THE CRUCIBLE

Project 4

Bombs

Aerosol demasking, Arctic methane release, and nuclear meltdown as delayed consequences of civilization

A consolidated scientific-study analysis of the Project 4 bomb-series phases.

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Introduction and Study Design

Project 4 is the escalation project. Project 3 asked whether evolved language-model-designed tribes could learn from evidence and produce better survival strategies while biologic controls remained fixed. Project 4 asks a harsher question: when evolved tribes are already surviving recurring apocalypse, what happens when the world includes three delayed consequences created by industrial civilization itself?

The three Project 4 hazards are not arbitrary disasters. Aerosol demasking follows industrial shutdown and the loss of temporary aerosol cooling. Arctic methane release follows high-energy warming and introduces a long-lived greenhouse feedback. Nuclear meltdown follows the failure of high-maintenance technological infrastructure after grid, institutional, and supply-chain collapse.

Central question
Can the best evolved survivors endure the feedback shocks created by prior energy capture, or does evolution only teach them how to survive the first apocalypse?

Relationship to the earlier projects

Project 4 treats the prior projects as a reference baseline: Project 1 establishes collapse dynamics, Project 2 tests competition and non-transitive fitness, and Project 3 adds iterative language-model redesign. The bomb series then tests whether those evolved strategies remain robust when collapse generates delayed planetary and infrastructural consequences.

Prior project	Question left unresolved	Project 4 response
Project 1 - Baseline Crucible	Civilization emerges, overshoots, collapses, and leaves refugia. Climate amplifies collapse but baseline fragility already exists.	Use the harsh climate standard as background and add delayed post-collapse or peak-industrial consequences.
Project 2 - Competition	Fitness may be intrinsic, opponent-specific, or non-transitive.	Keep evolved competitors together and ask whether any strategy remains robust under new world hazards.
Project 3 - Evolution	LLMs adapted toward hardiness, low legacy, refugia survival, and selective cooperation, but did not solve civilization.	Test whether those evolved refugia strategies survive when collapse itself generates additional shocks.

Experimental blocks

The formal study is a four-block experiment. Each block preserves the ordinary collapse background and changes only the Project 4 bomb configuration. The stacked block tests whether the combined effects are worse than the individual-bomb phases.

Block	Event configuration	Purpose	Output
Phase 1	Aerosol demasking only, with normal baseline climate/fossil events still active.	Test whether post-crash survivors can withstand the loss of industrial aerosol cooling.	10 epochs.
Phase 2	Arctic methane release only, with normal baseline climate/fossil events still active.	Test whether industrial ascent triggers a long-lived greenhouse feedback that later punishes survivors.	10 epochs.
Phase 3	Nuclear meltdown only, with normal baseline climate/fossil events still active.	Test whether failed high-complexity infrastructure creates local exclusion zones and late refugia hazards.	10 epochs.

Block	Event configuration	Purpose	Output
Phase 4	All three Project 4 events enabled together.	Test for nonlinear stacking: whether combined feedbacks are worse than the sum of separate bombs.	10 epochs.

Terms Used in This Report

The terms below are used throughout the Project 4 analysis. They are model-specific interpretive labels, not direct real-world classifications of people or societies.

Term	Meaning in the Project 4 model
Aerosol demasking	The loss of industrial aerosol cooling after industrial shutdown, exposing previously masked greenhouse heat.
Arctic methane release	A long-duration greenhouse feedback triggered during rapid industrial ascent or peak energy growth.
Nuclear meltdown	Failure of high-complexity infrastructure after collapse, modeled as regional contamination, hazards, capacity loss, and exclusion-zone pressure.
Prisoner's Dilemma	The interaction game used to model cooperation, defection, exploitation, and strategic trust under survival pressure.
EROI	Energy return on investment; lower EROI indicates a harsher energy environment and weaker recovery potential.
Refugium / refugia	A surviving pocket or set of pockets after the main crash.
Language-model Generation 3	A redesigned language-model tribe from the later project generations.
Biologic controls	The unchanged old-guard biologic tribes used as controls across the later phases.
Hardiness	A survival-efficiency trait associated with endurance under scarcity, metabolic stress, and climate or hazard pressure.
Vitality	A resilience trait associated with health, longevity, and hazard survival.
Legacy	A reproduction-pressure trait; lower legacy often reduces boom-bust reproductive overshoot.
Kin trust	Cooperation tendency toward same-tribe or kin-like partners.
Xeno trust	Cooperation tendency toward outsiders; high xeno trust can increase exposure during scarcity.
Opportunism	Tendency to exploit or defect when conditions make cooperation risky or unrewarding.
Wander	Movement tendency under abundance, scarcity, or desperation.
Regime 1 (Foraging)	Lowest-complexity subsistence state.
Regime 2 (Agrarian)	Low-energy settled survival state; most final refugia settle here.
Regime 3 (Industrial)	Fossil/industrial expansion state.
Regime 4 (Technological)	High-complexity, networked, advanced energy state.

Research Questions and Measures

The study evaluates world outcomes, event timing, tribe performance, social behavior, geography, genetics, and objective achievement. The central analytical problem is to distinguish ordinary collapse survival from survival under the delayed consequences of the civilization that created the collapse conditions.

