

## 737-7/8/9 Elevator Control System Description and Safety Analysis

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## 1. INTRODUCTION

### 1.1 PURPOSE

The purpose of this document is to provide a description of the Elevator Control Systems for the 737-7/-8/-9 (737 MAX) family of airplanes and to show compliance with applicable CFRs and CSs. This document is to be distributed to certification agencies and internally for coordination with other organizations.

### 1.2 SCOPE

This document is intended to describe the Elevator System operations, implementation, operator interface and systems interfaces. Compliance to applicable CFRs and CSs is shown along with supporting analysis as needed. Even though the control systems are essentially unchanged from previous 737 models, this document describes the implementation of the elevator control system for the 737 MAX family. (b) (4)

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Significant changes to either the airplane configuration, certification (i.e., amended type certificate (ATC)) or the flight controls design from the original 737-700/800/900ER type certification are discussed in this document.

### 1.3 SUMMARY

This safety analysis was developed to ensure the safety of the 737 MAX Elevator Control System design and to show compliance with certification agency requirements. As a result of this analysis, it is concluded that the 737 MAX Elevator Control System complies with all applicable CFRs and CSs.

The Functional Hazard Assessment (FHA) in Section 4 categorizes the severity of the potential hazards to the airplane and identifies those for which compliance will be shown numerically. Pilots evaluated the airplane handling qualities in the flight simulator as part of the hazard evaluation.

The Failure Modes and Effects Analysis (FMEA) in Section 5 ensures that Continued Safe Flight and Landing (CSF&L) is possible without requiring exceptional pilot skill or strength following any single failure. Each single failure meets the requirements of the CFRs and CSs.

The Fault Tree Analysis (FTA) in Section 6 ensures that multiple failures which prevent CSF&L or which require exceptional pilot skill or strength are extremely improbable in the elevator system, and that those resulting in Hazardous effects are extremely remote. Each of the failure scenarios identified as either Catastrophic or Hazardous by the Functional Hazard Assessment (Section 4) meets the necessary probability requirements of the CFRs and CSs.

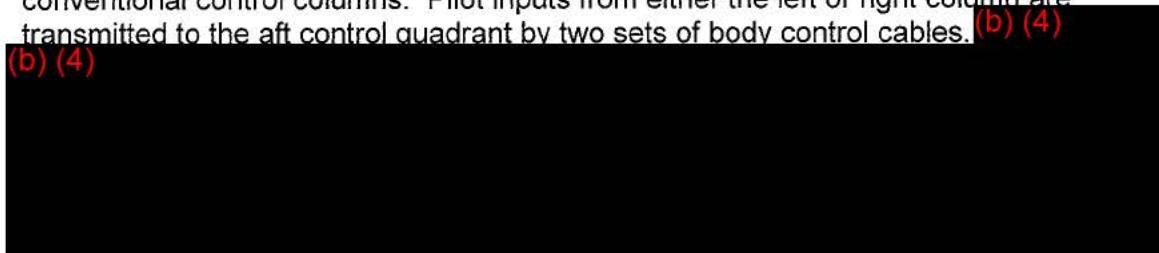
## 2. ELEVATOR CONTROL SYSTEM DESCRIPTION

Pitch control on the 737-7,-8,-9 (MAX) is accomplished using the elevators located on the horizontal stabilizer, see Figure 2-1. Elevator position changes are affected either manually by the captain and/or first officer deflecting the control column or automatically through the autopilot.

### 2.1 Elevator System Overview

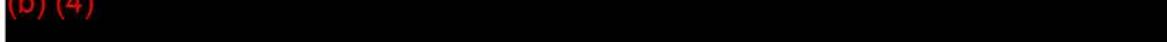
Control of the 737 MAX elevators by the captain and first officer is provided by a set of conventional control columns. Pilot inputs from either the left or right column are transmitted to the aft control quadrant by two sets of body control cables. (b) (4)

(b) (4)



Manual control of the elevators is inherently provided if both full time hydraulic systems are failed. (b) (4)

(b) (4)

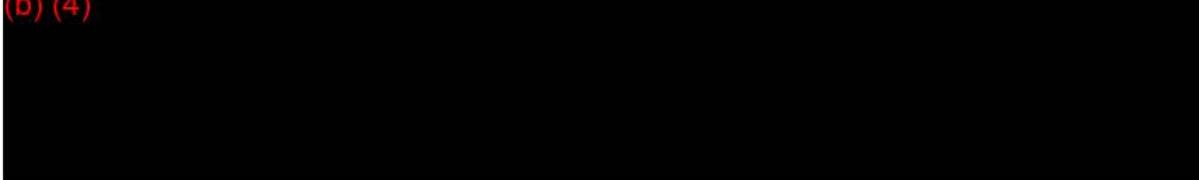


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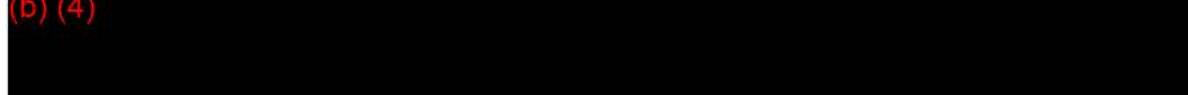
Indication of A and B system feel pressure disagreement is provided through an indication light in the flight deck overhead panel.

(b) (4)



Each elevator has three aerodynamic balance panels and a tab. (b) (4)

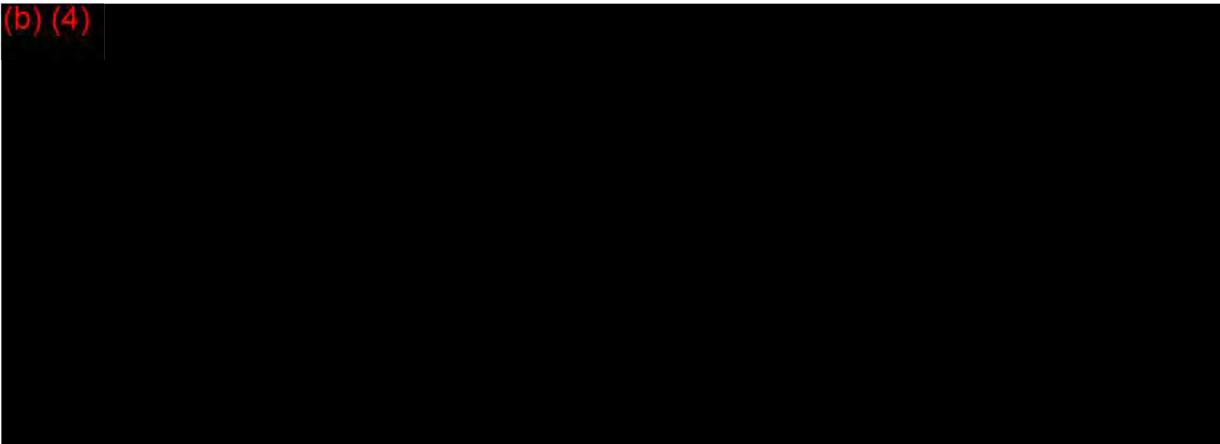
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(b) (4)



## 2.2 Pilot Interfaces

Pilot interfaces for the elevator control system are shown in Figure 2-5 through 2-8 and include:

### 2.2.1 Control Column

The Captain and First Officer control aircraft pitch with a conventional control column. To affect the pitch or attitude of the airplane nose up, the control column must be pulled back. To affect the pitch or attitude nose down, the control column must be pushed forward.

