AECC-6-9	6448	73	146	1002.64
AECC-6-10	5902	298	163	1362.06
AECC-6-11	5917	322	157	1674.31
ECC-7-0	172	91	<100	0
ECC-7-1	167	330	558	72.00
ECC-7-2	149	595	929	166.93
ECC-7-3	167	638	989	238.050
ECC-7-4	193	554	934	333.76
ECC-7-5	170	372	886	403.90
ECC-7-6	144	458	602	500.50
ECC-7-7	132	438	501	546.71
ECC-7-8	127	548	449	667.21
AECC-8-0	189	105	<100	0
AECC-8-1	176	163	148	71.20

AECC-8-2	185	164	124	166.93
AECC-8-3	182	163	125	238.05
AECC-8-4	170	160	138	333.77
AECC-8-5	135	153	139	403.90
AECC-8-6	173	173	163	500.50
AECC-8-7	160	177	166	546.71
AECC-8-8	154	178	181	667.21
AECC-8-9	126	177	217	1002.64
AECC-8-10	121	177	205	1362.06
AECC-8-11	90	173	264	1674.31

[iv] ECC-N-X or AECC-N-X: N is test design number and X is the nth sampling period.

Table 7. Analytical results for soluble boron concentrations.

Sample ID	[B], mg/L	Time, h.
ECC-7-0	48	0
ECC-7-1	116	71.97
ECC-7-2	184	166.93
ECC-7-3	198	238.05
ECC-7-4	239	333.76
ECC-7-5	244	403.90
ECC-7-6	263	500.50
ECC-7-7	279	546.71
ECC-7-8	307	667.21
AECC-8-0	47	0
AECC-8-1	75	71.97
AECC-8-2	66	166.93
AECC-8-3	76	238.05
AECC-8-4	62	333.76
AECC-8-5	58	403.90
AECC-8-6	67	500.50
AECC-8-7	58	546.71
AECC-8-8	50	667.21
AECC-8-9	67.4	1002.64

Table 8. Pseudo first order reaction rate summary.

Test Design	**Reaction rate constant, 1E-4 h^{-1}**	**Previous values 1E-4 h^{-1}**
ECC-1 = Enhance Comprehensive Catalyst Control (2.7 M Na^+)	17	13.1 to 26.7[3,6]

ECC-2 = Control + Pt	17	
ECC-3 = Control + all other 6 transition metals, excluding Pt	24	
ECC-4 = Control + all 7 transition metals	22	
AECC-5 = Simulated cycle 1	Slow reaction	
AECC-6 = Simulated cycle 1 + 7 transition metals	Slow reaction	
ECC-7 = ECC control (4.7M Na^+)	702	1830[7]
AECC-8 = Simulated Cycle 1 (4.7 M Na^+)	Slow reaction	

Conclusions and Recommendations

The following conclusions and recommendations are based on the observations and results obtained above:

- The previous NaTPB decomposition rate with the Enhanced Comprehensive Catalyst (ECC) system was readily reproduced as the control for this investigation.
- The ECC control simulant loaded with only one additional potential transition metal catalyst (platinum) had a NaTPB decompositon rate comparable with reactions involving only the ECC control simulant.
- Adjusted ECC (AECC) control test solutions, simulated to reflect actual waste in concentration and compositions, and loaded with or without the seven potential catalysts did not show any measurable NaTPB decomposition during 1600 hours of reaction time.
- One reason for no observed changes in the decomposition rate of NaTPB in the actual waste simulant might be due in part to failure to reduce the potential transition metal catalysts to an active form.
- We recommend the use of carbonyl transition metals precursors or transition metals on supports for additional testing, since these materials, especially the supported metals, can be obtained in reduced forms in comparison to chlorinated inorganic transition metal salts.

Quality Assurance

This study fulfils part of the "Sodium Tetraphenylborate Catalyst Development Task Technical and Quality Assurance Plan"as documented in WSRC-99-01114, Rev. 0.

Data obtained from this study are found in WSRC-NB-99-00076 and WSRC-NB-98-00122 laboratory note books. SRTC Analytical Development Section (ADS), using recommended standards, performed all analytical work.

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Appendix A

Target transition metals precursors, organics and potential catalyst compositions and concentrations for ECC and AECC test designs.