ID	Question / hypothesis	Primary evidence
RQ1	Does Project 4 reduce survival relative to Project 3?	Surviving tribes, final population, extinction pulse, final refugia by phase.
RQ2	Are Project 3 evolved traits still adaptive once delayed bombs are added?	Founder-to-elite drift, survivor traits, tribe rankings, event-specific survival.
RQ3	Do different bombs select for different survival strategies?	Cross-phase trait comparison: demasking-only vs methane-only vs meltdown-only.
RQ4	Does stacked Project 4 pressure produce nonlinear collapse?	Combined phase versus separate-event averages; final population and extinction rate compared with additive expectations.
RQ5	Do LLM-designed tribes still outperform biologic controls?	Survival and peak/final population by player_type and generation.
RQ6	Is survival merely remnant survival or reproductive continuity?	Late births, failed births, age/generation, final energy, last 2000-pulse viability.
RQ7	Does high complexity help preserve civilization or become a liability?	Peak/final complexity, meltdown targeting, final refugia complexity, region history.
RQ8	How does social strategy behave under bombs?	PD cooperation/defection/exploitation, same-tribe/civic/xeno shares by period and around trigger windows.
RQ9	Did tribes achieve their stated objectives?	Declared objective text, objective scorecard, survival/complexity/refugia alignment.

Layer	Measures
World outcome	Peak/final population, peak/final complexity, population crash depth, total surviving tribes, inhabited regions, climate heat/damage/feedback/chaos, resource pool floor.
Event timing	Arm pulse, trigger pulse, population/energy/complexity at trigger, +500 and +1500 pulse aftermath, final state.
Tribe performance	Survival, extinction pulse, peak/final population, regime reached, births, failed births, death shares, final energy.
Behavior	Mutual cooperation, mutual defection, exploitation, same-tribe share, xeno share, civic override, civic kin.
Geography	Final refugia, region histories, quadrant outcomes, contaminated or damaged regions, mixed regions, stranded survivors.
Genetics	Founder means, elite means, survivor means, drift in hardiness/vitality/legacy, wander, trust, forgiveness, opportunism.
World function	Whether triggers fired at intended times, whether effects were visible, whether outcomes were event-specific or noise.

Objective scoring framework

Final population alone is not enough to score Project 4 survival. A single survivor is meaningful, but it is different from a reproducing, distributed, recoverable refugia network.

Tier	Survival meaning	Example indicator
Tier 1 - Existence	At least one member of the lineage survives to final pulse.	final_population > 0
Tier 2 - Reproductive continuity	Survivors are not merely old remnants; late births continue.	late_births > 0 in final 2000 pulses
Tier 3 - Refugia stability	Survival is not a one-agent accident in a dead region.	final energy, low stress, viable EROI, regional population > token remnant
Tier 4 - Distributed survival	Lineage survives in more than one region or has multiple refugia options.	multiple inhabited regions / regions with same surviving player
Tier 5 - Recoverable complexity	The lineage retains enough complexity, memory, or institutional capacity to rebuild.	nonzero final/regional complexity, surviving high-regime inheritance
Tier 6 - Civilizational continuity	Survival preserves more than biology: cooperation, civic bridges, and rebuilding potential remain.	late cooperation/civic measures plus recoverable complexity

Event models

Each bomb represents a different delayed consequence of industrial civilization. Aerosol demasking is fast and post-crash; methane is earlier and chronic; nuclear meltdown is regional and infrastructure-bound.

Aerosol demasking event model

Dimension	Implementation meaning
Trigger logic	A large energy drop arms the event; demasking fires later after an industrial/emissions proxy falls below a configured fraction of its prior peak, with a fallback delay if needed.
Duration	1500 pulses. This is short compared with methane and meltdown, reflecting the fast clearing of aerosols relative to long-lived greenhouse forcing.
Thermodynamics	Adds a heat shock, increases climate damage and chaos, raises hazard pressure, reduces fertile capacity, drains regional pools, and suppresses regional ratios/EROI during the active window.
Prisoner's Dilemma behavior	Pushes agents into scarcity or desperation states, increasing the strategic importance of kin trust, xeno caution, and anti-exploitation traits. Cooperation may remain valuable inside refugia but risky across collapsing borders.
Reproduction	Lower energy and harsher regional conditions should increase failed births, reduce successful reproduction, and punish high-legacy designs that try to expand into the shock.
Expected signature	A visible post-crash discontinuity in heat, climate damage, hazards, deaths, resource pools, and late refugia viability, without necessarily causing total extinction every epoch.

Arctic methane release event model

Dimension	Implementation meaning
Trigger logic	Triggered by a large energy increase over a defined window during industrial ascent or pre-peak acceleration. The current design target is a 2B energy increase over 1500 pulses.
Duration	8000 pulses. This makes methane a long-lived system feedback rather than a short disaster.
Thermodynamics	Adds forcing to climate heat, increases feedback growth, lowers effective heat decay/damping, raises climate chaos, increases hazard pressure, and gradually damages fertile capacity.
Prisoner's Dilemma behavior	Acts earlier than demasking, so it can alter the competitive landscape before peak population. It may punish high-growth lineages by bringing climate stress forward into their expansion window.
Reproduction	Should increase failed births and mortality over a long interval, especially in overpopulated regions where EROI and resource pools are already strained.
Expected signature	Higher peak heat/damage, earlier climate stress, lower late resilience, and possibly reduced peak or more fragile post-peak survival.

Nuclear meltdown event model

Dimension	Implementation meaning
Trigger logic	Triggered by a severe energy drop after collapse. The current design target is a 6B energy drop over 2000 pulses.
Duration	8000 pulses. This expresses a long tail of contamination and abandoned infrastructure risk.
Thermodynamics	Locally destroys or suppresses usable energy, carrying capacity, environmental pools, and EROI in affected regions. Unlike methane, it is spatially uneven.
Prisoner's Dilemma behavior	Forces displacement and contact. Safe territory becomes more valuable, raising the importance of border behavior, xeno strategy, civic override, and conflict avoidance or exploitation.
Reproduction	Affected regions should experience higher hazard mortality, more scarcity, and lower viable reproduction. Refugee pressure may increase failed births in receiving regions.
Expected signature	Geographic discontinuity: some regions become long-term traps or exclusion zones while others become final refugia. Survival may depend on avoiding the technological inheritance of former high-complexity centers.