### 2.2.2 Trim Control and Position Indication

Pitch trim is controlled by the Stabilizer Trim System. (b) (4)

(b) (4)



### 2.2.3 Autopilot Control Switches

Autopilot control switches and warning lights are located on the glare shield mounted autopilot mode control panel. An autopilot disengage switch is located on each control wheel. (b) (4)

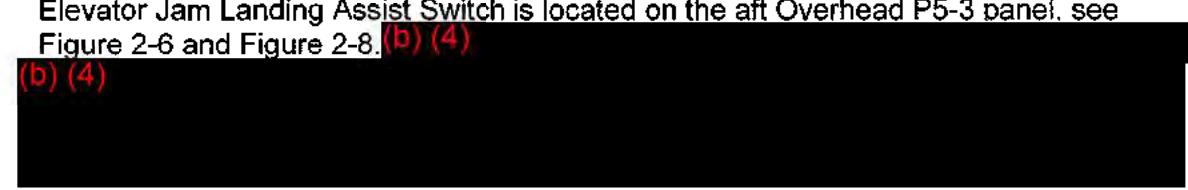
### 2.2.4 Hydraulic Systems A and B Switches

Hydraulic power to the primary flight control surfaces can be independently controlled through the Flight Control A and B switches, located on the forward overhead panel (P5); see Figure 2-6 and Figure 2-7.

### 2.2.5 Elevator Jam Landing Assist Switch

Elevator Jam Landing Assist Switch is located on the aft Overhead P5-3 panel, see Figure 2-6 and Figure 2-8. (b) (4)

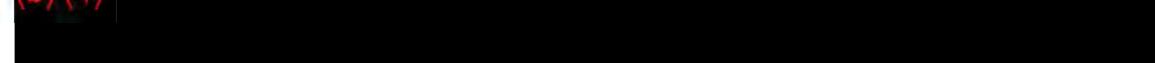
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### 2.2.6 Flight Deck Annunciations

A flight controls low pressure warning provides an indication of elevator, aileron and rudder low pressure. (b) (4)

(b) (4)



A feel differential pressure light (amber) is provided on the forward overhead control panel. (b) (4)

(b) (4)

A Mach trim light (amber) is provided on the forward overhead control panel and is driven by the FCC. (b) (4)

An ASSIST ON light is provided on the aft overhead panel to provide annunciation of activation of the Direct Lift Control function and is driven by the Spoiler Control Electronics (SCE). (b) (4)

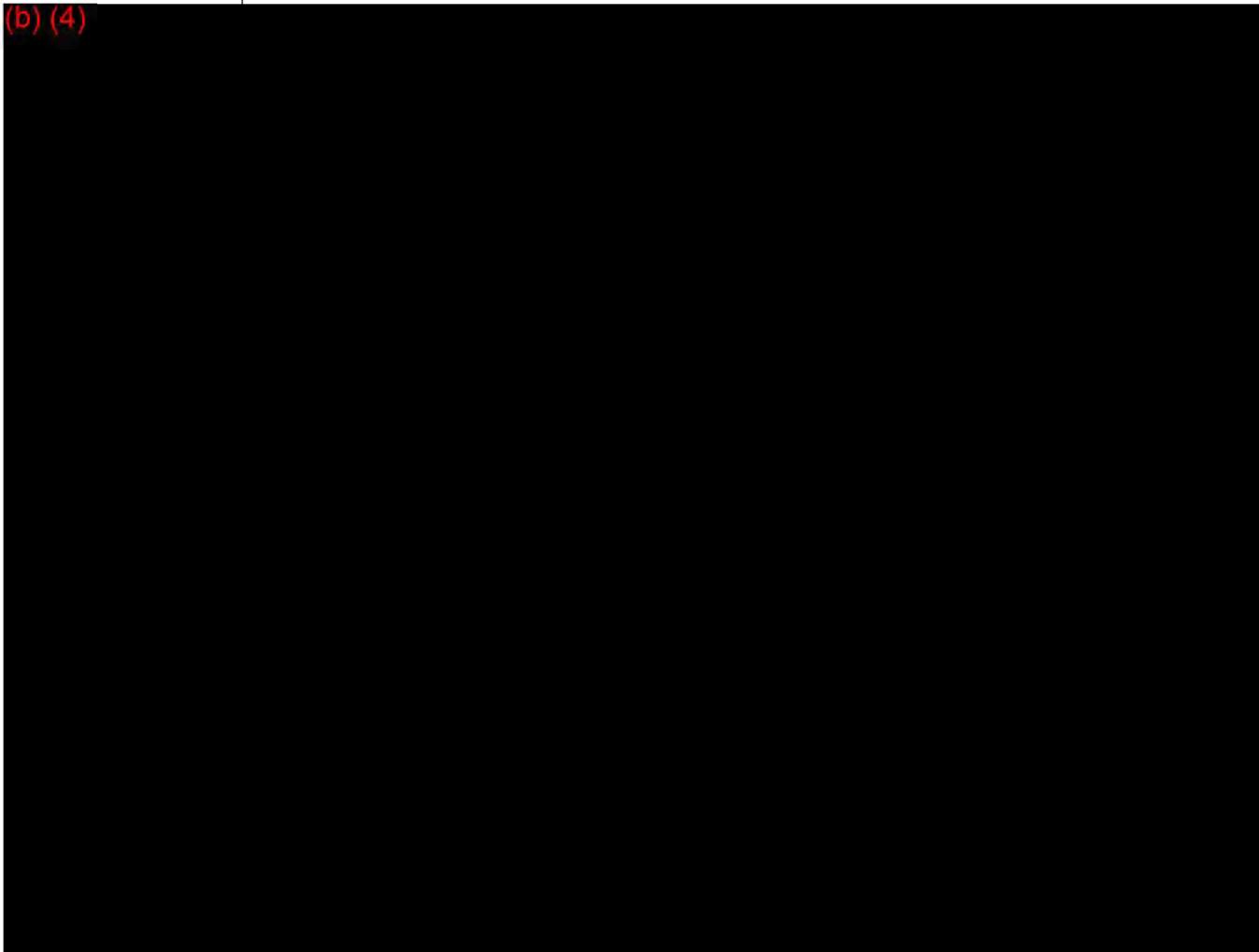
A stick shaker is fitted to each control column to alert the pilot to an impending stall condition. A Stall Identification system (Stall ID) is complementary to the stall warning system. The stick shakers and Stall ID system are controlled by the Stall Management and Yaw Damper (SMYD) Computer. (b) (4)

## 2.3 Maintenance Operations

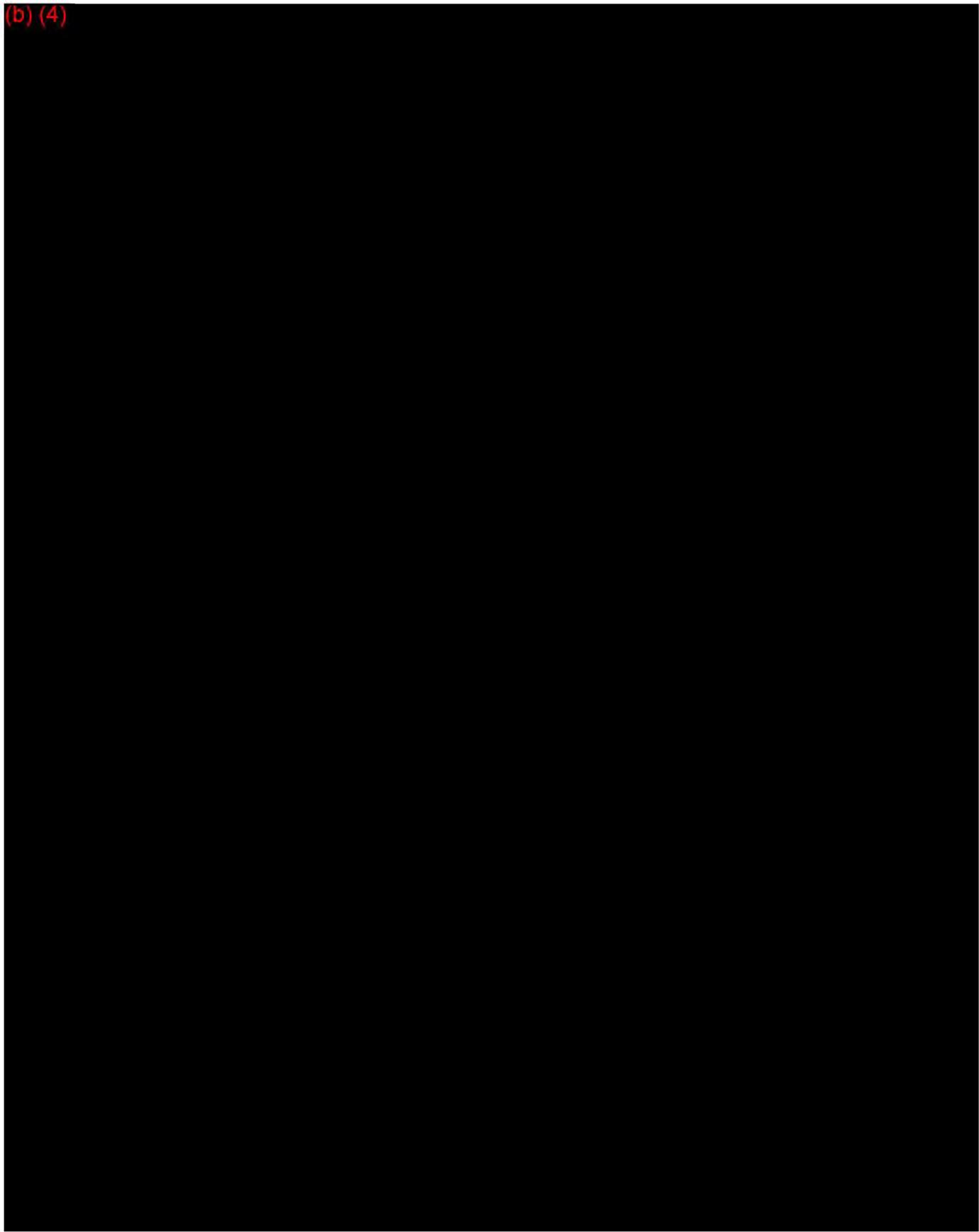
For maintenance operations details for the 737 MAX airplanes please refer to the Maintenance Training Manual (b) (4) and the Maintenance Planning Document.

