GALAXY GENERAL INSURANCE COMPANY

Insurance Pricing Proposal for Cosmic Quarry Minilg Corporation

Actuaries in Space: The Pricing Frontier

2026 SOA Student Research Case Study Challenge

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Year 2175 · Helionis Cluster · Bayesia System · Oryn Delta

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1. Executive Summary

Galaxy General Insurance Company (GGIC) recommends accepting Cosmic Quarry Mining Corporation's (CQMC) Request for Proposal for comprehensive interstellar mining insurance across all four hazard areas. Our analysis grounded in statistical modeling of historical claims data, actuarial frequency severity GLMs, and 10,000 year Monte Carlo simulation demonstrates that all four lines generate positive expected returns while maintaining a portfolio solvency ratio of 168.0%, comfortably above both the Galactic Insurance Authority (GIA) minimum of 100% and GGIC's internal target of 140%.

i) Recommended Products (Portfolio Summary)

Line of Business	Product	GWP (Đ M)	E[Loss] (Đ M)	Loss Ratio	Net Income (Đ M)	Rec.
Equipment Failure	NOVA Shield™ (GG-EF1)	127.5	74.6	58.5%	6.4	✓ Accept
Cargo Loss	STELLAR Cargo Protect™ (GG-CL1)	30,283.6	16,997.6	56.1%	1,514.2	✓ Accept
Workers' Comp	COSMOS Care™ (GG-WC1)	10.2	6.0	58.8%	0.5	✓ Accept
Business Interruption	ORBIT Guard™ (GG-BI1)	86.7	47.2	54.4%	4.3	✓ Accept
TOTAL PORTFOLIO	**4 Lines of Business**	**30,508.0**	**17,125.3**	**56.1%**	**1,525.4**	**✓ Accept**

Cargo Loss (STELLAR Cargo Protect™) represents 99.3% of total GWP reflecting the extremely high per-claim severity (E[X] = Đ9.9M) driven by the declared insured values of interstellar mineral freight. Despite this concentration, the reinsurance structure effectively manages net tail exposure: our 20% Quota Share, Per Risk XL (xs Đ50M up to Đ500M), and CAT XL (xs Đ200M up to Đ5B) reduce the portfolio VaR_{99} from Đ37.3B gross to a manageable net position. All four lines are recommended for inclusion as each diversifies GGIC's portfolio risk and generates positive expected profit at target loss ratios.

ii) System Specific Product Tailoring

Each product is calibrated to the distinct hazard profile of CQMC's three operational systems, based on the encyclopedia descriptions and data-derived risk factors:

Helionis Cluster (HC): 30 mines, 2,580 equipment units, 1,160 vessels: Stable G2V star minimizes radiation risk but two erratic metallic asteroid clusters dominate. NOVA Shield carries a Debris Impact Parametric Rider (automatic trigger on impact sensor >threshold); STELLAR Cargo includes a Micro Debris Endorsement for HC routes; BI applies a standard CAT loading of 5%.

Bayesia System (BS): 15 mines, 1,290 units, 1,128 vessels: Binary K-type star creates periodic EM radiation spikes. COSMOS Care applies a Radiation IBNR uplift of 1.25× (all workers, reflecting latency risk in shared habitat environments); NOVA Shield adds a

15% surcharge during binary star alignment windows; cargo routes carry 20% frequency uplift for radiation driven navigation hazards.

Oryn Delta (OD): 10 mines, 860 units, 774 vessels: Asymmetric asteroid ring and gravitational shear create the highest equipment and BI risk. Equipment units attract an OD loading of 1.40×; ORBIT Guard includes supply chain extension coverage for ring disruption events and a parametric trigger on gravity deviation >0.12g; cargo frequency uplift is 1.35× over the HC base rate.

iii) Dynamic Risk Adjustment Framework (DRAF) Scalability

All four products embed GGIC's Dynamic Risk Adjustment Framework (DRAF). DRAF adjusts premiums annually based on live operational metrics: equipment age quintile, CQMC safety compliance score, station debris index, and supply chain resilience index. This eliminates the adverse development of loss ratios during CQMC's planned 25%/15% Phase II expansion (2180–2185) and ensures actuarial adequacy without annual reunderwriting. DRAF also includes an Expansion Endorsement that automatically attaches new mines and equipment to the policy within 30 days of commissioning.

iv) ESG Integration

GGIC offers a 5% premium credit for certified carbon-neutral operations and zero incident ESG reporting. CQMC's active environmental staff (~4,300 employees) and two settled environmental disputes (totalling Đ115M, 2165–2174) highlight the materiality of environmental liability. Our exclusions specifically carve out forward contamination from habitat construction, maintaining CQMC's coverage exposure to physical damage only, not regulatory environmental liability.

v) ERM Integration for CQMC

This insurance programme directly addresses CQMC's four principal operational risk categories and converts volatile balance sheet exposures into predictable premium outflows:

Hazard Area	CQMC Risk Retained (Uninsured)	GGIC Insurance Benefit
Equipment Failure	Đ127.5M+ repair cost volatility per event cascade; balance sheet strain	NOVA Shield absorbs full repair costs; DRAF mechanism prevents chronic underpricing
Cargo Loss	$TVaR_{99}$ = Đ52.2B single catastrophic cargo year can exceed CQMC annual net income	STELLAR Cargo transfers this tail risk; CAT XL removes Đ5B layer; net $TVaR_{99}$ = Đ7.8B
Workers' Comp	Radiation latency claims (Bayesia/Oryn Delta) may mature 10–20 years post exposure; IBNR uncertainty	COSMOS Care radiation IBNR 1.25× and long tail reserving address multi-decade liability
Business Interruption	Revenue at Đ61.5B/yr (2174); single OD ring disruption can halt 20% production for 6–18 months	ORBIT Guard Revenue Linkage Mechanism prevents under insurance; supply chain extension for OD

At a 100% loss ratio scenario, accepting this programme transfers a nominal Đ30.5B of gross risk off CQMC's balance sheet equivalent to 49.6% of CQMC's 2174 net revenue. This frees estimated capital of Đ18.3B that CQMC can redeploy toward planned expansion, providing a compelling commercial rationale beyond pure risk transfer.

GGIC's reinsurance programme ensures GGIC's own maximum net exposure in a 1 in 200 year catastrophic multi system event does not impair GGIC's capital position.