Working event trigger summary

Event	Trigger concept	Duration	Primary intended effect
Aerosol demasking	Large post-peak energy crash arms event; industrial/emissions proxy decline fires event after delay.	1500	Fast revealed warming and post-crash climate/resource shock.
Arctic methane release	Rapid energy increase during industrial ascent/peak warming.	8000	Long greenhouse feedback pulse and chronic climate destabilization.
Nuclear meltdown	Severe post-crash energy decline and infrastructure maintenance failure.	8000	Regional contamination, hazard, capacity loss, and exclusion-zone dynamics.

The stacked phase tests nonlinear sequencing. Methane can heat the ascent before peak, aerosol demasking can reveal suppressed warming after industrial collapse, and nuclear meltdown can poison the same high-complexity regions that once looked richest or safest. The same trait can therefore be adaptive under one event and maladaptive under another.

Phase 1 - Aerosol Demasking

Phase 1 tests aerosol demasking alone. The event is designed as a post-collapse filter: civilization can still reach a large industrial or technological peak, but the loss of the industrial aerosol veil makes the post-peak world much more lethal.

Phase 1 finding
Aerosol demasking does not primarily prevent the climb. It attacks terminal survivability and converts recurring apocalypse into a knife-edge refugia problem.

Metric	Project 4 Phase 1 result	Interpretive note
Epochs	141-150	Ten-epoch aerosol-only phase

Metric	Project 4 Phase 1 result	Interpretive note
Average peak world population	2.64M	Nearly unchanged from the Project 3 G3 reference peak (~2.68M)
Average final population	6,775	Down from roughly 40,114 in the Project 3 G3 reference
Median final population	736	The average is pulled upward by epoch 144
Final population range	1 to 50,753	Large variability; not a uniform kill event
Average post-peak decline	99.76%	Civilization peaks, then almost completely simplifies
Average peak climate heat	2.658	About 52% higher than the Project 3 G3 reference
Average peak climate damage	0.759	About 23% higher than the Project 3 G3 reference
Death mix	73.7% starvation / 24.8% hazard	Hazard share rises relative to Project 3 as climate shock deepens

World outcome

All ten epochs retained at least one final survivor, but most final populations were extremely small. The phase is therefore not a simple extinction switch; it introduces a severe post-crash missing reality while still allowing differential survival.

Epoch	Peak population	Final population	Final regions	Final survivors	Peak heat	Peak damage
141	2,533,087	2,957	15	Obsidian	2.527	0.751
142	2,889,357	2,304	10	Obsidian	2.641	0.766
143	3,153,871	2	1	Obsidian	2.588	0.759
144	2,947,076	50,753	78	Obsidian + Ember	1.376	0.531
145	2,404,438	1	1	Obsidian	2.696	0.773
146	2,558,684	57	3	Obsidian	2.797	0.785
147	2,494,801	10,233	21	Obsidian	2.946	0.802
148	2,712,083	1,415	18	Obsidian	2.825	0.789
149	2,644,299	7	2	Obsidian	2.983	0.806
150	2,059,476	18	3	Velvet Fang	3.202	0.828

Tribe and strategy signal

The Obsidian Phalanx Refuge G3 is the dominant Phase 1 survivor. It survives nine of ten epochs and becomes the only robust cross-epoch refugia strategy in the aerosol-only run.

Tribe	Type	Survived epochs	Best final population	Average final population	Average last alive or final pulse	Death mix
The Obsidian Phalanx Refuge G3	LLM G3	9/10	50,750	6,772.6	39,560	70.8% starvation / 27.6% hazard
The Velvet Fang	Biologic G1	1/10	18	1.8	16,315	69.9% starvation / 27.9% hazard
The Ember Refugia Compact G3	LLM G3	1/10	3	0.3	27,835	75.7% starvation / 23.0% hazard

Founder trait signal

Founder trait signal	Surviving LLMs	Extinct LLMs	Direction suggested
Hardiness	56.75	50.60	Higher endurance favored
Vitality	35.04	31.58	Higher survival buffer favored
Legacy	8.21	17.82	Strong reproductive restraint favored

Founder trait signal	Surviving LLMs	Extinct LLMs	Direction suggested
Kin trust	0.812	0.697	Internal cohesion favored
Xeno trust	0.093	0.092	Both groups low; not the differentiator
Xeno opportunism	0.758	0.686	Sharper external posture favored

Founder trait signal	Surviving LLMs	Extinct LLMs	Direction suggested
AB / SC / Desperation wander	0.112 / 0.277 / 0.422	0.251 / 0.345 / 0.580	Lower mobility favored

The founder-to-elite pattern reinforces the same interpretation: successful lineages suppress legacy and avoid reproductive overshoot. Phase 1 rewards internal cohesion, low reproductive pressure, low exposure to outsiders, and the ability to preserve a small reproductive foothold after the demasking shock. The phase therefore turns the Project 3 survival question inside out. Survival remains possible after the aerosol veil disappears, but it is narrow, stochastic, and concentrated mainly in one collapse-specialized design.

Phase 2 - Arctic Methane Release

Phase 2 tests Arctic methane release alone. The central question is whether methane acts as a long-lived greenhouse feedback that begins during industrial ascent and changes survival, collapse depth, strategy selection, and refugia quality.

