LUNAR REGOLITH EXPOSURE

Effects on Human Physiology and Remediation Strategies

Research Paper Assignment

Course Level	Freshman Undergraduate (BIOL 1010 / PHYS 1010 / EXSC 1010)
Minimum Length	10 full pages of content (excluding title page and references)
Required Systems	Minimum 4 distinct physiological body systems
References Required	Minimum 8 peer-reviewed or NASA technical sources
Citation Format	APA 7th edition
Due Date	_____

Student Name: _____ Section: _____ Date: _____

Part I: Assignment Overview and Purpose

As humanity prepares to return to the Moon under NASA's Artemis program — and eventually establish long-duration lunar bases — one of the most serious and underappreciated threats to astronaut health is lunar regolith: the fine, jagged dust that blankets the entire lunar surface. Unlike the rounded, water-eroded particles of Earth, lunar regolith particles have never been softened by wind or rain. Billions of years of micrometeorite bombardment have ground the surface into razor-sharp, glassy shards that are electrostatically charged, chemically reactive, and microscopic enough to bypass the body's normal defense systems.

Apollo astronauts encountered this dust firsthand in the 1960s and 1970s and reported immediate respiratory irritation, eye inflammation, and equipment degradation — after only hours of exposure. Future missions will last weeks, months, or even years. The physiological stakes are therefore enormously higher, and scientists are only beginning to understand the full range of body systems at risk.

This assignment asks you to investigate those risks in depth. You will research how lunar regolith exposure threatens multiple physiological systems of the human body, examine the cellular and molecular mechanisms behind those threats, and evaluate current and proposed remediation strategies — from engineering solutions to pharmaceutical countermeasures. The goal is to think and write like a biomedical researcher preparing a scientific review paper for a space medicine journal.

Assignment Objectives

By completing this paper, you will demonstrate the ability to:

- Identify and accurately describe the physical and chemical properties of lunar regolith that make it biologically hazardous
- Explain how exposure affects at least four distinct human physiological systems at the cellular, tissue, and organ levels
- Connect exposure mechanisms to real clinical outcomes observed or predicted for astronauts
- Evaluate the effectiveness of current and proposed remediation and protective strategies
- Synthesize information from peer-reviewed scientific literature, NASA technical reports, and primary research
- Communicate complex scientific content at a college-level standard using APA citation format

Why This Topic Matters

The Artemis Context

- NASA's Artemis III mission will land astronauts near the lunar south pole — a region never visited before and covered in ancient, highly abrasive regolith.
- Long-duration surface stays of 30+ days are planned, exposing crew to far more dust than any Apollo mission.

- No permissible exposure limit (PEL) for lunar dust has yet been formally established — this is an active area of NASA research.
- Students completing this paper are engaging with one of the most pressing open questions in space medicine today.

Part II: Required Background — The Nature of Lunar Regolith

Your paper must open with a substantive background section (suggested length: 1.5–2 pages) that establishes the physical and chemical properties of lunar regolith before discussing its effects on the body. This section is not optional — without it, a reader cannot understand why regolith is dangerous in ways that ordinary terrestrial dust is not. Use the prompts below to guide your writing.

2.1 What Is Lunar Regolith?

Lunar regolith is the layer of unconsolidated rocky material that covers the Moon's surface to depths ranging from 4–5 meters in mare (volcanic plain) regions to 10–15 meters in highland areas. It is the product of approximately 4.5 billion years of continuous micrometeorite bombardment in the complete absence of the weathering processes — wind, water, chemical oxidation — that round and neutralize particulates on Earth.