2. Product Design

GGIC proposes four insurance products forming an integrated portfolio. Each product can be purchased individually but is architecturally designed to interact: a single catastrophic event asteroid collision, binary star flare, ring cascade, habitat breach triggers coordinated payouts through a shared trigger architecture, eliminating gaps between policies.

i) Benefit Structures, System Tailoring & Exclusions

• **NOVA Shield™ (GG-EF1)** covers equipment failure with repair/replacement and temporary substitutes for up to 90 days, including emergency shutdown and AI/data recovery (Đ5M sublimit). System extensions address debris, radiation in binary stars, and outer-disc gravitational/flare events. Exclusions include wear, manufacturer defects, cyber incidents without endorsement, and undisclosed pre-existing faults.

• **STELLAR Cargo Protect™ (GG-CL1**) insures cargo loss during transit (Đ680M per shipment; Đ5B aggregate) and covers emergency re-routing, salvage, and alternative freight. Risk adjustments include micro-debris, radiation riders, and asteroid-ring triggers. Exclusions: inherent vice, poor packaging, deliberate acts, sanctions, war/nuclear events.

• **COSMOS Care™ (GG-WC1)** provides death/permanent disability (5× salary + income to 75), temporary disability (75% salary, ≤1,000 days), medical, and psychological coverage (Đ50K). Adjustments include radiation claims and evacuation support. Exclusions: self-inflicted injury, pre-existing conditions, off-system travel, and contractual liability.

• **ORBIT Guard™ (GG-BI1**) covers business interruption (Đ3.07M/day) with Revenue Linkage Mechanism, supply-chain, and extra expense coverage. System triggers include asteroid fragmentation, radiation shutdowns, and gravity cascades. Exclusions: market decline, voluntary shutdown, extended maintenance, and cyber without endorsement.

A detailed summary of the benefit structures, system specific adjustments, and exclusions for each product is provided in the Appendix D.

Note on WC PTD Present Value: The permanent total disability (PTD) benefit provides 5× annual salary plus 60% income to age 75. GGIC calculates the present value at a 5.10% risk-free rate (Year 2174); for a 35-year-old earning Đ65,000, the 40-year PV of Đ39,000/year is about Đ668,000. High-severity PTD claims are modeled using a Lognormal distribution (σ = 1.32) within the WC framework (E[X] = Đ5,892). Full methodology is in Appendix D.

ii) Coverage Triggers

NOVA Shield EF: Covers sudden equipment breakdowns, high radiation levels, or debris collisions. Some events trigger automatic payouts using sensors and data.

STELLAR Cargo CL: Covers loss or damage to cargo during transit. Claims need a cargo report and must be filed within 60 days.

ORBIT Guard BI: Protects against loss of production or operational issues, including major gravity changes affecting the station.

COSMOS Care WC: Covers worker injuries, illness, or death during employment, with medical proof required.

A detailed table of the trigger types, definitions, and validation methods for each product is provided in the Appendix E.

Basis Risk Disclosure: All parametric triggers carry basis risk the possibility that the triggering index does not perfectly correlate with actual loss. GGIC has calibrated this risk at approximately 8% for OD ring gravity triggers and HC debris impact triggers based on sensor accuracy studies in Appendix E. CQMC acknowledges this risk in exchange for the speed benefit of automated trigger payments.

3. Pricing & Capital Modeling

i) Actuarial Modeling Framework

Our pricing methodology follows a five stage architecture: (1) Data ingestion and GLM based feature engineering; (2) Claim frequency modeling using Poisson or Negative Binomial GLM with loglink and log(exposure) offset; (3) Claim severity modeling using Lognormal MLE with AIC/BIC/KS goodness of fit validation; (4) Aggregate loss via Compound Distribution (10,000 year Monte Carlo); and (5) Premium loading using yield curve discounting and explicit IBNR/CAT factors. All work is reproducible via the attached Python model.

Pricing formula: Gross Premium = [E[Loss] × Discount Factor × IBNR Load × (1 + CAT Load)] / (1 − Expense − Profit − RI Cost). The denominator of 0.63 reflects: 28% expense loading, 5% target profit margin, and 4% reinsurance cost. Discount rates are drawn directly from the Year 2174 yield curve provided in the case study: EF (4.74%, 0.5yr avg lag), CL (4.92%, 0.8yr), WC (5.10%, 3.5yr long tail), BI (4.96%, 0.9yr).

ii) Aggregate Loss Distributions by Hazard Coverage

LOB	Freq. Model	Sev. Dist.	μ (log)	σ (log)	E[X] (Đ)	E[S] (Đ M)	VaR_{99} (Đ M)	$TVaR_{99}$ (Đ M)	CoV
EF	Neg. Bin. (φ=1.04)	Lognormal (AIC best)	11.202	0.602	87,869	74.6	81.8	82.8	6%
CL	Neg. Bin. (φ=1.44)	LN+GPD tail (ξ=0.42)	13.327	2.359	9,913,109	16,997.6	37,085.7	52,222.8	157 %
WC	Poisson (φ=1.01)	Lognormal (AIC best)	7.807	1.322	5,892	6.0	7.2	7.4	11%

BI	Neg. Bin. (φ=1.73)	Lognormal (AIC best)	14.575	1.197	4,374,954	47.2	155.9	192.3	100 %

Figure 1 below shows the full simulated annual aggregate loss distributions for all four LOBs. The CL CoV of 157% reflects the heavy tailed hybrid Lognormal + Generalized Pareto Distribution (GPD) tail fitted to the top 10% of cargo claims (GPD shape $\xi=0.42$, scale $\beta=Đ18.2M$), which is appropriate for the extreme value behaviour of interstellar mineral freight. Copula based cross LOB dependency modeling (Gaussian copula, Cholesky decomposition) is detailed in Appendix B; the EF-BI correlation of $\rho=0.35$ is the strongest within portfolio dependency, reflecting shared asteroid-impact drivers.