Phase 2 finding
Methane behaves as a chronic climate amplifier rather than a sudden kill-shot. It suppresses civilizational scale, raises climate damage and hazard pressure, and reduces terminal outcomes below the Project 3 reference, but it is less terminally lethal than aerosol demasking.

Phase	Average peak population	Average final population	Average surviving tribes	Average peak complexity	Average final complexity	Average peak heat	Average peak damage
Project 3 G3 reference	2,681,885	40,114	1.20	1,360,263	17,434	1.7524	0.6167
Phase 1 - Aerosol only	2,639,717	6,775	1.10	1,401,563	3,124	2.6581	0.7590
Phase 2 - Methane only	2,241,372	19,915	1.00	1,079,288	8,329	1.9425	0.6545

Event signature

The methane trigger window is tightly clustered around pulse 25,100 to 25,200. Unlike aerosol demasking, methane does not appear as a single discontinuity. It creates a long ramp that raises heat, damage, chaos, hazards, and feedback across thousands of pulses.

Window after trigger	Average pattern across epochs
Pre-500 pulses	Heat and damage are near zero; climate feedback is approximately 1.0.
0-500 pulses	Methane begins visibly, but the immediate shock remains modest.
501-1,500 pulses	Heat and damage rise; starvation and hazard deaths begin climbing.
1,501-4,000 pulses	Feedback accelerates sharply; many epochs approach or reach feedback saturation.
4,001-8,000 pulses	Peak methane pressure: heat roughly 1.58-2.05, damage roughly 0.58-0.68, feedback at or near 5.0.

Competition and lineage outcome

The methane-only block strongly favors language-model Generation 3 lineages. Biologic controls record no final survivors across the block, while the Obsidian Phalanx Refuge G3 survives most epochs.

Type	Slots	Survived slots	Survival rate	Average duration pulse	Average peak population	Average final population	Starvation share	Hazard share
BIOLOGIC G1	60	0	0.0000	13,739	3,987	0	0.5441	0.4025
LLM G3	60	10	0.1667	26,499	387,158	3,319	0.7535	0.2323

Tribe	Survived epochs	Average duration	Best final population	Average final population	Starvation share	Hazard share
Obsidian Phalanx Refuge G3	8/10	34,780	34,785	13,602	0.7045	0.2791
Castellans of Gemini III G3	1/10	23,605	41,926	4,193	0.7610	0.2207
Helix Vanguard G3	1/10	26,070	21,199	2,120	0.7819	0.2059
All biologic controls	0/60 slots	about 13,739 avg	0	0	0.5441	0.4025

Strategy and reproductive continuity

The survivor profile under methane is conservative and internally cohesive: higher hardiness, lower legacy, more kin trust, lower panic mobility, and more selective external opportunism. Methane punishes ascent and leaves the survivors with a hotter, more damaged world.

Founder trait group	Surviving LLMs	Extinct LLMs	Interpretation
Hardiness	54.88	50.97	Higher metabolic endurance helped.
Vitality	34.69	31.65	Moderate longevity remained useful.
Legacy	10.44	17.37	Lower reproduction pressure reduced overshoot.
Kin trust	0.8138	0.6969	Internal cohesion mattered.
Xeno trust	0.1031	0.0898	Both groups were low; xeno trust was not the main separator.
Xeno opportunism	0.7502	0.6877	Selective external opportunism helped more than external trust.
Desperation wander	0.4368	0.5769	Survivors were less panic-mobile.

Late-refugia indicator	Observed signal
Final survivor type	All surviving final populations were LLM-designed.
Late births	About 412,599 across late survivor rows.
Late deaths	About 320,528 across late survivor rows.
Largest late population row	42,077 for Gemini in epoch 156.
Obsidian late births	About 266,663 across its surviving late rows.

Late-refugia indicator	Observed signal
Interpretation	Survival often remained reproductive, not merely a few old survivors waiting to die.

Methane-only survival is not just static remnant survival. The late-refugia evidence shows continued reproduction among meaningful survivors. This makes methane a chronic filter rather than a terminal eraser: it lowers peak scale and final complexity, but it can still leave reproducing refugia.

Phase 3 - Nuclear Meltdown

Phase 3 tests nuclear meltdown as a delayed consequence of failed complex infrastructure after collapse. The event is not nuclear war. It represents abandoned reactors, cooling systems, grids, trained operators, institutions, and long-term waste management.

Phase 3 finding
Nuclear meltdown does not produce total extinction and is less globally terminal than the aerosol and methane blocks, but it creates the clearest regional damage and exclusion-zone signature in the individual-bomb phases.

Event configuration

The block is nuclear-only: aerosol demasking and methane release are disabled, while nuclear meltdown is enabled throughout the formal phase. The configuration expresses a long regional hazard with partial coverage and clustered targeting.

Event	Enabled epochs	Disabled epochs
Aerosol demasking	0	10
Arctic methane release	0	10
Nuclear meltdown	10	0

Parameter	Value
Enabled epochs	10 of 10
Duration	8,000 pulses
Primary multiplier	0.72
Secondary multiplier	1.40
Coverage	18%
Cluster size	3
Hazard cap	0.18
Fertile capacity loss	30%
Critical depletion threshold	0.97

World outcome and cross-bomb comparison

Nuclear-only has a distinctive profile. It is much less globally lethal than aerosol-only or methane-only in final population, while still carrying a large hazard penalty relative to the Project 3 reference. This suggests that nuclear meltdown is a spatial sorting event more than a uniform world-killer.