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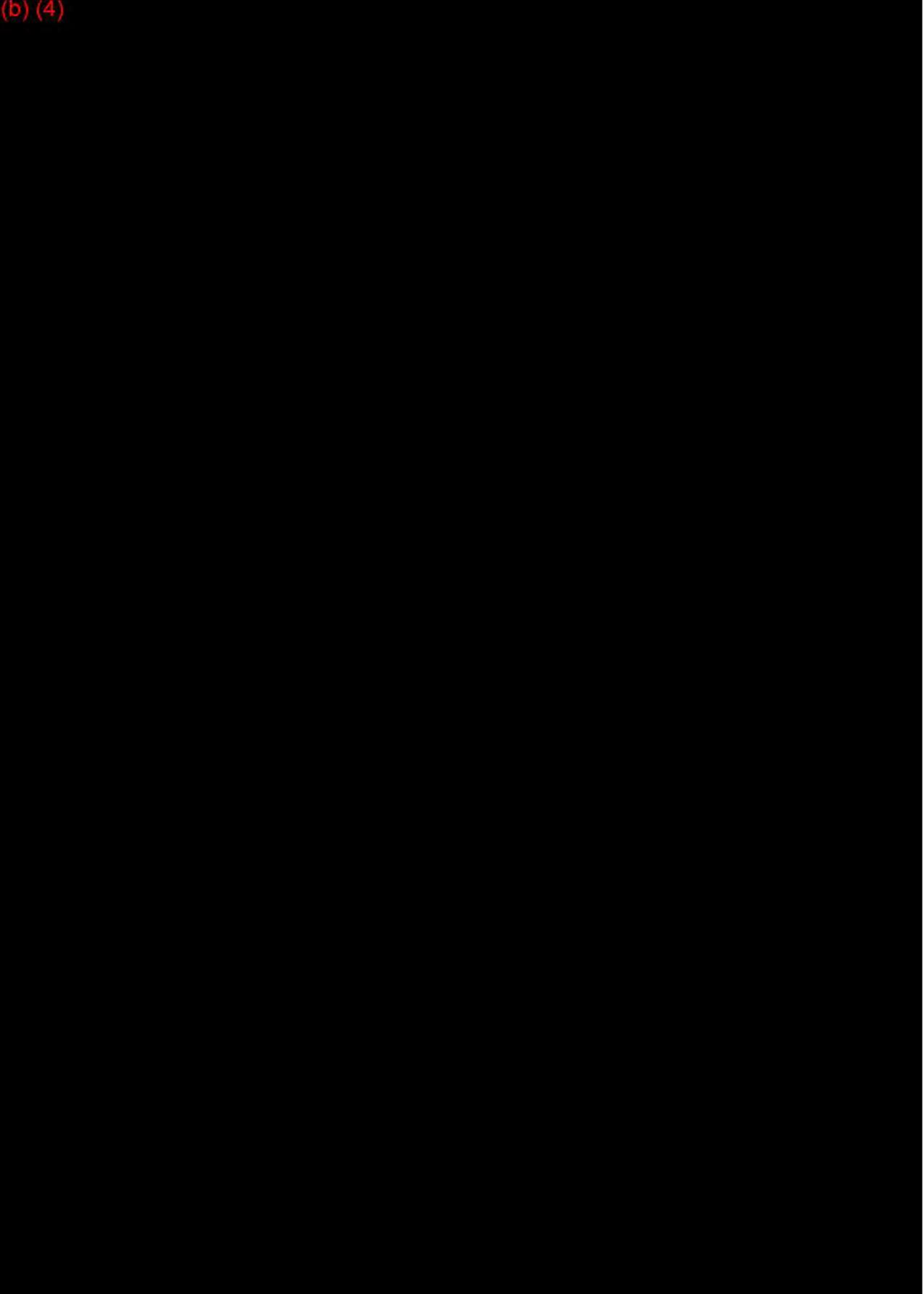
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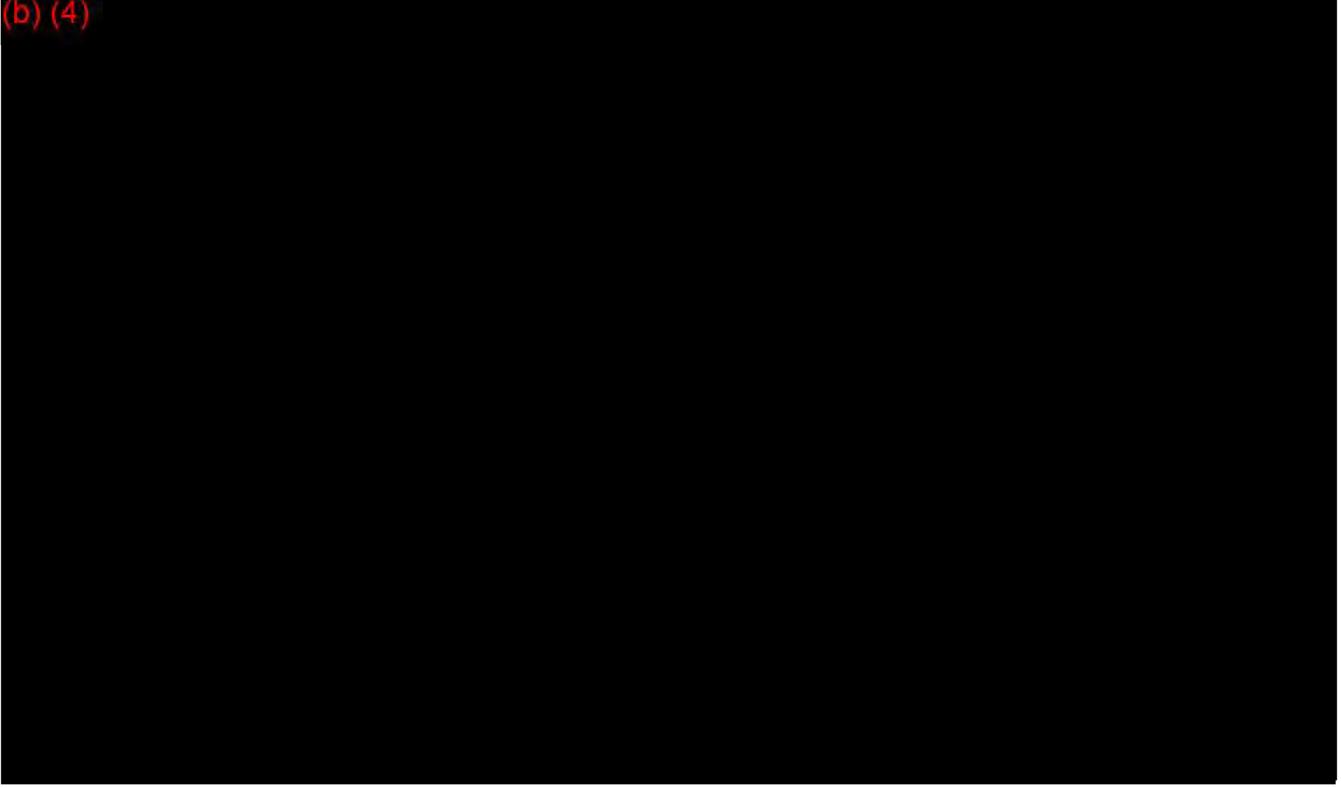
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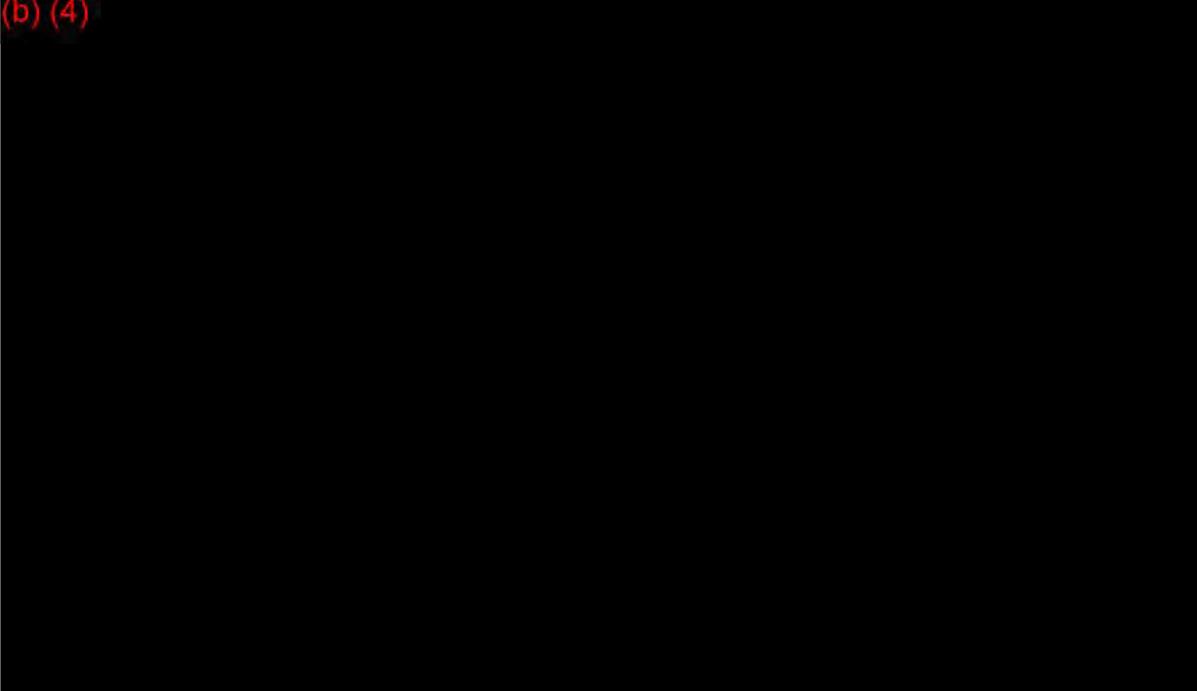