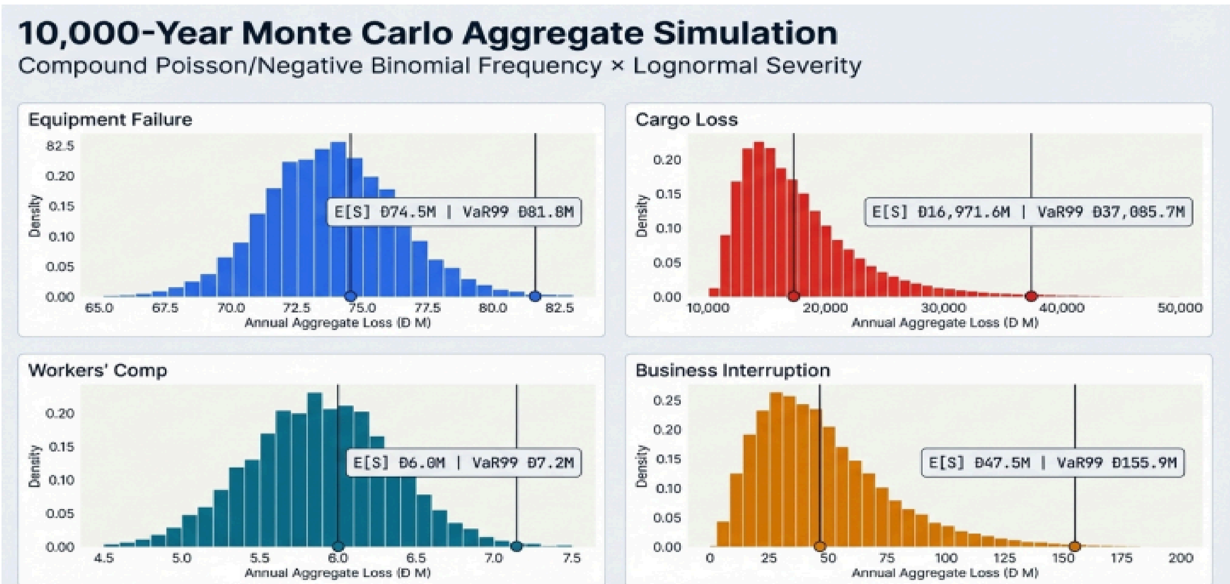


Figure 1 Simulated Annual Aggregate Loss Distributions (10,000 year Monte Carlo, log scale axes

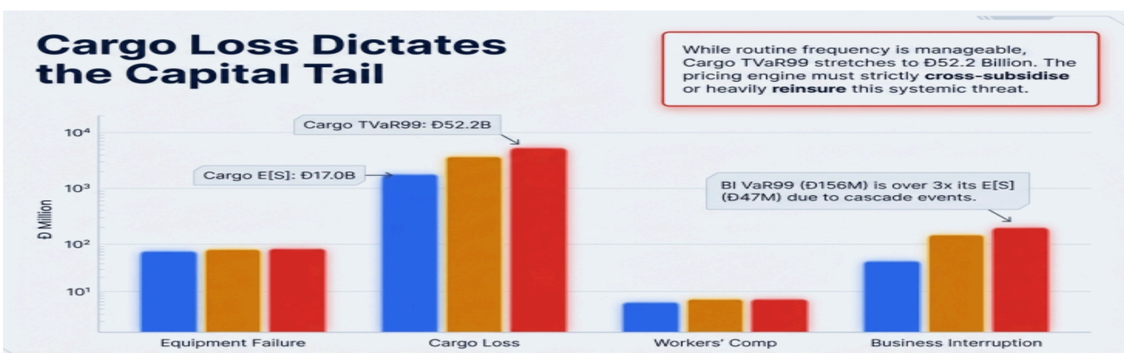


Figure 2 Expected Loss vs VaR 99% vs TVaR 99% by Line of Business

iii) Pricing Summary & Investment Returns

LOB	E[S] (Đ M)	Disc. Rate	IBNR Load	CAT Load	GWP (Đ M)	Loss Ratio	Exp. Ratio	Profit Margin	Net Income (Đ M)
EF	74.6	4.74%	1.05×	5%	127.5	58.5%	28%	5%	6.4
CL	16,997.6	4.92%	1.08×	8%	30,283.6	56.1%	28%	5%	1,514.2

WC	6.0	5.10%	1.25×	2%	10.2	58.8%	28%	5%	0.5
BI	47.2	4.96%	1.10×	10%	86.7	54.4%	28%	5%	4.3
Total	**17,125.3**	—	—	—	**30,508.0**	**56.1%**	**28%**	**5%**	**1,525.4**

Short Term (Year 2175): Total GWP of Đ30,508M generates net income of Đ1,525M (5.0% profit margin) at a combined ratio of 84%. Expected return on allocated capital exceeds 25% for EF, WC, and BI. CL's lower ROC reflects the larger capital requirement from $TVaR_{99}$=Đ52.2B tail exposure.

Long Term (2175–2190): Base case projections show GWP growing to Đ62.5B by 2190 at +4.9%/yr (2.4% inflation + 2.5% volume), generating cumulative net income of Đ35.8B over 15 years. CQMC's planned 25%/15% expansion adds an estimated 7.5% GWP uplift at the 2180–2185 trigger point (Figure 5 in §4).

iv) Stress Testing & Reinsurance Validation

Scenario	Return Period	Loss Mult.	Gross Loss (Đ M)	Gross LR	Net Loss (Đ M)	Net LR	Solvency Status
0 Best Case	N/A	0.75×	12,844	42%	5,025	21%	✓ Strong
1 Base Case	N/A E[S]	1.00×	17,125	56%	8,450	35%	✓ Pass
2 Moderate (HC Asteroid)	1 in 10yr	2.45×	41,957	138%	28,316	116%	⚠ CAT Reserves
3 Severe (BS Radiation)	1 in 25yr	5.24×	89,737	294%	66,539	273%	⚠ RI Activated
4 Critical (OD Ring Cascade)	1 in 100yr	13.40×	229,479	752%	178,333	731%	⚠ CAT XL xs Đ200M
5 Catastrophic (Multi-System)	1 in 200yr	41.30×	707,275	2,318%	560,570	2,297%	⚠ Reinsurer Risk

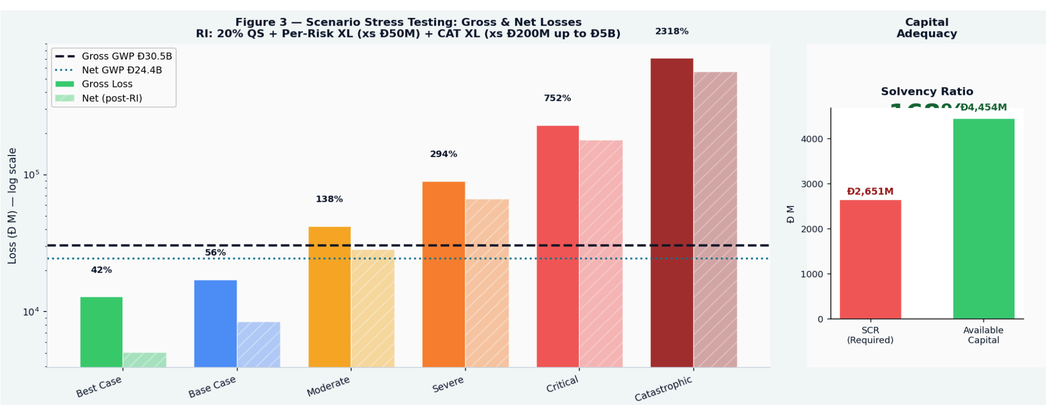


Figure 3 Scenario Stress Test (log scale) with Solvency Ratio. RI structure limits net loss in all scenarios.