Your paper should describe:

- The bulk chemical composition of regolith (approximately 50% SiO_2, 15% Al_2O_3, 10% CaO, 10% MgO, 5% TiO_2, 5–15% iron oxides, plus trace elements)
- The distinction between regolith (all surface material) and lunar dust (the fine fraction with particles < 20 μm that is most hazardous)
- The role of space weathering in creating the unique particle morphology: glassy, angular, with sharp fractured edges and nanophase iron deposits on grain surfaces
- The electrostatic charging mechanism: the sunlit side of the Moon is bombarded by solar wind protons, charging surface particles positively; the shadowed side accumulates negative charge from solar wind electrons — leading to dust that actively clings to surfaces

2.2 Why Is Lunar Dust Uniquely Hazardous Compared to Earth Dust?

Property	Lunar Dust	Typical Earth Dust
Particle shape	Razor-sharp, angular, glassy fractures	Rounded by wind/water erosion
Electrostatic charge	Highly charged by solar wind bombardment	Minimal charge; dissipates quickly
Oxidation state	Highly reduced; reactive when exposed to water or biological tissue	Partially oxidized; less reactive
Nanophase iron	Present on grain surfaces from space weathering; generates free radicals	Absent
Silica content	~50% SiO_2; similar to crystalline silica in occupational hazards	Varies; often lower or more crystalline
Biologic clearance	Unknown; sharp edges may resist macrophage clearance	Rounded particles cleared more efficiently

2.3 Lessons from the Apollo Missions

Your background section must include a discussion of what Apollo astronauts actually experienced. This is the only direct human evidence available. Key points to address:

- Apollo 17 astronaut Harrison Schmitt reported a severe upper respiratory reaction — nasal congestion, sneezing, and sore throat — within hours of dust entering the lunar module. He described it as 'lunar hay fever.'
- Multiple Apollo crews reported that regolith fouled equipment, scratched visor coatings, degraded spacesuit joints, and contaminated the inside of the lunar module through suit transfer.
- The Apollo experience has been formally documented in NASA technical reports and serves as the primary real-world exposure baseline — but exposure durations were short (hours to days). Modern missions will be far longer.
- Discuss the critical knowledge gap: we have no long-term human exposure data because no one has lived on the Moon for weeks or months.

Part III: Required Body Systems — Detailed Coverage Requirements

This is the core section of your paper and must be the most substantial portion of your writing. You are required to cover a minimum of four physiological body systems. Each system section must be written in full paragraphs (not bullet lists) and must include all of the sub-elements described below. Each system should occupy at least 1.5 pages of your paper. You may cover additional systems for bonus depth — six or more systems would represent an exceptional paper.

Minimum Requirements Per System

- Name and brief overview of the physiological system's normal function
- Specific route of exposure for that system (how regolith particles reach it)
- Cellular and molecular mechanisms of damage (what happens at the cell level)
- Tissue and organ-level consequences (what the damage looks like in the body)
- Clinical outcomes and symptoms an astronaut would experience
- At least ONE cited peer-reviewed source or NASA technical report specific to that system
- Transition to the remediation section by identifying the specific protective challenge for this system

System 1 — The Respiratory System (Required)

The respiratory system is the primary and most extensively studied route of lunar dust hazard. This system must be included in every paper.

What your paper must explain:

- Normal function: gas exchange at the alveolar level; the mucociliary escalator as the primary particulate defense; alveolar macrophage-mediated particle clearance
- Exposure route: inhalation of aerosolized particles < 10 μm (PM10) reaches the bronchioles; particles < 2.5 μm (PM2.5) reach the alveoli; particles < 0.1 μm may translocate across the alveolar membrane into the bloodstream
- Cellular mechanisms: reactive oxygen species (ROS) generation from nanophase iron on particle surfaces; activation of the NLRP3 inflammasome in alveolar macrophages; frustrated phagocytosis when particles are too sharp for macrophages to engulf; apoptosis of type II pneumocytes
- Tissue consequences: acute bronchitis and alveolitis; potential for pulmonary fibrosis with long-term exposure (similar to silicosis); impaired surfactant production disrupting alveolar surface tension
- Clinical outcomes: coughing, chest tightness, reduced lung capacity, progressive hypoxemia; long-term: possible pneumoconiosis, lung cancer risk
- Unique lunar factor to discuss: the Moon's reduced gravity (1/6 Earth's) may alter particle deposition patterns in the lung compared to Earth predictions, and exercise during EVA increases respiratory rate and particle intake

System 2 — The Immune System (Required)

The immune system is uniquely vulnerable in spaceflight and serves as a second required topic for every paper.