Metal	Precursor	Metal wt.	Stock Vol.	Solvent	Amt Salt	[stoc metal] [ECC]	[Cycle1]	Vol/0.1L
		g/mole	mL		g/0.1L	mg/L	mg/L	mL

V	VCl_3	50.94	100	0.1 M HNO3	0.8437	2750.00	2.75000	0.1
W	WCl_6	183.84	100	0.1 M HNO3	0.1596	740.00	0.74000	0.1
Re	$NaReO_4$	186.21	100	0.1 M HNO3	0.0003	2.10	0.00210	0.1
Os	$OsCl_3 \cdot 3H_2O$	190.23	100	0.1 M HNO3	0.0004	2.30	0.00230	0.1
Ir	H_2IrCl_6	192.22	100	0.1 M HNO3	0.0002	0.71	0.00071	0.1
Au	$AuCl_3$	196.97	100	0.1 M HNO3	0.0003	1.60	0.00160	0.1
Pt	$PtCl_4$	195.08	100	0.1 M HNO3	0.0017	9.60	0.00960	0.1
Tc	See Rhenium	98.91	100	0.1 M HNO3			3.70000	0.1
[Tc+Re]	See Rhenium	186.21	100	0.1 M HNO3	0.5431	3702.1	3.70210	0.1

ADJUSTED ECC CONCENTRATIONS

Metal	Precursor	Metal wt.	Stock Vol	Solvent	Amt Salt	[stoc metal] [ECC]	Cycle1]	Vol/0.1L
Cu	$CuSO_4 \cdot 5H_2O$	63.546	100	Water	1.3359	3,400	3.4	0.1
Mo	$Na_2MoO_4 \cdot 2H_2O$	95.94	100	0.1 MNaOH	5.1446	20400	20.4	0.1
Cr	Na_2CrO_4	51.996	100	0.1 MNaOH	9.0648	29100	29.1	0.1
Si	$NaSiO_3 \cdot 9H_2O$	28.086	100	0.1 MNaOH	19.8334	19600	19.6	0.1
Se	Na_2SeO_4	78.96	100	0.1 MNaOH	2.1775	9100	9.1	0.1
As	As_2O_3	74.922	100	0.1 MNaOH	9.0309	34200	34.2	0.1
Zn	$Zn(NO_3)_2 \cdot 6H_2O$	65.39	100	0.1 M HNO3	4.5947	10100	10.1	0.1
Pb	$Pb(NO_3)_2$	207.2	100	0.1 M HNO3	0.9111	5700	5.7	0.1
Fe	$Fe(NO_3)_3 \cdot 9H_2O$	55.847	100	0.1 M HNO3	120.0850	166000	166	0.1
Sn	$SnCl_2 \cdot 2H_2O$	118.71	100	0.1 M HNO3	0.5132	2700	2.7	0.1
Hg	$Hg(NO_3)_2 \cdot H_2O$	200.59	100	0.1 M HNO3	0.0905	530	0.53	0.1
Ca	$Ca(NO_3)_2 \cdot 4H_2O$	40.08	100	0.1 M HNO3	121.3745	206000	206	0.1
Sr	$Sr(NO_3)_2$	87.62	100	0.1 M HNO3	3.1882	13200	13.2	0.1
La	$La(NO_3)_3 \cdot 6H_2O$	138.9	100	0.1 M HNO3	0.8729	2800	2.8	0.1
Co	$Co(NO_3)_2 \cdot 6H_2O$	58.933	100	0.1 M HNO3	0.0691	140	0.14	0.1
Mg	$Mg(NO_3)_2 \cdot 6H_2O$	24.305	100	0.1 M HNO3	0.2532	240	0.24	0.1
Al	$Al(NO_3)_3 \cdot 9H_2O$	26.981	100	0.1 M HNO3	6687.7500	4810000	4810	0.1
Ti	$TiCl_4$	47.9	100	0.1 M HNO3	68.1213	172000	172	0.1
Ni	$Ni(NO_3)_3 \cdot 6H_2O$	58.71	100	0.1 M HNO3	5.7954	11700	11.7	0.1
Zr	$ZrOCl_2 \cdot 8H_2O$	91.22	100	0.1 M HNO3	0.8125	2300	2.3	0.1
Cd	$Cd(NO_3)_2 \cdot 4H_2O$	112.41	100	0.1 M HNO3	1.0702	3900	3.9	0.1
Ce	$Ce(NO_3)_3 \cdot 6H_2O$	140.12	100	0.1 M HNO3	0.0806	260	0.26	0.1
Ru	$RuCl_3 \cdot H_2O$	101.07	100	0.1 M HNO3	0.0185	90	0.09	0.1
Rh	$Rh(NO_3)_3 \cdot 2H_2O$	102.9	100	0.1 M HNO3	0.1389	440	0.44	0.1
Pd	$PdCl_2$	106.4	100	0.1 M HNO3	0.0433	260	0.26	0.1
Ag	$AgNO_3$	107.87	100	0.1 M HNO3	1.5590	9900	9.9	0.1
3PB, 2PB, 1PB						125 mg/L		
Phenol						125 mg/L		
Isopropanol			Density = 0.7855 g/cc			50 mg/L		
Methanol			Density = 0.7914 g/cc			5 mg/L		
Diphenylmercury						720 mg/L		
Biphenyl						150 mg/L		
Benzene			Density = 0.87865 g/cc			150 mg/L		