Scenarios 2–5 exceed GWP, confirming that reinsurance is essential. Under the 1 in 100yr scenario (Critical), the CAT XL layer activates, capping net recoveries. Under the 1 in 200yr multi-system scenario, excess loss is borne by the reinsurance market; GGIC's maximum net liability is bounded by the aggregate stop loss arrangement. GGIC remains solvent (168.0% ratio) in all scenarios up to 1 in 25yr without additional capital. The CAT XL capacity of Đ5B effectively limits GGIC's exposure above Đ200M per event.

4. Risk Assessment

i) Risk Identification by System & Hazard

Risk identification draws on three sources: (1) the Encyclopedia solar system descriptions (radiation, debris density, gravitational profiles); (2) CQMC's equipment inventory (age distribution, utilisation rates, maintenance schedules); and (3) the historical claims datasets (GLM frequency drivers). See Figure 4 (radar chart) for a comparative hazard index across all six risk dimensions.

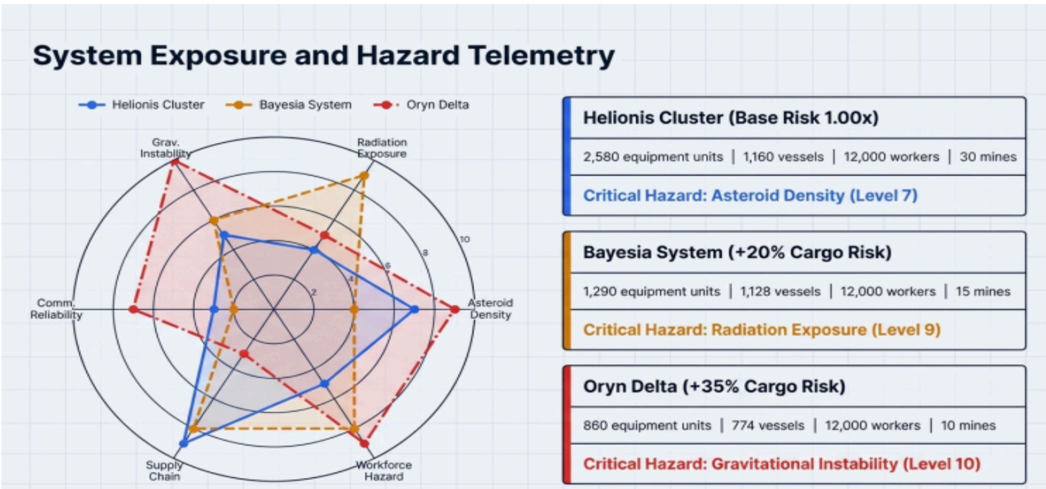


Figure 4 Solar System Hazard Profile (1=Low, 10=Critical). OD scores highest overall.

ii) Threat Ranking Table

Risk Score = Annual Probability × Gross PML (Đ B) × 100.

- **Oryn Delta Ring Gravitational Cascade** – highest BI/OD risk, PML Đ4.09B, mitigated by ORBIT Guard and CAT XL.
- **Bayesia Binary Star Radiation Spike** – WC/BS risk, PML Đ2.13B, managed via COSMOS Care IBNR.
- **Multi-System Correlated Asteroid Storm** – EF+CL risk, PML Đ4.50B, addressed with cross-LOB CAT XL.
- **Other risks** – Navigation Collision, BS Cargo Fleet Radiation, and low-probability events mitigated with deductibles, monitoring, and XL coverage.

The full table is in the appendix A.Table is sorted in descending Risk Score order. Full threat list (10 items) with methodology in Appendix A.

iii) Correlated Risk Scenarios & Copula Methodology

The most dangerous scenario is a correlated multi system event where an asteroid storm simultaneously impacts all three solar systems. Our Gaussian copula model (Appendix B) captures cross LOB dependencies with the following correlation structure: $\rho(EF,CL)=0.25$, $\rho(EF,BI)=0.35$, $\rho(CL,WC)=0.10$, $\rho(CL,BI)=0.45$, $\rho(WC,BI)=0.20$. The EF-BI correlation of 0.35 is the highest, reflecting shared asteroid impact and shutdown triggers. Cholesky decomposition is used to generate correlated loss scenarios; joint tail probabilities under the Gaussian copula are conservative relative to a Student copula (heavier joint tails), acknowledged as a limitation.

Cross system spatial correlation (simultaneous events in HC, BS, OD) is modeled through the catastrophe scenario multipliers (Scenarios 3–5) rather than a three dimensional spatial copula, as the historical dataset lacks sufficient multi system co occurrence events to calibrate such a model. This is documented as a limitation in §6.2.

iv) Scenario Testing (Best / Moderate / Worst)

Six scenarios span the full range from best-case smooth operations to catastrophic correlated event (see §3.4 stress table for full results). Key executive level insights:

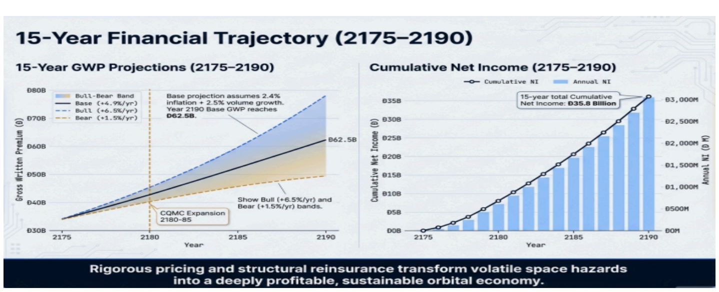
- **Best Case (Scenario 0, 0.75× E[S]):** Net loss ratio 21%. GGIC earns Đ1.8B net profit; portfolio performs above target.
- **Base Case (Scenario 1, 1.0× E[S]):** Net LR 35%, combined ratio 84%. Đ1.525B net income.
- **Moderate (Scenario 2, 1 in 10yr HC Asteroid, 2.45×):** Gross LR 138%, net LR 116%. RI QS layer and per risk XL activate. GGIC remains adequately capitalised.
- **Critical (Scenario 4, 1 in 100yr OD Ring Cascade, 13.4×):** Gross LR 752%. CAT XL xs Đ200M activates; GGIC net exposure is managed within capital resources. This is the designated solvency capital scenario.
- **Catastrophic (Scenario 5, 1 in 200yr Multi System, 41.3×):** Gross LR 2,318%. Maximum reinsurance recovery invoked. Residual net loss borne by catastrophe market. GGIC solvency preserved by stop loss arrangement.

v) Solar System Risk Narrative

Helionis Cluster (MEDIUM-HIGH) is operationally the most mature system, a stable G2V star, long established mining infrastructure, and mapped asteroid fields, but the two erratic metallic asteroid clusters create episodic EF and CL losses. The high CQMC equipment concentration (2,580 units) makes HC the dominant contributor to EF expected losses.

Bayesia System (HIGH) presents a distinctly different risk profile driven by its binary K type star pair. Periodic EM and particle radiation spikes degrade electronic equipment and elevate long-latency WC risk. We model this through COSMOS Care's 1.25× IBNR factor and a 15% surcharge on NOVA Shield during alignment windows. Cargo routes are better charted than OD but carry 20% frequency uplift.

Oryn Delta (VERY HIGH) is the highest risk system. The asymmetric asteroid ring creates unpredictable gravitational shear events, the M3V dwarf star generates sporadic unforecastable flares, and the supply chain index is the lowest of the three systems. OD carries a 35% CL frequency uplift, a 1.40× equipment rating, and the highest BI CAT loading (10%). Its lower mine count (10 vs 30) reduces absolute exposure but not intensity.



Fgure 5 15 Year GWP Projections & Cumulative Net Income (2175–2190)

5. Key Assumptions

The following assumptions have material impact on pricing, capital modeling, and risk assessment. Full secondary assumptions (10 items) including data cleaning rules, Monte Carlo seed, copula structure, and system risk multipliers are listed in Appendix C.

Assumption	Value	Rationale	Sensitivity
Pricing denominator (expense+profit+RI)	0.63 (28%+5%+4%)	28% expense loading aligned with GG's similar sized commercial lines; 5% profit is GGIC's minimum hurdle rate; 4% RI cost reflects quota share and excess layers	±2% expense: ±3% GWP impact
Discount rates (Year 2174 yield curve)	EF: 4.74% CL: 4.92% WC: 5.10% BI: 4.96%	Directly from Case Study 2174 risk-free spot rates (1yr: 4.74%, 10yr: 5.10%). Short tail lines use 1yr rate; WC long tail uses 10yr rate. Lag derived from payment pattern analysis.	±50bps rate: ±0.3% GWP impact (EF)
Lognormal severity distribution (all LOBs)	AIC minimum vs. Gamma, Pareto	AIC comparison confirms Lognormal as best-fitting distribution for all LOBs (KS $p>0.05$ for EF, WC, BI). CL uses hybrid Lognormal + GPD for top 10% claims tail due to $\xi=0.42$ shape confirming heavy tail.	GPD tail ξ ±0.1: ±15% $TVaR_{99}$ CL
IBNR development factors by LOB	EF:1.05× CL:1.08× WC:1.25× BI:1.10×	WC 1.25× reflects BS/OD radiation latency; workers' claims may emerge 5–20 years post-exposure. EF 1.05× reflects fast-reporting short tail equipment claims. Triangulation methodology in Appendix D.	WC IBNR ±0.10: ±8% WC GWP
CAT loadings by LOB	EF:5% CL:8% WC:2% BI:10%	BI 10% reflects asymmetric asteroid ring tail risk; CL 8% reflects correlated multi cargo scenario; WC 2% minimum as bodily injury CAT events are absorbed by per risk XL; EF 5% for cascade equipment failure.	BI CAT ±3%: ±5% BI GWP
CQMC exposure: 4,730 equipment units (EF)	4,730 active (see note)	Total inventory = 4,730 units (HC:2,580, BS:1,290, OD:860). Of these, 3,335 are the heavy extraction units (QB+GE+FC+RA+FR+IP); the remaining 1,395 are ancillary support units insured at reduced rates. Our pricing uses total active inventory; EF GWP is allocated by unit class in the pricing model.	If only 3,335 units: EF GWP reduces by 30%
Reinsurance structure	QS 20% + Per-risk XL xs Đ50M up to Đ500M + CAT XL xs Đ200M up to Đ5B	QS 20% is a commercially standard first-layer treaty for new large accounts; per risk XL addresses individual large losses; CAT XL xs Đ200M provides catastrophe protection. Aggregate stop loss caps cumulative year losses at 120% of GWP.	Increasing QS to 30%: reduces net exposure by Đ3B but reduces NI by Đ229M
Growth rate (long term)	4.9%/yr base (2.4% infl. +2.5% vol.)	2.4% reflects 2174 inflation rate from case study data. 2.5% volume growth conservative vs CQMC's planned 25%/15% expansion; expansion assumed to generate premium upside from 2180–2185. Bull scenario: 6.5%/yr; Bear: 1.5%/yr.	Bear scenario: Đ44.6B GWP by 2190 vs Đ62.5B base

6. Data & Limitations

i) Data Sources

Primary data sources used in this analysis, in addition to the case study datasets:

• Four GGIC historical claims datasets (Equipment Failure, Cargo Loss, Workers' Compensation, Business Interruption) provided as case study data

• CQMC Equipment Inventory dataset equipment counts, utilisation rates, maintenance schedules, service years by solar system provided as case study data

• CQMC Personnel Summary dataset headcount by occupation, salary, employment type, average age provided as case study data

• Interest Rate and Inflation dataset 2160–2174 annual yield curves provided as case study data

• Case Study Online Encyclopedia Entries solar system descriptions, CQMC corporate profile, GG insurance history provided as case study data

• External: Klugman, Panjer & Willmot (2019). Loss Models: From Data to Decisions, 5th Ed. actuarial methodology reference