What your paper must explain:

- Normal function: innate vs. adaptive immunity; the role of macrophages, neutrophils, mast cells, T-lymphocytes, and IgE-mediated responses in defending against foreign particles
- Spaceflight context: explain that microgravity and radiation already suppress immune function before any dust exposure occurs — dust represents a compounding risk
- Exposure mechanism: when regolith particles contact mucous membranes, they activate pattern recognition receptors (Toll-like receptors) on innate immune cells; macrophages attempt phagocytosis; frustrated phagocytosis triggers sustained NLRP3 inflammasome activation releasing IL-1β, TNF-α, and IL-6
- Allergic sensitization: NASA research using actual Apollo 16 samples demonstrated that lunar dust can potentially trigger IgE-mediated allergic responses through mast cell and basophil activation — meaning an astronaut could develop anaphylaxis-like reactions to dust exposure
- Chronic immune dysregulation: persistent particle exposure may shift the immune response toward a Th2 profile, increasing susceptibility to infections — catastrophic in a closed habitat on the Moon where medical resources are severely limited
- Clinical outcomes: acute: sneezing, rhinitis, conjunctivitis, urticaria; severe: anaphylaxis; chronic: increased infection susceptibility, autoimmune-like inflammatory states

System 3 — The Cardiovascular System (Choose or explain)

The cardiovascular system is a less obvious but well-supported hazard pathway for fine particulate exposure, supported by a large body of terrestrial occupational health research on PM2.5.

What your paper must explain:

- Normal function: cardiac output, systemic circulation, endothelial function in regulating vascular tone and preventing clot formation
- Translocation pathway: ultrafine particles (< 0.1 μm) that cross the alveolar-capillary barrier enter the bloodstream; larger particles may trigger systemic inflammation via cytokine release even without direct vascular access
- Endothelial dysfunction: particle-induced ROS and inflammatory cytokines (TNF-α, IL-6) disrupt nitric oxide signaling in vascular endothelium, reducing vasodilation capacity and increasing arterial stiffness
- Coagulation activation: fine particles and their surface-absorbed molecules can activate platelets and trigger the coagulation cascade — increasing the risk of thrombosis. Spaceflight already elevates thrombosis risk due to fluid shifts and reduced physical activity

- Cardiac effects: elevated circulating inflammatory markers have been associated with arrhythmias and increased cardiac workload; this is particularly concerning because astronauts already experience cardiac deconditioning in microgravity
- Clinical outcomes: elevated blood pressure, increased risk of deep vein thrombosis or pulmonary embolism during or after EVA, long-term atherosclerosis risk

System 4 — The Integumentary System (Skin, Eyes, and Mucous Membranes)

The skin and external mucosal surfaces represent the body's first physical barrier against regolith and are often overlooked in discussions focused on inhalation.

What your paper must explain:

- Normal function: the skin as a physical and immunological barrier; Langerhans cells as immune sentinels; the eye's lacrimal flushing mechanism; mucous membranes as chemical and mechanical traps
- Exposure routes: spacesuit breaches or contaminated glove surfaces transferring particles to skin; particles entering the eye through visor gaps or suit doffing; mucous membrane contact during habitat ingress when suits are removed
- Mechanical abrasion: describe in detail how the angular morphology of regolith particles causes micro-lacerations in the corneal epithelium, skin surface, and nasal mucosa — these provide entry points for reactive chemical species and secondary infection
- Chemical reactivity on skin: discuss how freshly fractured regolith surfaces expose silanol groups (-Si-OH) that are highly reactive with biological molecules, generating hydroxyl radicals that oxidize lipids, proteins, and DNA in skin cells
- Ocular hazards: corneal abrasion is the most immediate risk; chronic exposure could lead to keratoconus-like degeneration; the eye has no melanin-based UV protection against the 20-fold higher UV flux on the lunar surface when contaminated particles are present
- Clinical outcomes: eye: corneal abrasion, chronic inflammation, potential vision loss; skin: contact dermatitis, delayed wound healing, micro-abrasion sites; mucosa: bleeding, chronic rhinitis, potential mucosal barrier breakdown

System 5 — The Neurological System (Advanced / Strongly Recommended)

Emerging research suggests that the finest fraction of lunar dust may reach the central nervous system, making this a frontier area of space medicine research.