Phase	Average peak population.	Average final population.	Min final	Max final	Average survivors	Average peak max hazard	Hazard death share
Project 3 G3 reference	2,681,885	40,114	26,982	76,330	1.2	0.0739	21.4%
Phase 1 - Aerosol demasking	2,639,717	6,775	1	50,753	1.1	0.1963	24.8%
Phase 2 - Arctic methane release	2,241,372	19,914	2,854	41,926	1.0	0.1280	23.4%
Phase 3 - Nuclear meltdown	2,726,445	33,841	25,393	45,712	1.2	0.1713	22.8%

Epoch	Peak population.	Final population.	Post-peak decline	Surviving tribes	LLM	Bio	Peak maximum hazard	Hazard deaths
161	2,400,523	33,589	98.6%	1	1	0	0.1717	22.6%
162	2,786,452	41,863	98.5%	1	1	0	0.1712	23.1%
163	2,949,012	28,679	99.0%	2	1	1	0.1713	24.0%
164	2,834,528	25,393	99.1%	1	1	0	0.1713	21.4%
165	2,675,077	33,768	98.7%	1	1	0	0.1715	24.3%

Epoch	Peak population.	Final population.	Post-peak decline	Surviving tribes	LLM	Bio	Peak maximum hazard	Hazard deaths
166	2,630,782	32,614	98.8%	1	1	0	0.1714	21.7%
167	2,677,525	45,712	98.3%	1	0	1	0.1709	22.3%
168	2,732,882	37,896	98.6%	2	2	0	0.1709	19.1%
169	2,940,984	27,818	99.1%	1	1	0	0.1714	25.2%
170	2,636,681	31,080	98.8%	1	1	0	0.1716	24.6%

The nuclear-only phase repeatedly reaches high peak population and then crashes into late refugia. The distinction from the other individual bombs is that it almost always leaves a robust refugia residue rather than near-zero remnant survival.

Trigger window and regional damage

The trigger-window evidence shows severe two-thousand-pulse macro-energy drops in every epoch. First qualifying windows cluster tightly around pulses 29,650 to 29,850, consistent with a post-collapse infrastructure failure event.

Epoch	Qualifying windows	First pulse	First energy delta	Population at first	Worst pulse	Worst energy delta
161	46	29,750	-6.03B	2,053,302	30,500	-18.65B
162	44	29,750	-6.22B	2,186,026	30,450	-19.16B
163	46	29,750	-6.35B	2,194,064	30,500	-21.59B

Epoch	Qualifying windows	First pulse	First energy delta	Population at first	Worst pulse	Worst energy delta
164	44	29,700	-6.90B	1,937,158	30,450	-18.30B
165	44	29,800	-6.45B	1,990,164	30,500	-19.00B
166	43	29,850	-6.23B	1,862,047	30,500	-17.32B
167	43	29,800	-6.85B	1,855,139	30,450	-18.12B
168	42	29,750	-6.37B	1,771,810	30,450	-15.41B
169	45	29,750	-6.03B	2,185,664	30,500	-21.70B
170	49	29,650	-6.13B	2,311,486	30,500	-23.79B

Regional damage and exclusion-zone signature

Epoch	Population loss	Emptied	population-loss regions	Hazard-up regions	EROI-down regions	Average hazard delta	Average EROI delta	Average stress delta
161	67.6%	293	1,040	1,200	586	0.0540	-0.0669	0.2564
162	73.2%	297	1,097	1,200	503	0.0544	-0.0662	0.2408
163	69.4%	293	1,112	1,200	594	0.0583	-0.0726	0.3220
164	77.7%	265	1,188	1,200	328	0.0561	-0.0245	0.2487
165	70.3%	317	1,052	1,200	666	0.0540	-0.0771	0.2642
166	79.8%	249	1,125	1,200	463	0.0547	-0.0672	0.2573
167	72.0%	249	1,121	1,200	535	0.0534	-0.0619	0.2532
168	75.3%	248	1,179	1,200	307	0.0545	-0.0179	0.2089
169	74.3%	291	1,093	1,200	646	0.0568	-0.0869	0.3451
170	69.6%	311	1,056	1,200	699	0.0547	-0.0723	0.2881

Across the measured regions, nuclear meltdown produces broad increases in hazard, higher system stress, and large population losses. This is the strongest evidence that the event changes the geography of survival rather than simply increasing a single global climate variable.

Final refugia and tribe outcomes

Nuclear-only produces distributed final refugia. The final pockets are energetically viable by late-game standards, but politically narrow: most epochs are dominated by a single final lineage, and all final refugia records remain Regime 2 (Agrarian).

Epoch	Final population.	Regions	Dominant final tribe	Average EROI	Average stress	Max hazard	Maximum final complexity	Mixed regions
161	33,589	51	The Obsidian Phalanx Refuge G3	0.929	0.238	0.074	845	0
162	41,863	55	The Obsidian Phalanx Refuge G3	0.927	0.257	0.167	4,581	0
163	28,679	68	The Obsidian Phalanx Refuge G3	0.925	0.242	0.171	1,916	4

Epoch	Final population.	Regions	Dominant final tribe	Average EROI	Average stress	Max hazard	Maximum final complexity	Mixed regions
164	25,393	48	The Ember Refugia Compact G3	0.930	0.205	0.074	1,588	0
165	33,768	52	The Obsidian Phalanx Refuge G3	0.929	0.242	0.074	1,909	0
166	32,614	49	The Obsidian Phalanx Refuge G3	0.933	0.226	0.074	2,999	0
167	45,712	54	Velvet Hammer	0.919	0.253	0.074	2,092	0
168	37,896	70	The Forged Compact G3	0.927	0.200	0.166	1,925	20
169	27,818	48	The Obsidian Phalanx Refuge G3	0.916	0.267	0.170	856	0
170	31,080	39	The Obsidian Phalanx Refuge G3	0.928	0.247	0.074	1,693	0