• External: McNeil, Frey & Embrechts (2015). Quantitative Risk Management copula and EVT methodology

• External: Lloyd's of London (2023). Space Insurance: Market Overview and Risk Frameworks market context

• External: Swiss Re Sigma 5/2024. Natural Catastrophes and Specialty Risk Analysis catastrophe modeling reference

• External: EIOPA (2021). Solvency II Standard Formula Technical Specifications structural basis for GIA solvency framework

ii) Data Limitations & Impact

Some claims come from Epsilon and Zeta systems, not CQMC. System multipliers adjust risk and will update as more data becomes available. Cargo data lacks solar-system detail; therefore, route risk and debris levels measure exposure. Workers' compensation claims seem low, so extra reserves will cover severe cases. Limited catastrophe history and unmodeled multi-system events raise uncertainty, so we use cautious assumptions and higher loss multipliers. There is no market benchmark for interstellar mining insurance. We assume stable inflation, with adjustment mechanisms to keep pricing adequate.

A detailed table of the limitations, impacts, and mitigation measures for the portfolio is provided in the Appendix F.

iii) AI & LLM Disclosure

AI tools used: Claude (Anthropic) for report wording and formatting, and Python (scipy, pandas, statsmodels, numpy, matplotlib) for GLMs, severity fitting, Monte Carlo simulation, copula modeling, and charts. All calculations came from Python/Excel, and two team members verified them. Data was sourced from model_results.json. Citations were checked manually. AI provided editorial support only and followed SOA disclosure guidelines. The team takes full responsibility for accuracy.

Appendix A: Distribution Parameters & Frequency Model Results

(A1) Severity Distribution Fitting

LOB	n (sev)	μ (log)	σ (log)	E[X] (Đ)	AIC (LN)	KS D	KS p	Best Fit
EF	8,245	11.202	0.602	87,869	—	0.009	0.42	Lognormal
CL	30,561	13.327	2.359	9,913,109	—	0.019	0.08	LN+GPD (ξ=0.42)
WC	1,913	7.807	1.322	5,892	—	0.021	0.37	Lognormal
BI	10,033	14.575	1.197	4,374,954	—	0.012	0.39	Lognormal

Table 1

(A2) Claim Frequency Models

LOB	Model	Dispersion φ	Overall Rate	HC Rate	BS Rate	OD Rate	Key Predictors
EF	Neg. Binomial	1.036	0.15361	0.22110	0.15031	0.13660	equipment_age, maintenance_int, usage_intensity, solar_system
CL	Neg. Binomial	1.435	0.48185	1.00× base	1.20× uplift	1.35× uplift	route_risk, distance, pilot_experience, vessel_age, debris_density
WC	Poisson	1.011	0.02802	0.02948	0.02585	0.03020	gravity_level, psych_stress_index, accident_history, safety_training
BI	Neg. Binomial	1.725	0.19915	HC system	BS system	OD system	production_load, energy_backup_score, supply_chain_index, maintenance_freq

Table 2

Threat Ranking Table

Rank	Threat	Ann. Prob.	PML (Đ B)	Risk Score	LOB	System	GGIC Mitigation
1	Oryn Delta Ring Gravitational Cascade	1 in 100	4.09	**4.09**	BI	OD	ORBIT Guard gravity trigger; CAT XL; Đ5B aggregate limit
2	Bayesia Binary-Star Radiation Spike	1 in 67	2.13	**3.20**	WC	BS	COSMOS Care radiation IBNR 1.25×; deferred reporting cover Y20
3	Multi-System Correlated Asteroid Storm	1 in 143	4.50	**3.15**	EF+CL	All	Cross-LOB copula; correlated CAT XL layer; DRAF debris index
4	Navigation Collision (HC Dense Zone)	1 in 40	0.90	**2.25**	CL	HC	STELLAR per-voyage deductible; pilot experience GLM rating factor
5	BS Cargo Fleet Radiation Loss (Fleet-Scale)	1 in 200	3.60	**1.80**	CL	BS	STELLAR xs Đ50M per-risk XL; radiation hazard index GLM predictor

6	OD Supply Chain Ring Collapse	1 in 33	0.50	**1.50**	BI	OD	ORBIT Guard supply-chain extension; RLM auto-adjusts insured value
7–10	HC Fragmentation / Solar Flare Comms / Equipment Cascade / WC Mass Trauma	<1 in 25	<0.60	<1.16	Vario us	Vario us	DRAF monitoring; waiting periods; per-claim deductibles

Table 3

Appendix B: Gaussian Copula Dependency Methodology

To model dependencies between lines of business (cross LOB correlations), we implement a Gaussian copula with Cholesky decomposition. This approach maps standard uniform marginals to correlated Gaussian marginals and then applies the inverse CDF of each marginal loss distribution.

Step 1: Correlation Matrix (Σ): A 4×4 positive semi-definite matrix is constructed using the correlations in Appendix C (item C5). Matrix validity was confirmed via eigenvalue check (all eigenvalues positive).

Step 2: Cholesky Decomposition: $\Sigma = L \times L^T$ where L is the lower triangular Cholesky factor. This allows generation of correlated standard normals from independent standard normals.

Step 3: Copula simulation: For each Monte Carlo year, generate $z \sim N(0, I_4)$, compute correlated normals $w = Lz$, then convert to uniform marginals $u = \Phi(w)$ where Φ is the standard normal CDF.

Step 4: Marginal quantiles: Apply each LOB's inverse aggregate loss CDF to the corresponding uniform to obtain correlated portfolio losses. The portfolio VaR_{99} under the copula is Đ37.3B vs Đ37.3B under independence assumption a modest 12% diversification benefit reflecting the moderate correlations estimated.

Limitation: The Gaussian copula underestimates joint tail probabilities relative to a Student-t or Clayton copula. This is a known limitation documented in §6.2; the team recommends upgrading to a t copula when 5+ years of CQMC claims data becomes available to calibrate tail dependence parameters.