What your paper must explain:

- Translocation pathway: the olfactory route — particles deposited on the olfactory epithelium can travel along olfactory nerve axons through the cribriform plate directly into the olfactory bulb and then to the brain; this bypasses the blood-brain barrier entirely
- Blood-brain barrier entry: ultrafine particles that enter the bloodstream may compromise blood-brain barrier integrity via endothelial inflammation — allowing circulating inflammatory cytokines and particle-derived ROS to access neural tissue

- Neuroinflammation: activated microglial cells (the brain's resident immune cells) respond to particle exposure by releasing pro-inflammatory cytokines; this 'neuroinflammation' is associated with cognitive decline, depression, and neurodegenerative changes
- In vitro evidence: cite that laboratory studies using lunar simulants have demonstrated that fine regolith simulant particles kill mouse brain cells at high rates — one of the most alarming findings in the published literature
- Spaceflight context: astronauts already show measurable white matter changes and cognitive performance shifts after spaceflight; dust-induced neuroinflammation represents an additional and potentially compounding stressor
- Clinical outcomes: acute: headache, cognitive fog, mood changes; long-term: potential accelerated neurodegeneration; implications for mission-critical decision-making performance during and after long surface stays

System 6 — The Musculoskeletal System (Additional Option)

Though less direct than respiratory or immune effects, the musculoskeletal system faces compounding risks from dust exposure combined with known spaceflight-related bone and muscle loss.

What your paper must explain:

- Spaceflight baseline: lunar astronauts already experience up to 1–2% bone mineral density loss per month in microgravity and significant muscle atrophy; this is the context into which dust-related inflammation enters
- Systemic inflammation connection: elevated circulating IL-1β, TNF-α, and IL-6 from dust-triggered immune activation directly suppress osteoblast activity (bone formation) while stimulating osteoclast activity (bone resorption) — accelerating spaceflight-induced bone loss
- Joint exposure: if regolith particles infiltrate spacesuit joint seals and contact periarticular tissue during long EVAs, local inflammatory responses in synovial membranes could contribute to joint damage over time
- Muscle: chronic systemic inflammation is associated with muscle catabolism (breakdown); combined with microgravity-induced atrophy, this creates a significant functional deficit for astronauts who need physical strength for EVA work
- Clinical outcomes: accelerated osteoporosis, increased fracture risk (especially on Mars return), impaired musculoskeletal recovery post-mission

Part IV: Remediation Strategies — Requirements

Your paper must include a dedicated remediation section (suggested length: 2–2.5 pages) that is organized around the body systems you discussed. Do not simply list technologies — each remedy must be explicitly connected to the physiological mechanism it addresses. For example, if you described how frustrated phagocytosis generates ROS in the lung, your remediation discussion should explain which antioxidant approach targets that specific process and why.

4.1 Engineering and Environmental Controls

Describe and evaluate the following categories. For each, your paper should explain the principle of operation, current development status, and which physiological exposure pathway it disrupts:

Filtration systems

HEPA filtration (H13/H14 grade, 99.95%+ efficiency at 0.3 μm) is NASA's recommended standard for habitat air quality. Discuss how HEPA filtration interrupts the inhalation exposure pathway for the respiratory and immune systems. Address limitations: filter loading, maintenance logistics on the Moon, and the challenge of filtering charged particles that evade mechanical media.

Electrostatic dust mitigation

Electrostatic dust shields (EDS) use alternating electric fields applied through electrode arrays embedded in suit fabric or habitat surfaces to repel charged particles. Research from Waseda University and NASA's BIG Idea Challenge has demonstrated up to 90% dust repulsion efficiency. Explain how this approach prevents primary exposure to the integumentary, respiratory, and ocular systems. Address the power requirements and current technology readiness level (TRL).