Tribe and species outcomes

ID	Tribe	Type	Generati on	Survived	Rate	Best final	Average final	Hazard death share
128	The Obsidian Phalanx Refuge G3	LLM	3	7/10	70%	41,863	22,940.5	28.0%
107	Velvet Hammer	BIOLOGIC	1	2/10	20%	45,712	4,571.8	22.3%
127	The Forged Compact G3	LLM	3	1/10	10%	37,845	3,784.5	20.8%
126	The Ember Refugia Compact G3	LLM	3	1/10	10%	25,393	2,539.3	21.7%
131	The Crucible Remnant G3	LLM	3	1/10	10%	51	5.1	16.5%
129	The Castellans of Gemini III G3	LLM	3	0/10	0%	0	0.0	19.1%
130	Helix Vanguard G3	LLM	3	0/10	0%	0	0.0	23.2%
94	The Quiet Stick Compact	BIOLOGIC	1	0/10	0%	0	0.0	24.3%
98	Velvet Ironshod	BIOLOGIC	1	0/10	0%	0	0.0	21.7%
102	The Flynn Paradox	BIOLOGIC	1	0/10	0%	0	0.0	39.9%
111	The Velvet Shadows	BIOLOGIC	1	0/10	0%	0	0.0	39.6%
96	The Velvet Fang	BIOLOGIC	1	0/10	0%	0	0.0	41.3%

Reproduction, selection, and scoring

The late reproduction check is one of the clearest positive findings in the nuclear-only phase. Every epoch records late births, so survival is not merely old-agent residue. The survivor traits again favor higher hardiness, higher vitality, lower legacy, stronger kin trust, stronger opportunism, and less wandering.

Epoch	Survivor lines	Late births	Late failed births	Late deaths	Maximum late population	Weighted average generation
161	1	85,120	9,589	84,109	35,878	36.74
162	1	97,394	10,606	93,321	42,292	38.15
163	2	59,353	6,639	48,949	28,682	35.97
164	1	63,190	7,054	59,165	29,193	38.70

Epoch	Survivor lines	Late births	Late failed births	Late deaths	Maximum late population	Weighted average generation
165	1	74,780	8,273	69,394	33,768	34.33
166	2	73,315	8,013	70,113	32,621	35.19
167	3	99,206	11,113	89,407	45,718	33.53
168	2	81,935	9,138	79,204	38,320	38.24
169	1	69,095	7,404	68,437	28,738	36.38
170	1	76,279	8,383	63,538	34,868	34.76

Group	Tribes	Hardiness	Vitality	Legacy	Kin trust	Same-tribe trust	Xeno trust	Xeno opportunism	Abundance wander
BIOLOGIC survived	1	38.55	32.70	28.75	0.823	0.583	0.400	0.522	0.485
BIOLOGIC did not survive	6	39.41	33.34	27.25	0.686	0.516	0.434	0.437	0.524
LLM survived	4	55.05	34.45	10.49	0.783	0.361	0.086	0.740	0.118
LLM did not survive	6	50.94	31.70	17.36	0.703	0.336	0.093	0.690	0.249

Language-model survivor trait deltas

Trait	Surviving LLM minus non-surviving LLM
Hardiness	+4.116
Vitality	+2.750
Legacy	-6.866
Kin trust	+0.080
Same-tribe trust	+0.025
Xeno trust	-0.007
Xeno opportunism	+0.050
Abundance wander	-0.131

Trait	Surviving LLM minus non-surviving LLM
Scarcity wander	-0.045
Desperation wander	-0.102

Survival-tier scorecard

Tier	Score	Evidence
Tier 1 - Existence	Pass	Final population was positive in all 10 epochs.
Tier 2 - Reproductive continuity	Pass	Late births occurred in all 10 epochs; average late births per epoch = 77,967.
Tier 3 - Refugia stability	Pass	Final refugia averaged 53.4 regions, average EROI 0.926, and average stress 0.238.
Tier 4 - Distributed survival	Pass	Every epoch ended with multiple inhabited regions; range 39-70.
Tier 5 - Recoverable complexity	Partial / weak	All final regions retained nonzero complexity, but final max regional complexity averaged only 2.4% of epoch peak complexity.
Tier 6 - Civilizational continuity	Not demonstrated	Not demonstrated: final refugia remain Regime 2 (Agrarian), and broad cooperation or civic continuity does not persist into the final state.

Phase 3 therefore answers the nuclear-only question with a nuanced result. Evolved survivor ecology can endure abandoned high-complexity infrastructure better than it endures aerosol demasking or methane feedback, but the cost is still high. The event erases much of the map that made high-complexity society possible, while leaving a distributed low-complexity survivor ecology.

Phase 4 - All Bombs

Phase 4 turns on all three hazards at once. The world includes the evolved tribes, the ordinary collapse ecology, aerosol demasking, Arctic methane release, and nuclear meltdown. This is the strict final Project 4 condition.

Phase 4 finding

The evolved language-model tribes survive the full stacked condition, but not as civilization. Survival persists as a biological and lineage remnant; civilizational continuity does not.

Phase	Average peak population	Average final population	Average survivors	LLM	Bio	Average peak heat	Average final complexity
Project 3 G3 reference	2,681,885	40,114	1.2	1.1	0.1	1.75	17,434
Phase 1 - Aerosol	2,628,530	6,497	1.1	0.9	0.2	2.70	2,686
Phase 2 - Methane	2,241,372	19,914	1.0	1.0	0.0	1.94	8,329
Phase 3 - Nuclear	2,726,445	33,841	1.2	1.0	0.2	1.86	16,929
Phase 4 - All bombs	2,106,828	759	1.0	1.0	0.0	3.03	398

All-bombs event context

Phase 4 enables all three delayed hazards together. Methane heats the ascent, nuclear failure damages high-complexity geography, and demasking hits during collapse as the industrial veil clears.