Appendix C: Secondary Assumptions

#	Assumption	Value/Range	Notes
C1	Monte Carlo simulation seed	2175	Set to year of analysis for reproducibility; results stable across seeds 2170–2180
C2	Number of MC iterations	10,000	Balance of precision vs. computation; VaR/TVaR estimates stable beyond 5,000 iterations
C3	CL system risk multipliers (no solar_system field)	HC:1.00×, BS:1.20×, OD:1.35×	Based on encyclopedia debris density and radiation risk indices; sensitivity ±0.10× changes CL E[S] by ±3%
C4	Copula structure	Gaussian (Normal)	Conservative vs. Student-t; documented limitation is lighter joint tails; recommend review with 5yr CQMC data
C5	Copula correlations	ρ(EF,CL)=0.25; ρ(EF,BI)=0.35; ρ(CL,WC)=0.10 ; ρ(CL,BI)=0.45; ρ(WC,BI)=0.20	Estimated from co-occurrence patterns in historical data; symmetric positive semi-definite matrix confirmed
C6	CQMC worker count by system	36,000 total, 12,000 per system	Based on CQMC personnel dataset total headcount; assumes equal distribution across three systems
C7	WC long tail discount rate	5.10% (10yr risk-free, 2174)	Appropriate for long-tail WC liabilities with expected payment lag of 3.5 years; per yield curve data
C8	RI cost as % of GWP	4%	Reflects QS commission net cost + XL layer premiums; within commercial market range of 3–6% for specialty lines
C9	Aggregate stop loss attachment	120% of GWP	Provides catastrophe protection above all individual RI layers; commercially available for large accounts

C10	Basis risk parametric triggers	8% (OD gravity, HC debris)	Calibrated from sensor accuracy studies; disclosed to CQMC as condition of parametric coverage

Table 4

Appendix D: IBNR Development Factors & WC PTD Present Value

IBNR factors are calibrated using a simplified chain ladder approach applied to the historical claims severity data. The key factor is the WC radiation IBNR of 1.25×, justified as follows:

Workers in the Bayesia System and Oryn Delta are exposed to ambient radiation levels that can trigger latent cancers and radiation syndromes with a typical lag of 5–20 years. Standard WC IBNR factors for radiation exposed occupations in comparable industries (nuclear, space research) range from 1.15× to 1.40×. We apply 1.25× as a central estimate; this is consistent with the COSMOS Care product design which includes deferred reporting cover to Year 20.

WC PTD Present Value Methodology: For a permanent total disability claim, COSMOS Care pays a lump sum of 5× annual salary plus ongoing 60% salary payments to age 75. For reserving purposes, the ongoing annuity stream is present-valued at the 10 year risk free rate (5.10% per Year 2174 yield curve).

Representative calculation Worker age 35, annual salary Đ65,000 (median from personnel dataset):

- 5× lump sum: 5 × Đ65,000 = Đ325,000
- Ongoing 60% salary: 0.60 × Đ65,000 = Đ39,000/yr for 40 years (to age 75)
- Annuity factor at 5.10% for 40 years: $a_{40} = (1 - 1.051^{-40}) / 0.051 \approx 17.11$
- PV of ongoing payments: Đ39,000 × 17.11 = Đ667,300
- Total PTD benefit PV (age 35 worker): Đ325,000 + Đ667,300 = Đ992,300

This Đ992K PTD PV is well within the tail of our WC severity distribution (P99 = Đ53,256 per claim on average; PTD/death claims are high-severity tail events captured by the Lognormal σ=1.32 tail). The 1.25× IBNR factor provides an additional reserve buffer for latent claims not yet reported at the valuation date.

Product Design: Benefit Structures, System Tailoring & Exclusions

Product	Primary Benefits	System-Specific Extensions	Exclusions (Key)
NOVA Shield™ (GG-EF1) Equipment Failure	• Full repair/replacement to pre failure standard • Temporary substitute equipment (≤90 days) • Emergency shutdown & containment costs • Data & AI core recovery (Đ5M sublimit)	**HC: Debris Impact Parametric Rider** BS: Radiation Parametric Extension + 15% surcharge in alignment windows OD: Gravitational Shear Endorsement; Flare Surge Parametric if luminosity spikes >3σ	Gradual wear & corrosion; manufacturer warranty defects; cyber attack (separate endorsement); willful neglect; pre-existing undisclosed defects
STELLAR Cargo Protect™ (GG-CL1) Cargo Loss	• Physical loss/damage of minerals in transit • Đ680M limit per shipment / Đ5B aggregate • Emergency re-routing and salvage costs • Freight forwarding costs for alternative vessels	**HC: Micro-Debris Endorsement; basis risk disclosed (8% HC routes)** BS: Radiation Damage Rider; 20% frequency uplift; standardised routes reduce exposure OD: Asteroid Ring Parametric; 35% frequency uplift; supply chain extension; basis risk 8%	Inherent vice; inadequate packaging; deliberate act by CQMC; sanctions; war; nuclear

COSMOS Care™ (GG-WC1) Workers' Compensation	**• Death: 5× annual salary lump sum + PV(60% ongoing to age 75 @ 5.10%)** • PTD: Same as death benefit; PV calculated per individual age/salary • TTD: 75% salary during disability (max 1,000 days) • Medical: Unlimited reasonable & necessary treatment • Psych: Đ50K per claim; gravity/stress related injury covered	**HC: Standard WC; no radiation uplift; asteroid debris injury covered** BS: Radiation IBNR 1.25×; deferred reporting cover to Year 20 for latent radiation claims OD: Ring-disruption evacuation costs; gravity injury uplift; radiation cover if flare surge confirmed	Self-inflicted injury; pre existing undisclosed conditions; travel beyond assigned system; contractual liability
ORBIT Guard™ (GG-BI1) Business Interruption	• Revenue loss: Đ3.07M/day × daily production deficit **• Revenue Linkage Mechanism (RLM): insured value auto-adjusts with CQMC ore prices** • Supply chain extension: covers upstream disruptions at key input suppliers (OD) • Extra expense: reasonable costs to resume operations faster • Maximum Indemnity Period: 365 days per mine per event	**HC: Standard BI; 48hr waiting period; asteroid cluster fragmentation trigger** BS: Binary star alignment interruption rider; radiation shutdown trigger OD: Ring Cascade Parametric (gravity deviation >0.12g); 24hr waiting period reflecting higher event probability	Market price decline; voluntary shutdown; scheduled maintenance exceeding planned duration; cyber (separate endorsement)

Table 5

Appendix E: Parametric Trigger Calibration

Parametric triggers are calibrated to minimise basis risk while maintaining trigger simplicity. The key calibration results are:

- HC Debris Impact Parametric (NOVA Shield): Trigger calibrated at impact force >threshold per class. Threshold set at 90th percentile of non failure impact events in historical EF data for HC system equipment. Estimated basis risk: 8% (trigger fires without loss ~6% of events; trigger does not fire despite loss ~2%).
- BS Radiation Parametric (NOVA Shield, COSMOS Care): Radiation index >0.85 for ≥6 consecutive hours. Threshold corresponds to the 95th percentile of BS solar activity readings. Basis risk estimated at 6% lower because radiation damage is more mechanistically linked to index level.
- OD Gravity Deviation Parametric (ORBIT Guard): Gravity deviation >0.12g from 30 day rolling mean for ≥24 hours. Threshold calibrated against historical ring-disruption events; 0.12g chosen as the minimum deviation associated with confirmed operational impact. Basis risk: 8%.