## 2.5 Functional Elements

### 2.5.1 Control Columns and Forward Quadrant

The captain's and first officer's control column are identical in operation and are connected together (b) (4). The captain's column is connected to the left cable system through the forward control quadrant and the first officer's column is connected to the right cable system.

(b) (4)



(b) (4)



#### 2.5.2 Cable Runs

The left and right cable runs are routed between the forward control quadrants and the aft quadrants attached to the input torque tube. (b) (4)

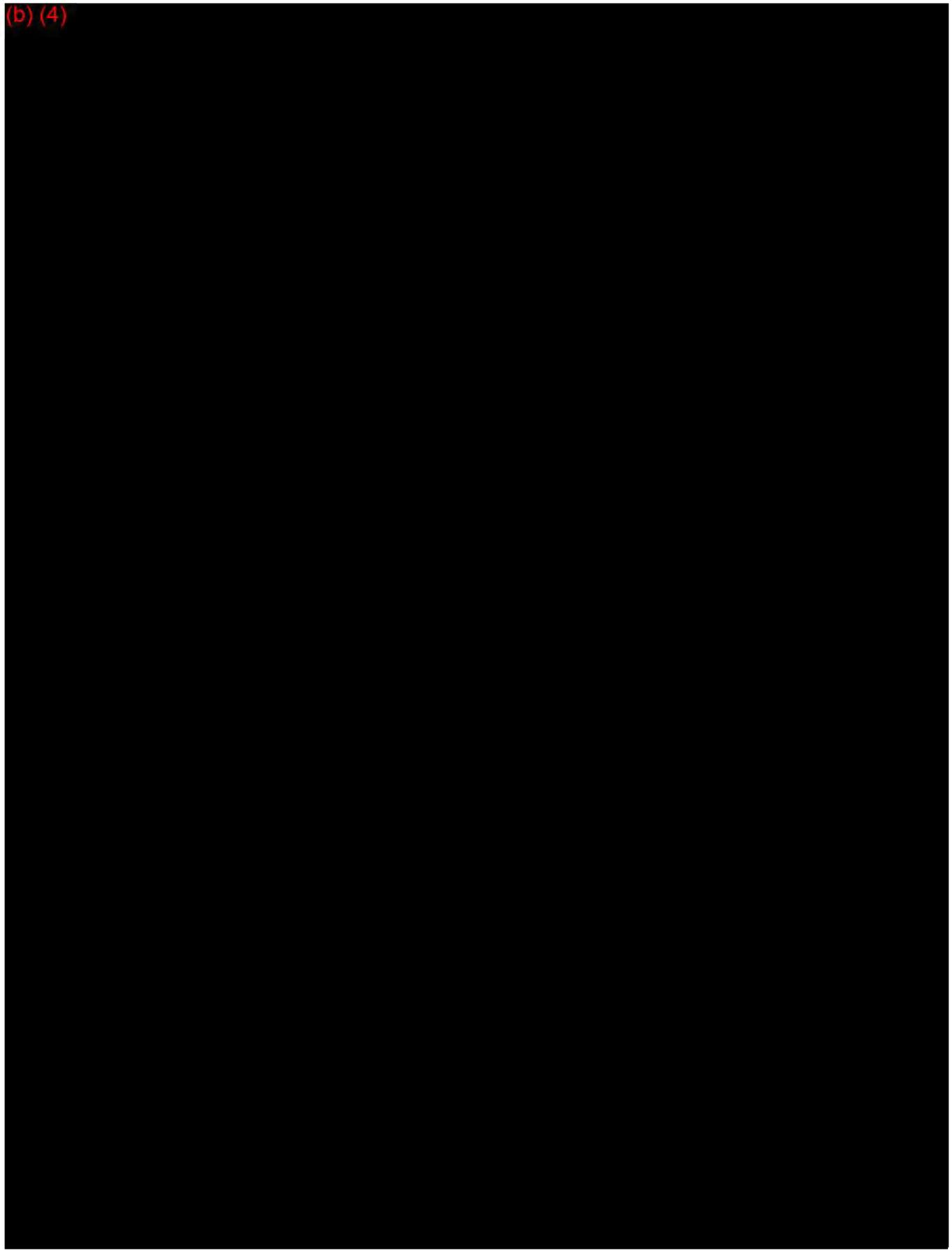
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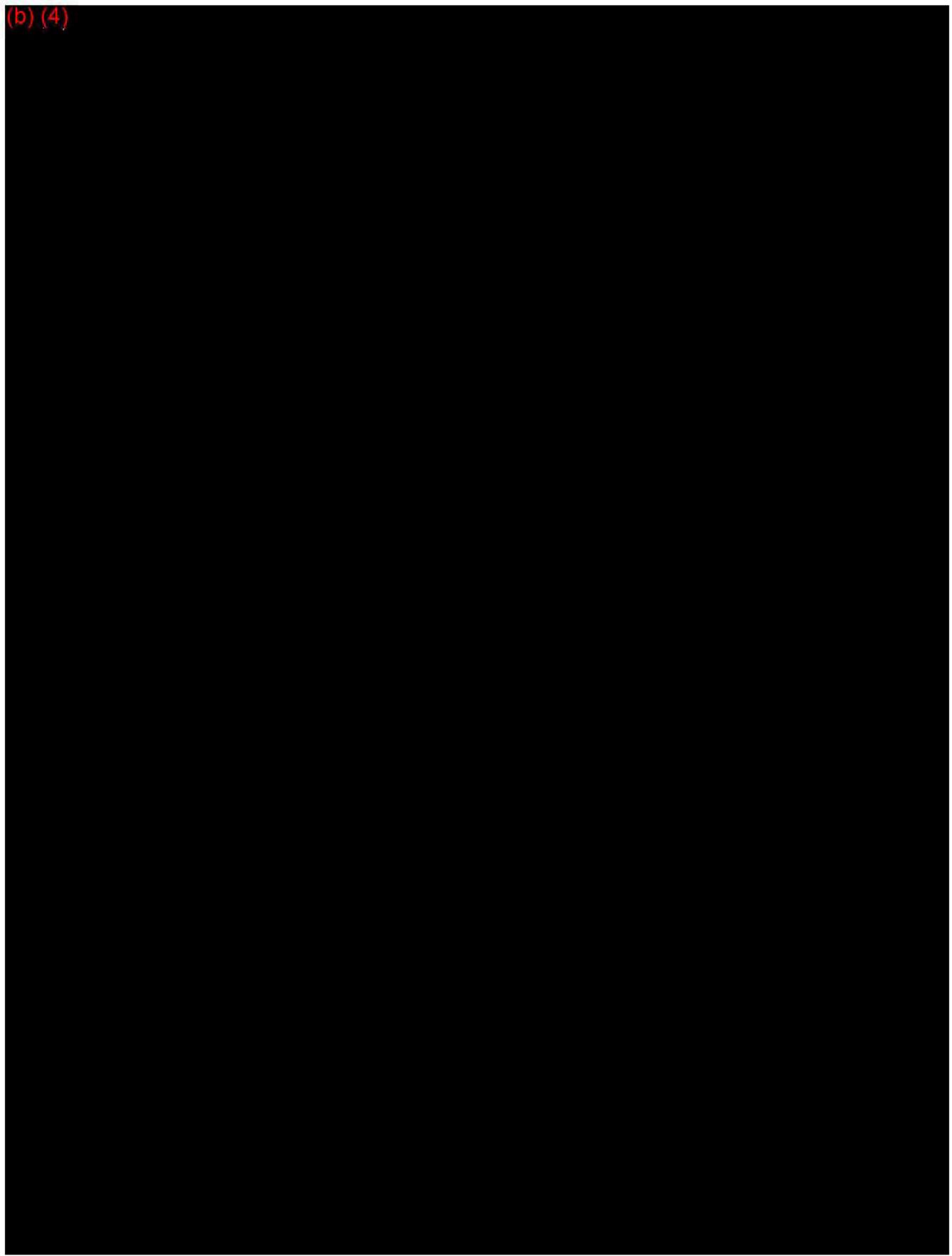
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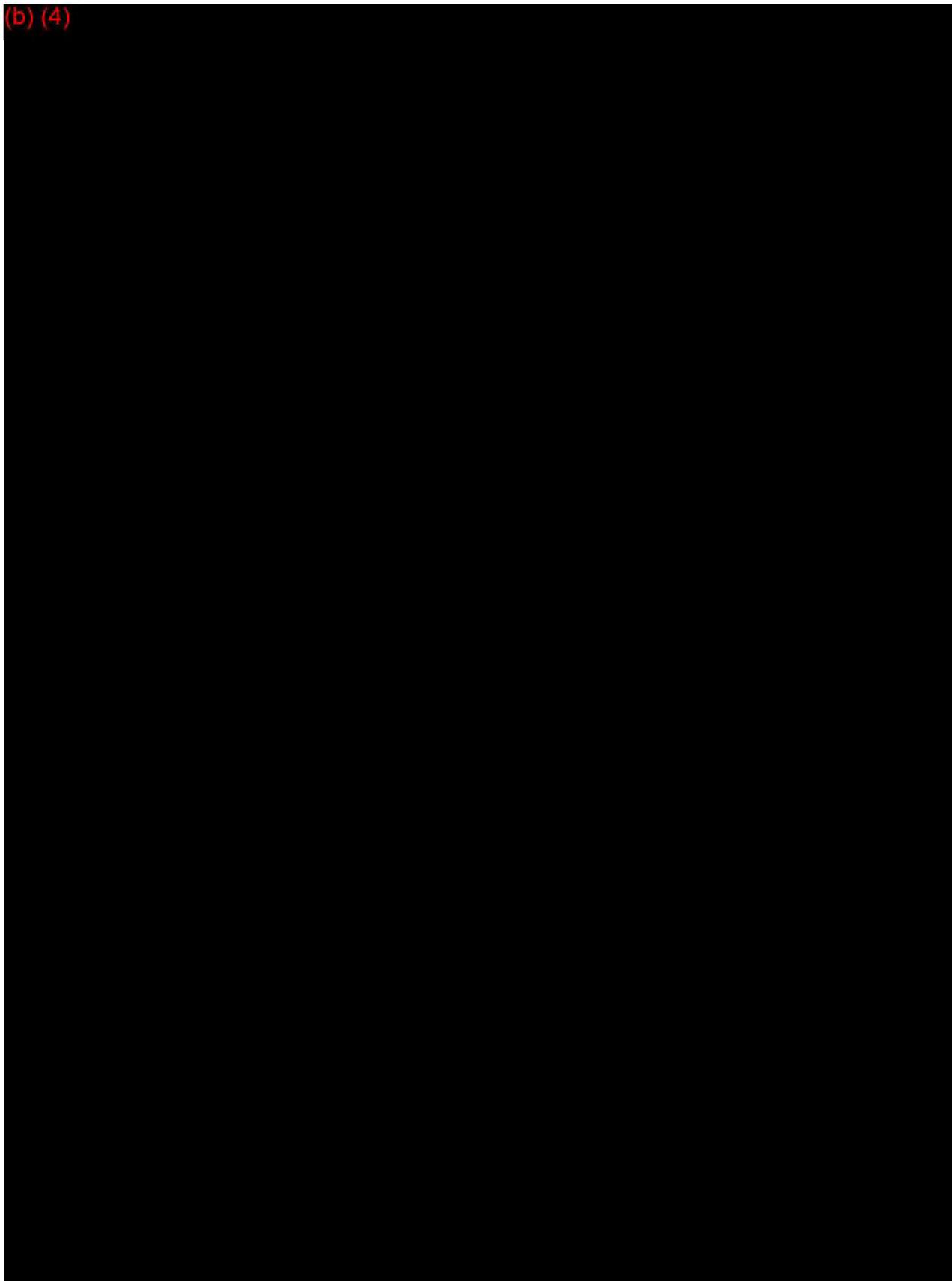