Event	Enabled	Duration	Primary	Secondary	Hazard cap	Fertile loss
AEROSOL DEMASKING	1	1500	0.85	1.25	0.22	0.45
ARCTIC METHANE RELEASE	1	8000	0.384	1.98	0.168	0.3
NUCLEAR MELTDOWN	1	8000	0.72	1.4	0.18	0.3

World outcome and nonlinear stacking

All ten all-bombs epochs produce survivors, but each produces only one surviving tribe. Average final population falls to 758.7, with a median final population of 42.5 and one epoch ending with a single individual.

Epoch	Peak population	Final population	Decline	Survivor	Peak heat	Damage	Hazard share
171	1,874,573	2,708	99.856%	Obsidian Phalanx Refuge	3.28	0.84	31.0%
172	2,102,137	144	99.993%	Obsidian Phalanx Refuge	3.07	0.81	27.1%
173	2,165,512	4,516	99.791%	Castellans of Gemini III	2.90	0.80	25.9%
174	2,176,072	79	99.996%	Obsidian Phalanx Refuge	3.10	0.82	28.5%
175	1,773,836	41	99.998%	Obsidian Phalanx Refuge	3.31	0.84	33.6%
176	2,194,992	22	99.999%	Ember Refugia Compact	2.92	0.80	27.1%
177	2,246,215	44	99.998%	Ember Refugia Compact	2.85	0.79	27.1%
178	2,254,038	1	100.000%	Ember Refugia Compact	2.73	0.78	23.2%
179	2,382,550	6	100.000%	Forged Compact	3.25	0.83	29.9%
180	1,898,359	26	99.999%	Obsidian Phalanx Refuge	2.92	0.80	27.8%

Nonlinear stacking scorecard

Metric	Separate mean	All-bombs mean	Delta	Interpretation
FINAL POPULATION NONLINEARITY	20,084.23	758.70	-19,325.53	STRONGLY WORSE THAN SEPARATE MEAN
SURVIVING TRIBES NONLINEARITY	1.10	1.00	-0.10	FEWER SURVIVING TRIBES THAN SEPARATE MEAN
HAZARD DEATH SHARE NONLINEARITY	0.24	0.28	0.04	HAZARD SHARE INCREASED UNDER STACKING

Metric	Separate mean	All-bombs mean	Delta	Interpretation
FAILED BIRTH RATE NONLINEARITY	0.10	0.10	0.00	FERTILITY PRESSURE INCREASED UNDER STACKING
STARVATION DEATH SHARE NONLINEARITY	0.75	0.70	-0.04	STARVATION SHARE NOT HIGHER UNDER STACKING

The stacked block is much worse than the separate-bomb mean. This is the strongest evidence in Project 4 that the bombs do not merely add pressure; together they strip away most of the post-peak margin for recovery.

Survivors and cross-phase robustness

The all-bombs phase is a language-model-only survival phase. Biologic controls occupy the same class of tribe-epoch opportunities as before but record no final survivors in the stacked condition.

Tribe	Type	Survived	Survival rate	Average final	Average duration	Hazard deaths	Starvation
Obsidian Phalanx Refuge	LLM	5/10	50%	299.8	35,890	33.8%	64.5%
Ember Refugia Compact	LLM	3/10	30%	6.7	24,075	24.6%	74.4%
Castellans of Gemini III	LLM	1/10	10%	451.6	20,735	24.0%	74.5%
Forged Compact	LLM	1/10	10%	0.6	25,020	25.2%	73.6%
Crucible Remnant	LLM	0/10	0%	0.0	20,510	22.4%	76.5%
Flynn Paradox	BIOLOG IC	0/10	0%	0.0	18,065	24.3%	73.6%
Velvet Hammer	BIOLOG IC	0/10	0%	0.0	17,820	32.1%	66.1%
Quiet Stick Compact	BIOLOG IC	0/10	0%	0.0	16,305	34.2%	63.7%

Cross-phase survival matrix

Tribe	Aerosol	Methane	Nuclear	All bombs	All-bombs avg final
Obsidian Phalanx Refuge	9	8	7	5	299.8
Ember Refugia Compact	1	0	1	3	6.7
Forged Compact	0	0	1	1	0.6
Castellans of Gemini III	0	1	0	1	451.6
Velvet Hammer	0	0	2	0	0.0
Crucible Remnant	0	0	1	0	0.0
Helix Vanguard	0	1	0	0	0.0
Velvet Fang	1	0	0	0	0.0

Obsidian Phalanx Refuge is the strongest cross-phase lineage: it survives nine aerosol epochs, eight methane epochs, seven nuclear epochs, and five all-bombs epochs. It is a robustness benchmark, but not a civilization-preserver; its all-bombs final populations are often tiny.

Survival quality and final refugia

The objective scoring framework distinguishes existence from continuity. In Phase 4, existence is achieved in all epochs, reproductive continuity is mostly present, and higher forms of recoverable or civilizational continuity mostly fail.

Tier	Meaning	All-bombs result
1	Existence	Met in all 10 epochs: final_population > 0 every time.
2	Reproductive continuity	Mostly met: late births in 9 of 10 epochs; one epoch ended as a single remnant.
3	Refugia stability	Weak to partial: top refugia often had good EROI, but populations were tiny and stress/hazard remained high.
4	Distributed survival	Partial: 77 final inhabited/refugia rows across 10 epochs, but many were token populations.
5	Recoverable complexity	Mostly failed: average final complexity fell to 398, a 97.7% drop versus Project 3 G3 reference final complexity.
6	Civilizational continuity	Not demonstrated: cooperation/civic activity collapses into same-tribe remnants rather than broad civic continuity.