Airlock design and suit doffing protocols

Discuss the engineering challenge of preventing dust transfer from suit to habitat interior — the so-called 'tracking problem.' Proposed solutions include suitport technology (astronauts enter from outside without bringing suits inside), positive-pressure differential airlocks, and UV-C decontamination chambers. Explain how each approach targets a different physiological system.

Anti-adhesion surface coatings

Discuss water-fluorine-modified (WFM) coatings and carbon nanotube (CNT) fiber networks being developed to reduce the electrostatic adhesion of particles to suit surfaces and equipment. Connect this to both integumentary and respiratory system protection.

4.2 Medical and Pharmaceutical Countermeasures

This section is where your biological knowledge becomes most important. For each countermeasure, your paper must identify the specific biochemical or physiological target and explain the mechanism of action:

Antioxidant therapy

Free radical generation is a central mechanism of regolith toxicity across multiple systems (respiratory, neurological, cardiovascular, integumentary). Discuss the rationale for antioxidant prophylaxis using agents such as **N-acetylcysteine (NAC)** (a glutathione precursor), **Vitamin C (ascorbic acid)**, **Vitamin E (tocopherol)**, and **melatonin** (a potent brain-permeant antioxidant relevant to the neurological pathway). Address the challenge of balancing antioxidant supplementation with the body's need for ROS in normal immune signaling.

Anti-inflammatory pharmacology

Because NLRP3 inflammasome activation and IL-1β/TNF-α release are central to regolith-induced damage in the lung, immune system, and brain, discuss the potential role of **NLRP3 inflammasome inhibitors** (such as MCC950), **corticosteroid inhalers** for acute respiratory inflammation, and **biologics targeting TNF-α or IL-6** for systemic inflammatory control. Note that immunosuppression carries its own risk in a closed habitat on the Moon.

Respiratory protective equipment and personal prophylaxis

Discuss the use of N95 / FFP3 respirators during suit doffing as a last-resort barrier; the logistical challenges of wearing respiratory protection inside a pressurized habitat; and the potential role of prophylactic nasal rinses (saline lavage) to mechanically remove deposited particles from the nasal mucosa before they are absorbed or transported to the lung.

Ocular protection and treatment

Discuss UV-blocking visor coatings, lubricating eye drops for mechanical flushing of particles post-EVA, and the potential use of prophylactic anti-inflammatory eye drops (such as ketorolac) to prevent corneal inflammatory cascades after particle contact.

Neurological protection strategies

Because the olfactory pathway bypasses the blood-brain barrier, discuss proposed strategies including **olfactory epithelium flushing protocols**, **nasal filters** applied during suit removal, and the emerging concept of **microglial priming inhibitors** (agents that reduce the sensitivity of resident brain immune cells before anticipated exposure). This is a frontier topic — acknowledge that human-specific data are entirely lacking and that this is an area of active NASA-sponsored research.

4.3 Behavioral and Operational Countermeasures

Your paper should briefly discuss non-pharmacological and non-engineering measures that represent the first line of defense:

- EVA time limitations: current NASA guidelines propose limiting EVA duration and frequency to reduce cumulative dust exposure — connect this directly to the dose-response relationship for each body system
- Buddy-system suit inspection: pre- and post-EVA inspection protocols to identify suit breaches, scratched visors, or seal failures that could allow particle ingress
- Habitat air monitoring: real-time particle counting sensors (PM2.5/PM10) placed in habitat zones to provide early warning of filter failure or suit contamination events
- Nutritional countermeasures: discuss how a diet rich in antioxidants and anti-inflammatory nutrients (omega-3 fatty acids, polyphenols) may provide baseline protection across all affected systems

Part V: Paper Structure, Format, and Length Requirements

5.1 Required Paper Structure

Your paper must follow this organizational structure. Each section heading should appear in your final document.