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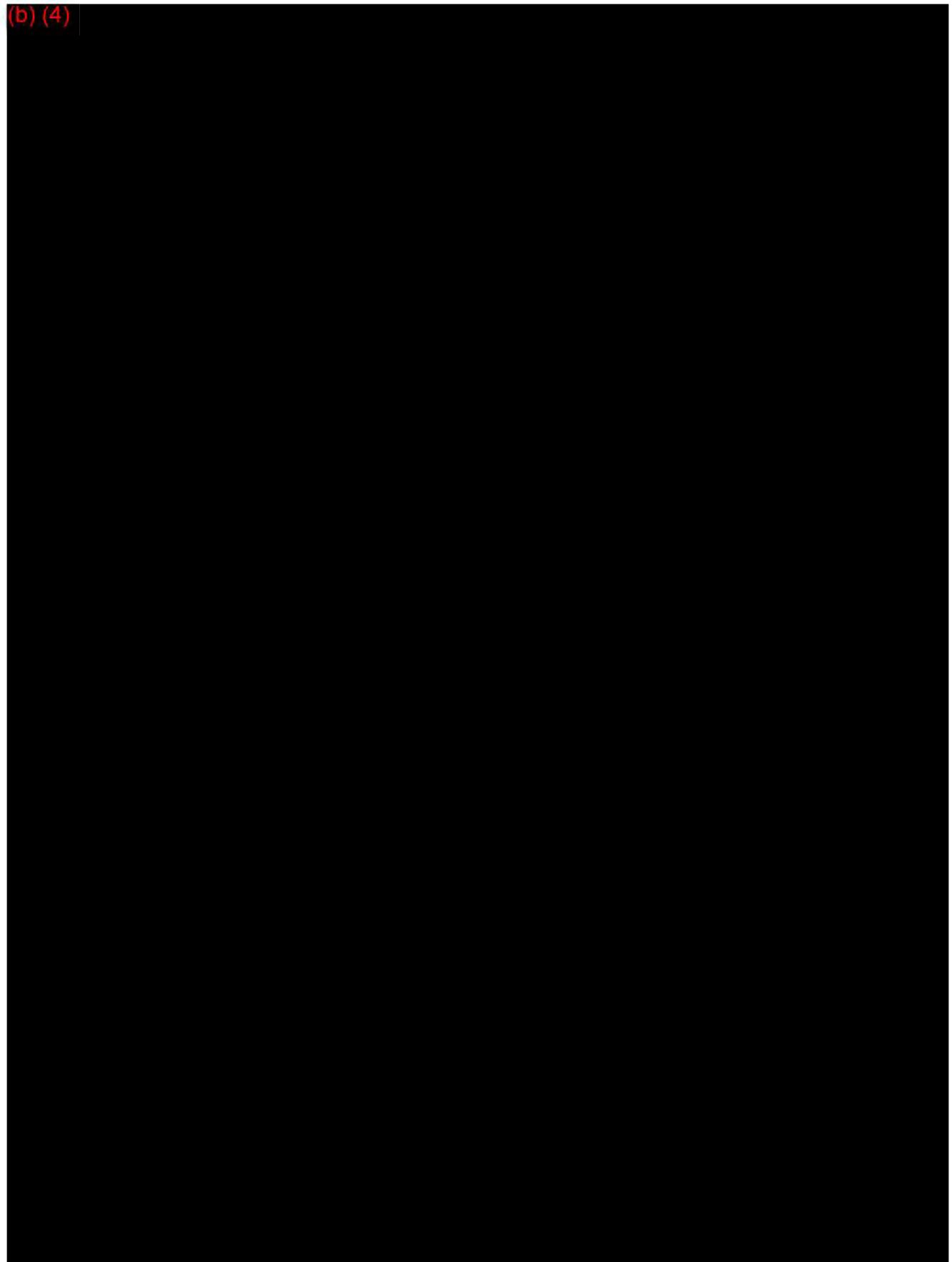
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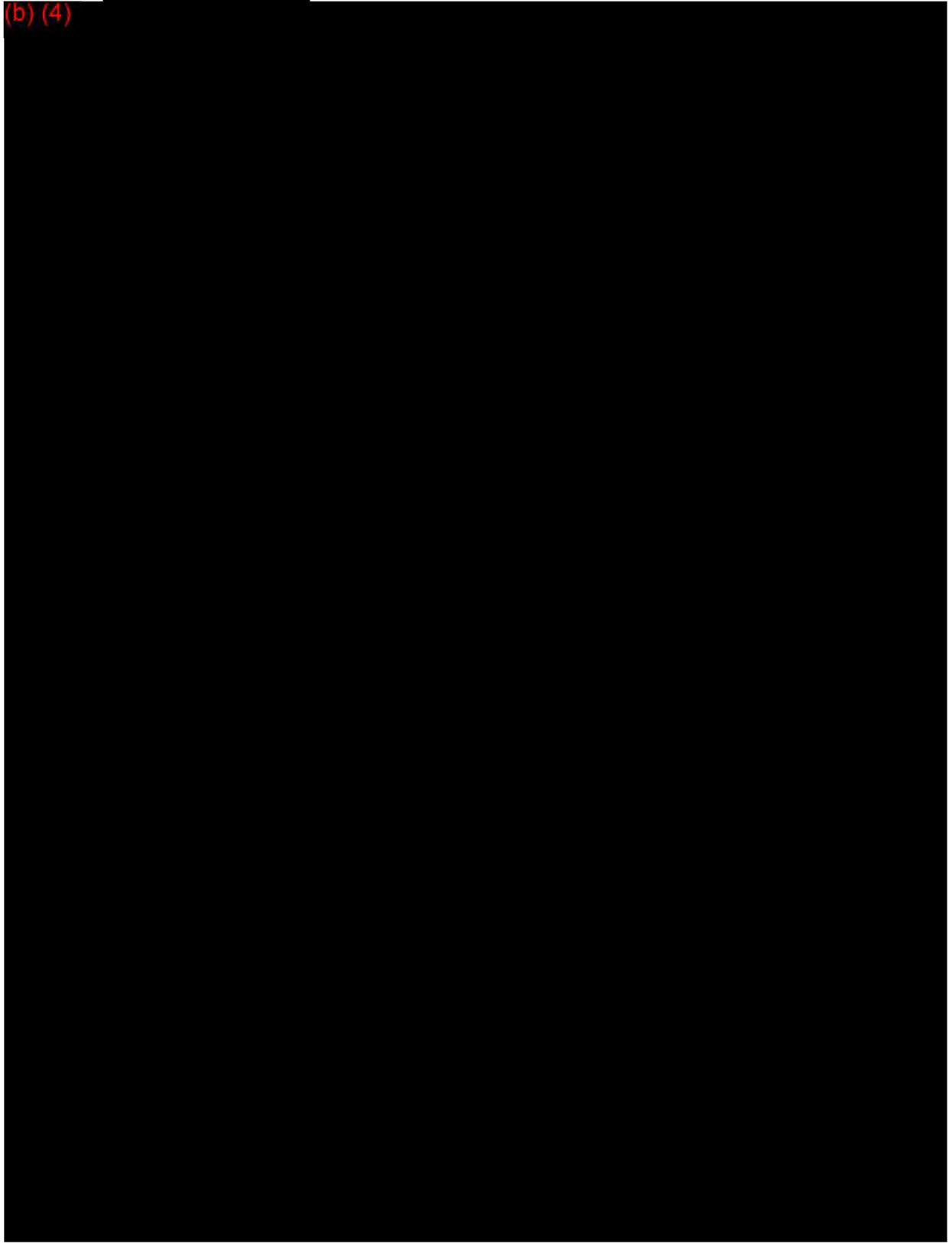
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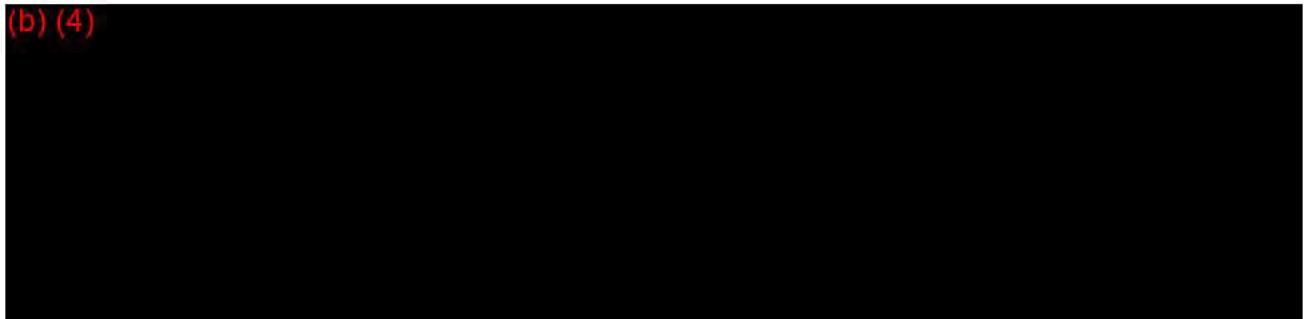
### 2.5.5 Elevator Control Surface