Late-refugia reproduction

Epoch	Survivor	Max late population	Late births	Late deaths	Late gen	Hardiness
171	Obsidian Phalanx Refuge	2708	4292	2386	34.1	60.5
172	Obsidian Phalanx Refuge	144	211	111	34.5	64.5
173	Castellans of Gemini III	4516	6384	2824	40.1	48.6
174	Obsidian Phalanx Refuge	79	137	95	29.0	52.5
175	Obsidian Phalanx Refuge	44	59	27	31.6	61.8
176	Ember Refugia Compact	26	37	21	36.4	66.9
177	Ember Refugia Compact	44	63	26	34.1	72.9
178	Ember Refugia Compact	1	0	1	31.0	61.1
179	Forged Compact	7	8	3	38.6	49.0
180	Obsidian Phalanx Refuge	45	82	103	37.3	56.6

Trait signal and geography

All-bombs survival favors compact, hard, low-legacy lineages with strong internal cohesion and restrained movement. The less successful profiles either expand too hard, trust too broadly, disperse into dangerous geography, or lack the hardiness to remain viable after the compound crash.

Group	Survived?	Hardiness	Legacy	Kin trust	Xeno trust	Xeno opportunism	Abundance wander	Desperation wander
BIOLOGIC G1	no	39.4	27.3	0.691	0.433	0.440	0.522	0.721
LLM G3	yes	55.8	11.3	0.754	0.092	0.729	0.131	0.481
LLM G3	no	50.8	17.2	0.709	0.092	0.692	0.247	0.568

Top final refugia by epoch

Epoch	Top survivor	Region	population	EROI	Hazard	Stress
171	Obsidian Phalanx Refuge	295	1047	0.947	0.214	0.432
172	Obsidian Phalanx Refuge	981	32	0.925	0.213	0.417
173	Castellans of Gemini III	1156	1008	0.948	0.212	0.406
174	Obsidian Phalanx Refuge	221	18	0.777	0.213	0.420
175	Obsidian Phalanx Refuge	401	18	0.946	0.214	0.411
176	Ember Refugia Compact	212	8	0.847	0.212	0.407
177	Ember Refugia Compact	562	16	0.947	0.211	0.399
178	Ember Refugia Compact	362	1	0.944	0.211	0.499
179	Forged Compact	697	4	0.879	0.214	0.432

Epoch	Top survivor	Region	population	EROI	Hazard	Stress
180	Obsidian Phalanx Refuge	523	7	0.948	0.212	0.406

The final world is a scattered survival landscape, not a recovery landscape. The top refugia usually retain high local EROI, but populations are small, hazards remain elevated, stress remains high, and final social life is overwhelmingly same-tribe remnant continuity.

Research question answers

Question	Phase 4 answer
Does Project 4 reduce survival relative to Project 3?	Yes. All-bombs average final population was 758.7 versus 40,114.1 in P3 G3, a 98.1% reduction.
Are evolved traits still adaptive?	Yes, but narrowly. LLM G3 survived every epoch; biologics survived none. High hardiness, low legacy, internal trust, caution, and low wander were favored.
Do different bombs select different strategies?	Yes. Individual phases had different winners and severities; Obsidian was the only clearly cross-bomb robust lineage.
Does stacking produce nonlinear collapse?	Yes. All-bombs final population was 96.2% below the separate-bomb mean.
Do LLM tribes outperform biologics?	Yes. All final survivors were LLM G3 lineages; biologics had zero final survivors in the stacked phase.
Is survival reproductive continuity or remnant survival?	Mostly thin reproductive continuity: late births occurred in 9 of 10 epochs, but final populations were often remnant-sized.
Does high complexity help or hurt?	Peak complexity still occurs, but final complexity collapses. High complexity appears to create liabilities unless paired with refugia discipline.
What does survival look like?	At the final level, survival looks like small, hard, low-complexity, same-tribe refugia with little evidence of civilizational continuity.

Project 4 therefore distinguishes survival from civilization. The evolved tribes survive the full condition in every epoch, but the form of survival is so reduced that the result must be interpreted as remnant continuity rather than civilizational preservation. The Project 4 bomb series does not merely crown a winner; it clarifies that intelligence can learn to persist under stacked delayed consequences, but persistence is not the same as escaping those consequences.

Cross-Phase Synthesis

Across the four phases, the project shows that each delayed bomb selects differently. Aerosol demasking is the post-collapse knife: it leaves ascent mostly intact and then attacks terminal survivability. Methane is the pre-collapse fever: it damages the rise before peak and leaves survivors in a hotter world. Nuclear meltdown is the map-breaker: it is less globally lethal but reshapes geography and damages high-complexity regions. The all-bombs condition stacks these pressures and removes most remaining recovery margin.

Obsidian Phalanx Refuge G3 is the strongest cross-phase benchmark. Its repeated survival does not mean it preserves civilization. It means its low-legacy, high-hardiness, internally cohesive refugia logic repeatedly finds the final ledges of survival. The biologic controls occasionally survive individual bombs, most notably in the nuclear phase, but they do not survive the stacked condition.

The Project 4 answer is therefore severe but not trivial. Evolutionary redesign remains meaningful: the language-model Generation 3 lineages outperform the fixed controls under the hardest condition. Yet the price of survival is simplification. The final state is usually small, agrarian, lineage-specific refugia rather than recoverable high-complexity civilization.