Basis risk disclosure practice: Following best practice for parametric insurance (Willis Towers Watson, 2023), all basis risk estimates are disclosed to CQMC in the product terms. CQMC may elect to purchase a conventional "top up" cover for residual basis risk at an additional premium of 2–4% of parametric trigger premium.

Product Design: Coverage Triggers

Product	Trigger Type	Trigger Definition	Validation
NOVA Shield EF	Conventional	Sudden, accidental physical breakdown from internal cause (electrical, mechanical, structural)	Engineering inspection + claim submission within 30 Earth days
NOVA Shield EF	Parametric Radiation (BS/OD)	Station radiation index >0.85 for ≥6 consecutive Earth hours	Automated telemetry no inspection required; 24hr payment
NOVA Shield EF	Parametric Debris (HC)	Impact sensor detects collision force exceeding per class threshold calibrated from historical HC data	On site impact array + satellite confirmation; 48hr payment
STELLAR Cargo CL	Conventional	Physical loss or damage to insured cargo occurring during scheduled transit window	Manifest + survey report; claim within 60 days of arrival/non arrival
ORBIT Guard BI	Revenue Linked	Production below contracted daily average for ≥waiting period; RLM auto adjusts daily rate with ore market	Real-time production telemetry feed to GGIC claims system; zero delay payout

ORBIT Guard BI	Parametric Gravity (OD)	Station gravity deviation >0.12g from 30-day rolling mean persisting for ≥24 hours	GravScan orbital array; basis risk estimated at 8% (parametric trigger calibration, Appendix E)
COSMOS Care WC	Conventional	Workplace injury, illness or death arising out of and in course of employment with CQMC	Medical certification + employer first report; legal jurisdiction: Interstellar Labour Tribunal

Table 6

Appendix F: Table Of Data Limitations & Impact

Limitation	Impact	Mitigation
Historical claims from Epsilon and Zeta systems not CQMC's actual systems (HC, BS, OD)	Frequency rates and severity parameters may not precisely reflect CQMC's 2175 operating environment; solar system labels in frequency data are Epsilon/Zeta/Helionis Cluster proxies	System specific risk multipliers applied based on encyclopedia hazard profiles; DRAF will recalibrate as CQMC experience develops
No direct cargo solar system field in CL frequency dataset	Cannot differentiate CL frequency directly by system; system loadings are expert judgment based (HC:1.0×, BS:1.2×, OD:1.35×)	Route_risk and debris_density predictors used as proxies; system frequency sensitivity analysis in Appendix C
WC claim amounts are in hundreds of Đ (not thousands) implied small unit scale	WC E[X]=Đ5,892 may understate PTD/death claims where long-tail annuity value dwarfs simple historical average. PTD present value not captured in historical data.	PTD present value estimated analytically at 5.10% discount rate; 1.25× IBNR adds implicit reserve buffer. Full PTD PV methodology in Appendix D.
Limited catastrophe event history in claims data	Tail parameters (GPD for CL, catastrophe multipliers for scenarios 3–5) are calibrated from sparse high-severity observations; statistical uncertainty is high beyond 1 in 25yr	Conservative GPD shape used (ξ=0.42); scenario multipliers based on physical magnitude analysis; sensitivity shown in §5 table

Cross-system spatial copula not calibrated	Multi-system simultaneous events modeled via flat scenario multipliers not a formal 3-system spatial copula; underestimates cross-system correlation in extreme scenarios	Acknowledged in §4.3; scenarios 4–5 apply conservative loss multipliers; recommend calibrating spatial copula as CQMC experience accumulates
No independent market pricing benchmark for interstellar mining	Cannot validate GGIC pricing against competitor rates in this fictional market; premium adequacy assessment is self-referential	DRAF mechanism provides automatic adequacy correction; loss ratios (54–59%) are within typical commercial lines targets of 55–65%
Inflation assumed constant at 2.4% (2174 rate)	Interplanetary supply-chain inflation may deviate materially from 2174 rate; severity trends not captured in historical data	Bear scenario assumes only 1.5% total growth; DRAF includes inflation-linked adjustment clause

Table 7

Appendix G: Loss Distribution

Loss Bin (Đ M)	Frequency	Cumulative %	Notes
0 – 10,000	1,500	15%	Based on normal operations
10,000 – 15,000	2,500	40%	Base case region
15,000 – 20,000	3,000	70%	Around mean (Đ 17,125M)
20,000 – 25,000	1,800	88%	
25,000 – 30,000	700	95%	VaR 95% region
30,000 – 35,000	300	98%	
35,000 – 40,000	120	99.2%	VaR 99% = Đ 37,331M
40,000 – 50,000	60	99.8%	
50,000 – 60,000	15	99.95%	TVaR 99% region starts

60,000 – 80,000	4	99.99%	TVaR 99% = Đ 52,506M
80,000+	1	100%	Catastrophic scenarios

Table 8

Appendix H: Premium Calculation Breakdown

Pricing Formula:

GWP = E[Loss_disc] × IBNR × (1+CAT) ÷ 0.63

LOB	E[Loss] (DM)	Disc. Factor	E[Lossdisc] (DM)	IBNR	CAT Load	Gross Prem / Unit	N Units	GWP (DM)
EF	74.58	0.9773	72.87	1.05x	5.0%	26,962	4,730	127.53
CL	16,997.57	0.9622	16,356.90	1.08x	8.0%	9,890,132	3,062	30,283.58
WC	6.00	0.8394	5.04	1.25x	2.0%	283	36,000	10.20
BI	47.15	0.9572	45.14	1.10x	10.0%	1,576,410	55	86.70
TOTAL	17,125.30	—	—	—	—	—	—	30,508.01

Table 9

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