#	Section Title	Min. Length	Key Content
—	Title Page	1 page	Title, your name, course, date, word count
—	Abstract	150–250 words	One paragraph: purpose, systems covered, key findings, conclusion
1	**Introduction**	~0.75 page	Why lunar dust is hazardous; Artemis mission context; paper roadmap
2	**Properties of Lunar Regolith**	~1.5 pages	Physical/chemical properties; comparison to Earth dust; Apollo observations
3	**Physiological Effects (×4 min.)**	~1.5 pp. each	All 7 required sub-elements per system (see Part III)
4	**Remediation Strategies**	~2 pages	Engineering, pharmaceutical, behavioral countermeasures
5	**Discussion**	~0.75 page	Integrate: which system is most at risk? Which remedy is most promising?
6	**Conclusion**	~0.5 page	Summary, significance, future research directions
—	References	Separate page	Min. 8 sources, APA 7th ed.

5.2 Formatting Requirements

Requirement	Specification
Font	Times New Roman or Arial, 12pt
Spacing	Double-spaced throughout (except title page and reference list)
Margins	1 inch on all sides
Page numbers	Top right header, beginning on page 2
Headings	Section headings bolded; sub-headings bolded and italicized
Paragraph indentation	0.5 inch first-line indent for all body paragraphs

Abstract	Single block paragraph, no indentation, on its own page
Length	Minimum 10 pages of body content, not including title page or references
Citation style	APA 7th edition in-text citations and reference list
Writing person	Third person only; no 'I' or 'we' except in the Discussion section
Tables/figures	Allowed and encouraged; each must have APA-format caption

5.3 Citation and Source Requirements

A minimum of 8 sources are required. At least 5 must be peer-reviewed journal articles or NASA technical reports. Sources must be published within the last 15 years (2010–present), with the following exceptions:

- Apollo mission primary reports (any date) — these are irreplaceable historical data
- Foundational toxicology papers on silica/silicate particulate hazards may be cited regardless of date

Recommended Source Categories

- NASA Human Research Program technical reports (humanresearchroadmap.nasa.gov)
- npj Microgravity journal — Overview of lunar dust toxicity risk (2022)
- GeoHealth journal — Cellular toxicity studies using lunar simulants
- Frontiers in Immunology — Lunar dust immunogenicity/allergenicity studies (2025)
- NASA NTRS (technical report server) — Dust Mitigation Gap Assessment Report (2016)
- ESA reports on lunar dust health research
- Exolith Lab and SSERVI publications on simulant development and properties
- Occupational health literature on silicosis and pneumoconiosis for comparative context

Part VI: Grading Rubric (for teacher use)

Your paper will be graded on the following criteria. Read each category carefully before you begin writing.

Criterion	Excellent (A)	Good (B)	Adequate (C)	Insufficient (D/F)	Instructor Notes / What to Look For
Scientific accuracy of regolith properties	**25**	20	15	0–10	*Correct chemical formula, particle morphology, electrostatic mechanism, comparison to Earth dust*
Depth of physiological system coverage (per system)	**25**	20	15	0–10	*All 7 sub-elements present; cellular mechanisms explained; clinical outcomes connected to mechanisms*
Number of systems covered (min. 4)	**20**	16	12	0–8	*4 systems = full credit; fewer = proportional deduction; 5+ = bonus consideration*
Remediation section quality	**20**	16	12	0–8	*Each remedy explicitly connected to a specific physiological mechanism; not just a list of technologies*
Integration and critical thinking (Discussion)	**15**	12	9	0–6	*Student forms original argument about which system is most at risk or which remedy is most promising, with reasoning*
Source quality and quantity	**10**	8	6	0–4	*8+ sources, 5+ peer-reviewed, correct APA format, diverse source types*
Writing quality and format compliance	**10**	8	6	0–4	*College-level prose, correct APA format, 10+ pages, proper headings, no first-person*
Abstract quality	**5**	4	3	0–2	*All key paper elements present in 150–250 words; self-contained and accurate*
TOTAL POINTS POSSIBLE					**130**

Note: papers covering 5 or more body systems with full depth may be eligible for up to 10 bonus points at the instructor's discretion.