Metal	Precursor	Molec wt.	Stock Vol.	Solvent	Amt Salt	[stoc metal] [ECC]	[ECC]	Vol/0.1L
		g/mole	mL		g/0.1L	mg/L	mg/L	mL
Cu	$CuSO_4 \cdot 5H_2O$	249.68	100	Water	1.4538	3,700	3.7	0.1
Mo	$Na_2MoO_4 \cdot 2H_2O$	241.95	100	0.1 MNaOH	3.0263	12000	12	0.1
Cr	Na_2CrO_4	161.97	100	0.1 MNaOH	18.6903	60000	60	0.1
Si	$NaSiO_3 \cdot 9H_2O$	284.2	100	0.1 MNaOH	16.1905	16000	16	0.1
Se	Na_2SeO_4	188.94	100	0.1 MNaOH	0.2393	1000	1	0.1
As	As_2O_3	197.84	100	0.1 MNaOH	0.0106	40	0.04	0.1
Zn	$Zn(NO_3)_2 \cdot 6H_2O$	297.47	100	0.1 M HNO3	4.0033	8800	8.8	0.1
Pb	$Pb(NO_3)_2$	331.2	100	0.1 M HNO3	0.1918	1200	1.2	0.1
Fe	$Fe(NO_3)_3 \cdot 9H_2O$	404	100	0.1 M HNO3	1.8808	2600	2.6	0.1
Sn	$SnCl_2 \cdot 2H_2O$	225.63	100	0.1 M HNO3	0.3991	2100	2.1	0.1
Hg	$Hg(NO_3)_2 \cdot H_2O$	342.61	100	0.1 M HNO3	0.3758	2200	2.2	0.1
Ca	$Ca(NO_3)_2 \cdot 4H_2O$	236.15	100	0.1 M HNO3	7.1882	12200	12.2	0.1
Sr	$Sr(NO_3)_2$	211.63	100	0.1 M HNO3	0.0242	100	0.1	0.1
La	$La(NO_3)_3 \cdot 6H_2O$	433.02	100	0.1 M HNO3	0.0156	50	0.05	0.1
Co	$Co(NO_3)_2 \cdot 6H_2O$	291.03	100	0.1 M HNO3	0.0198	40	0.04	0.1
Mg	$Mg(NO_3)_2 \cdot 6H_2O$	256.41	100	0.1 M HNO3	2.1099	2000	2	0.1
Al	$Al(NO_3)_3 \cdot 9H_2O$	375.14	100	0.1 M HNO3	133.4770	96000	96	0.1
Ti	$TiCl_4$	189.71	100	0.1 M HNO3	380.2121	960000	960	0.1
Ni	$Ni(NO_3)_2 \cdot 6H_2O$	290.81	100	0.1 M HNO3	24.7666	50000	50	0.1
Zr	$ZrOCl_2 \cdot 8H_2O$	322.25	100	0.1 M HNO3	17.6633	50000	50	0.1
Cd	$Cd(NO_3)_2 \cdot 4H_2O$	308.47	100	0.1 M HNO3	0.1098	400	0.4	0.1
Ce	$Ce(NO_3)_3 \cdot 6H_2O$	434.23	100	0.1 M HNO3	0.0930	300	0.3	0.1
Ru	$RuCl_3 \cdot H_2O$	207.43	100	0.1 M HNO3	1.1083	5400	5.4	0.1
Rh	$Rh(NO_3)_3 \cdot 2H_2O$	324.95	100	0.1 M HNO3	0.4421	1400	1.4	0.1
Pd	$PdCl_2$	177.31	100	0.1 M HNO3	0.4333	2600	2.6	0.1
Ag	$AgNO_3$	169.87	100	0.1 M HNO3	1.0709	6800	6.8	0.1
3PB, 2PB, 1PB							125 mg/L	
Phenol							125 mg/L	
Isopropanol			Fw= 60.11, density = 0.7855 g/cc				50 mg/L	
Methanol			Fw =32.04 Density =0.7914 g/cc				5 mg/L	
Diphenylmercury							720 mg/L	
Biphenyl							150 mg/L	
Benzene			Fw=78.12; Density =0.87865 g/cc				150 mg/L	

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