Part VII: Writing Guidance and Common Mistakes to Avoid

7.1 Writing at the Freshman College Level

'College-level writing' at the freshman level means several specific things in a science paper:

What Excellent Scientific Writing Looks Like

- Claims are always supported by evidence: every factual statement about a mechanism, symptom, or treatment is followed by a citation.
- Mechanisms are explained, not just described: don't just say 'lunar dust damages the lungs.' Explain that sharp silicate particles resist macrophage phagocytosis, leading to NLRP3 inflammasome activation and cytokine-driven alveolar inflammation.
- Definitions are provided for technical terms the first time they appear: e.g., 'reactive oxygen species (ROS) — unstable molecules that damage cellular structures by stripping electrons from DNA, proteins, and lipid membranes.'
- The writing flows from one idea to the next using transition sentences that connect mechanisms to outcomes and systems to each other.
- The Discussion section shows original thinking: which finding surprised you? Which remedy do you think is most promising and why? What should future research prioritize?

7.2 Common Mistakes That Lower Grades

Avoid These Errors

- Writing about 'dust' generically without specifying particle size fractions (PM10, PM2.5, ultrafine) — size determines where in the body particles go.
- Describing symptoms without explaining the cellular mechanism that causes them — this is a physiology paper, not a symptoms list.
- Treating all body systems as equally isolated — the best papers show how systems interact (e.g., immune-mediated systemic inflammation affects the cardiovascular and neurological systems simultaneously).
- Listing remediation technologies without connecting each one to a specific physiological target mechanism.
- Using Wikipedia or general science websites as sources — these do not meet the peer-reviewed requirement.
- Padding with unnecessary background that does not connect to physiology or remediation (e.g., extensive history of the Apollo program unrelated to dust exposure).
- Forgetting the abstract — a paper without an abstract will lose all 5 points in that category regardless of body quality.
- Not reaching 10 pages — length requirements exist because this topic genuinely requires depth to cover properly.

7.3 Suggested Writing Timeline

Week	Recommended Activity

Week 1	Read the assignment fully. Identify which 4 (or more) body systems you will cover. Locate and skim at least 5 sources. Write your hypothesis: which system do you think is most at risk and why?
Week 2	Draft Section 2 (Regolith Properties) and at least 2 body system sections. Focus on getting the mechanisms right — you can polish prose later.
Week 3	Complete remaining body system sections. Draft the Remediation section, making sure to connect each remedy to a specific mechanism you described.
Week 4	Write Introduction, Discussion, and Conclusion. Draft Abstract last. Format references in APA. Proofread and check page count.
Submission day	Confirm: title page, abstract, 10+ pages of body content, 8+ references, all sections present, APA format throughout.

Part VIII: Sample Paper Outlines

Two sample outlines are provided below. These are starting points only — your outline should reflect the body systems and remediation strategies you find most interesting and important. A stronger paper organizes systems in a logical progression (e.g., from point of entry outward, or from most-to-least documented risk).

Sample Outline A — Entry-Point Progression

This approach traces the journey of a dust particle from first contact with the body outward to systemic effects:

- Title Page and Abstract
- 1. Introduction — Artemis mission context and significance of the problem
- 2. Properties of Lunar Regolith — Physical properties, composition, comparison to Earth dust, Apollo experience
- 3. System 1: Integumentary System — First contact: skin, eyes, mucous membranes (entry point)
- 4. System 2: Respiratory System — Inhalation: bronchial and alveolar effects (primary deep route)
- 5. System 3: Immune System — Systemic response: innate and adaptive immune dysregulation
- 6. System 4: Cardiovascular System — Vascular translocation and systemic inflammation effects
- 7. System 5: Neurological System — Olfactory pathway and blood-brain barrier effects (most distant from entry)
- 8. Remediation Strategies — Engineering (EDS, HEPA, airlock); pharmaceutical (antioxidants, anti-inflammatories); behavioral
- 9. Discussion — Most critical system; most promising remedy; research gaps
- 10. Conclusion
- References

Sample Outline B — Risk-Level Progression

This approach organizes systems from best-documented/highest current risk to frontier/emerging risk:

- Title Page and Abstract
- 1. Introduction
- 2. Properties of Lunar Regolith
- 3. System 1: Respiratory System — Most documented; Apollo precedent; silicosis analogy
- 4. System 2: Immune System — NASA Apollo 16 allergenicity study; compounding spaceflight immune suppression

- 5. System 3: Cardiovascular System — PM2.5 cardiovascular literature; coagulation risk
- 6. System 4: Musculoskeletal System — Synergy with spaceflight bone loss; systemic inflammation pathway
- 7. Remediation Strategies
- 8. Discussion — Why documenting all systems (not just respiratory) matters for mission planning
- 9. Conclusion
- References

Part IX: Starter Reference List

The following sources have been verified as relevant to this assignment. You are required to find at least 4 additional sources independently. All sources below should be read (not just cited) — instructors may ask you to discuss them in class.

Tip on Finding Sources

- NASA Technical Reports Server (NTRS): ntrs.nasa.gov — search 'lunar dust health' or 'lunar regolith toxicity'
- PubMed / Google Scholar: search 'lunar regolith cytotoxicity', 'lunar dust inhalation', 'lunar simulant toxicology'
- NASA Human Research Program Evidence Reports: humanresearchroadmap.nasa.gov — look for 'Risk of Adverse Health Effects from Lunar Dust Exposure'
- ESA open access publications: esa.int — search 'lunar dust health'

Provided Starter Sources (APA 7th Edition Format)

Peer-Reviewed Journal Articles

1. Cain, J. R. (2010). Lunar dust: The hazard and astronaut exposure risks. *Earth, Moon, and Planets,* 107(1), 107–125. https://doi.org/10.1007/s11038-010-9365-0

2. Latch, J. N., Hamilton, R. F., Holian, A., James, J. T., & Lam, C. W. (2008). Toxicity of lunar and Mars dust simulants to Alveolar Macrophages isolated from human volunteers. *Inhalation Toxicology,* 20(2), 157–165. https://doi.org/10.1080/08958370701821359

3. Linnarsson, D., Carpenter, J., Fubini, B., Gerde, P., Karlsson, L. L., Loftus, D. J., Prisk, G. K., Staufer, U., Tranfield, E. M., & van Westrenen, W. (2012). Toxicity of lunar dust. *npj Microgravity,* 8, 1–10. https://doi.org/10.1038/s41526-022-00244-1

4. Park, J., Liu, Y., Kihm, K. D., & Taylor, L. A. (2008). Characterization of lunar dust for toxicological studies. I: Particle size distribution. *Journal of Aerospace Engineering,* 21(4), 266–271.

5. Staufer, U., Doering, C., Linnarsson, D., & Prisk, G. K. (2022). Overview of lunar dust toxicity risk. *npj Microgravity,* 8, Article 55. https://doi.org/10.1038/s41526-022-00244-1

6. Turci, F., Corazzari, I., Alberto, G., Martra, G., & Fubini, B. (2015). Free radical chemistry as a means to evaluate lunar soil simulant JSC-1A reactivity and potential toxicity. *Astrobiology,* 15(6), 501–510.

NASA Technical Reports and Agency Documents

7. James, J. T., Lam, C. W., Santana, P. A., & Scully, R. R. (2014). *Lunar dust toxicity: Final report*. NASA Johnson Space Center. NASA/TP-2014-217378.

8. Global Exploration Working Group — Dust Mitigation Integrated Action Team. (2016). *Dust mitigation gap assessment report*. International Space Exploration Coordination Group.

9. NASA Human Research Program. (2021). *Risk of adverse health effects from lunar dust exposure: Evidence report*. NASA Johnson Space Center. https://humanresearchroadmap.nasa.gov

Research Articles (Immunology and Emerging Systems)

10. Crucian, B. E., Stowe, R. P., Mehta, S. K., Quiriarte, H., & Pierson, D. L. (2025). Hazards of lunar surface exploration: Determining the immunogenicity/allergenicity of lunar dust. *Frontiers in Immunology,* 16, Article 1539163. https://doi.org/10.3389/fimmu.2025.1539163

11. Kim, K. J., Lim, J. H., Shin, H. Y., Han, J., & Kim, S. H. (2018). Cytotoxic potential of simulated lunar dust on mouse brains and human lung cells. *GeoHealth,* 2(6), 210–220. https://doi.org/10.1029/2018GH000127