Each elevator surface is installed with a tab, three balance panels and mass balance weights(b) (4)

(b) (4)



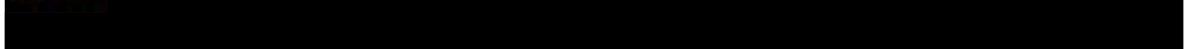
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## 2.5.7 Elevator Feel & Centering Unit

Artificial column feel forces are produced by the feel and centering unit which uses variable hydraulic feel pressure in combination with a centering cam and spring. (b) (4)

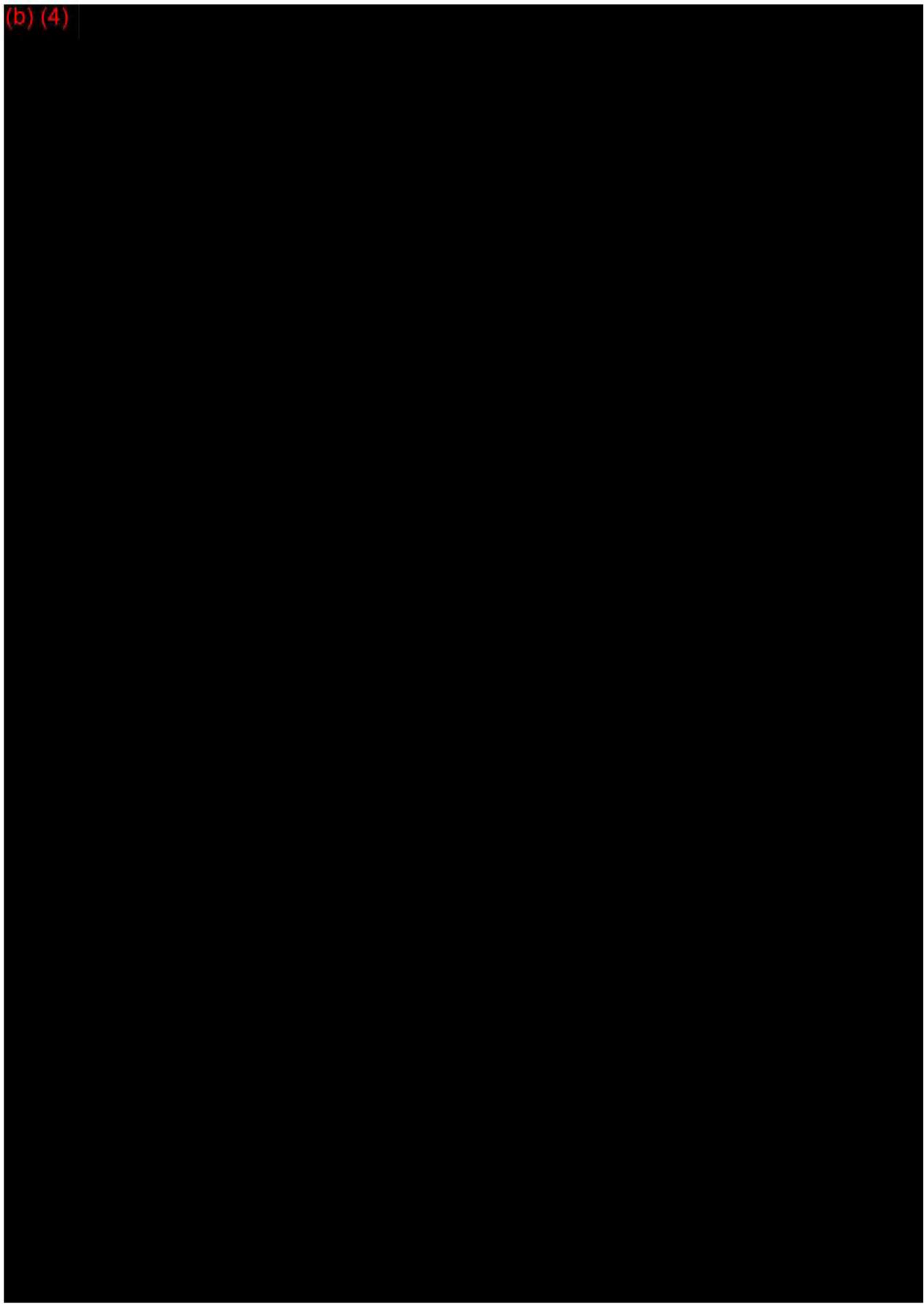
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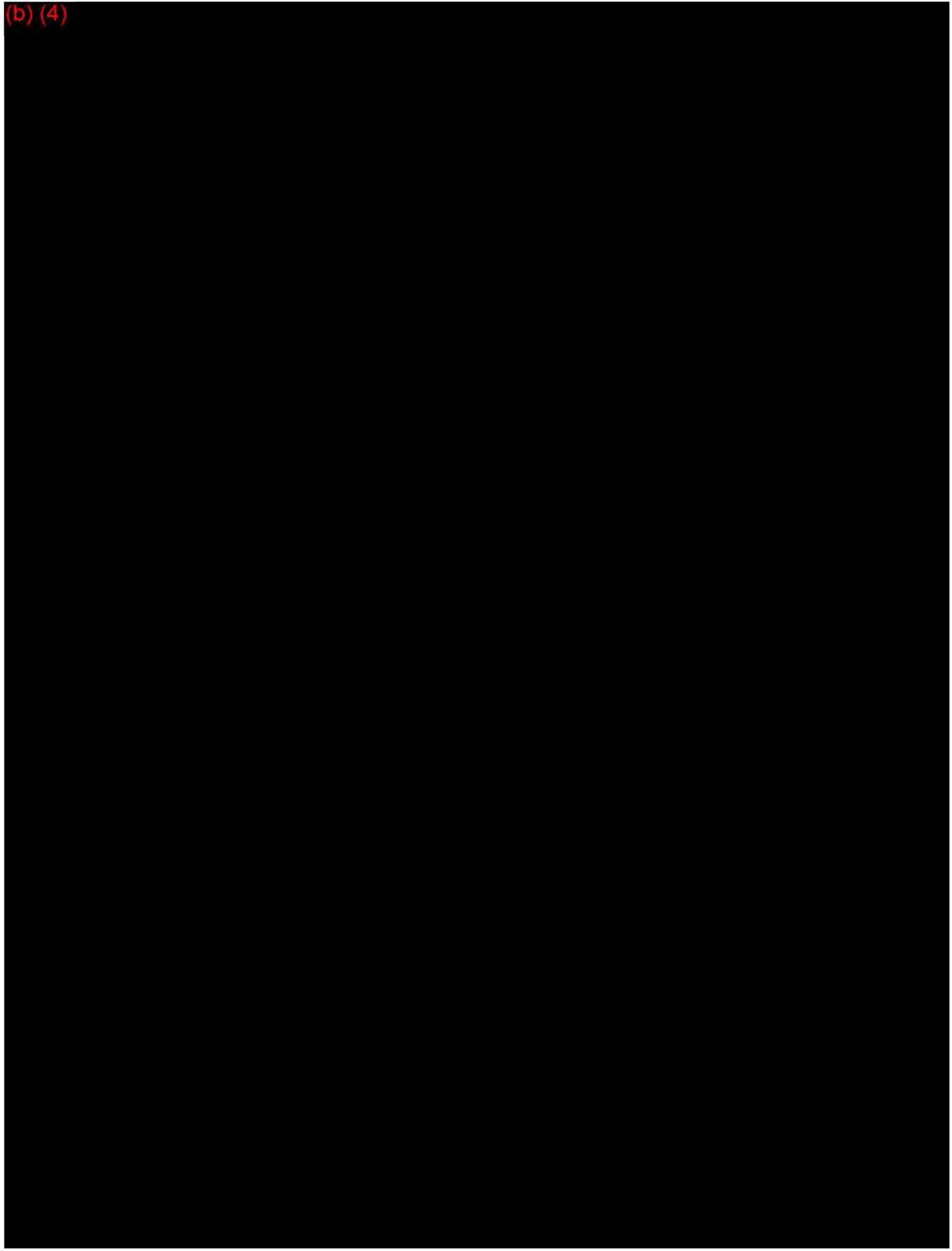
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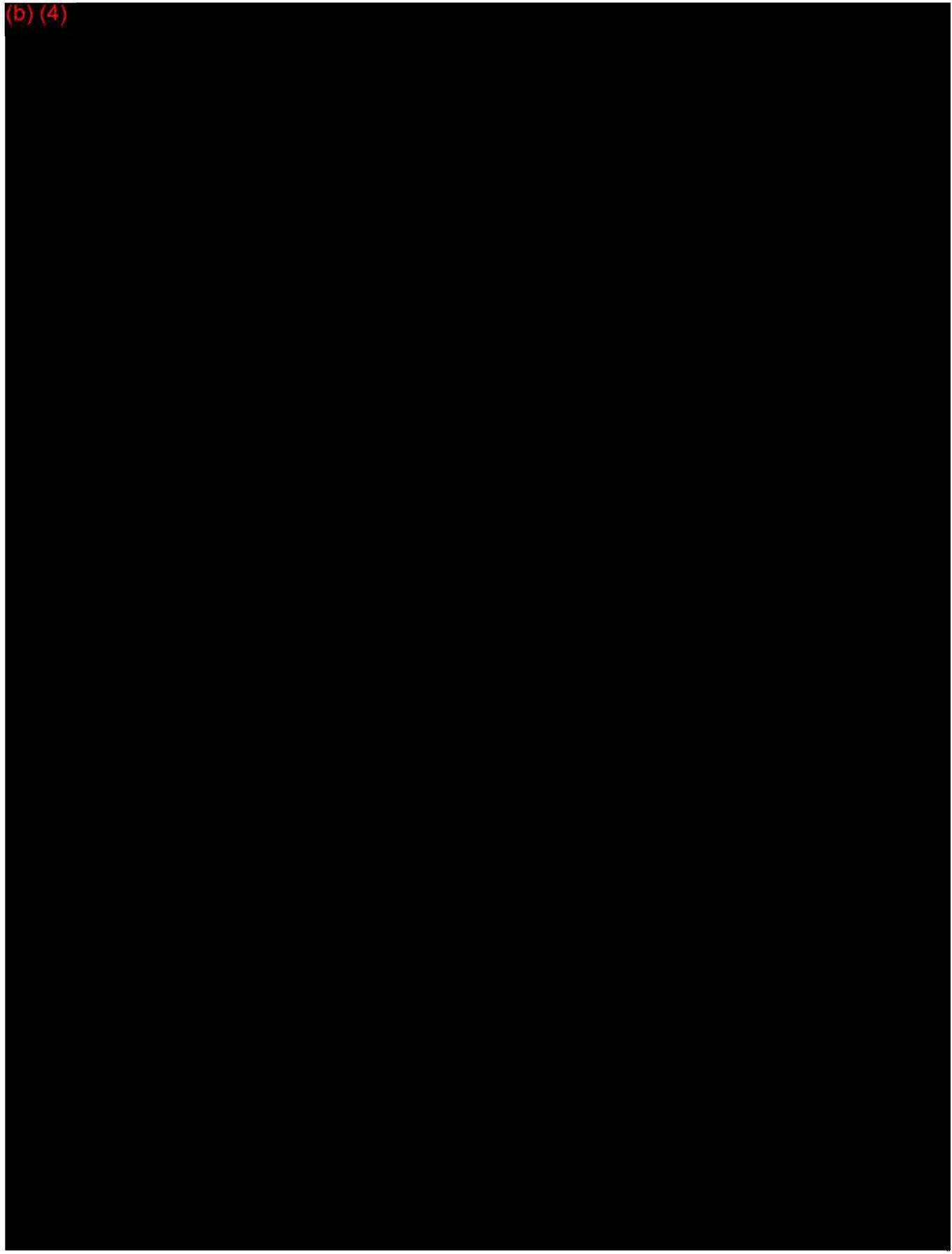
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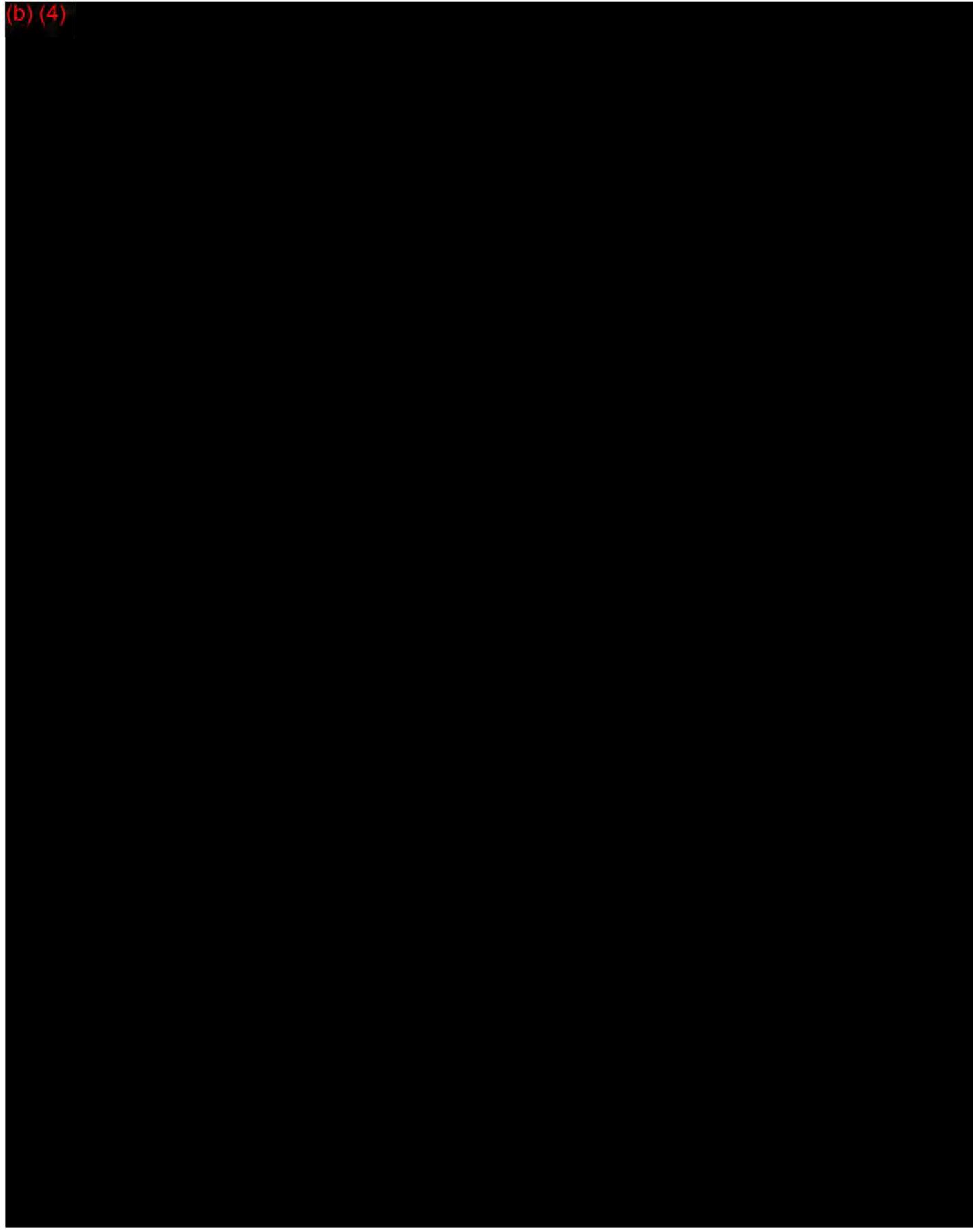
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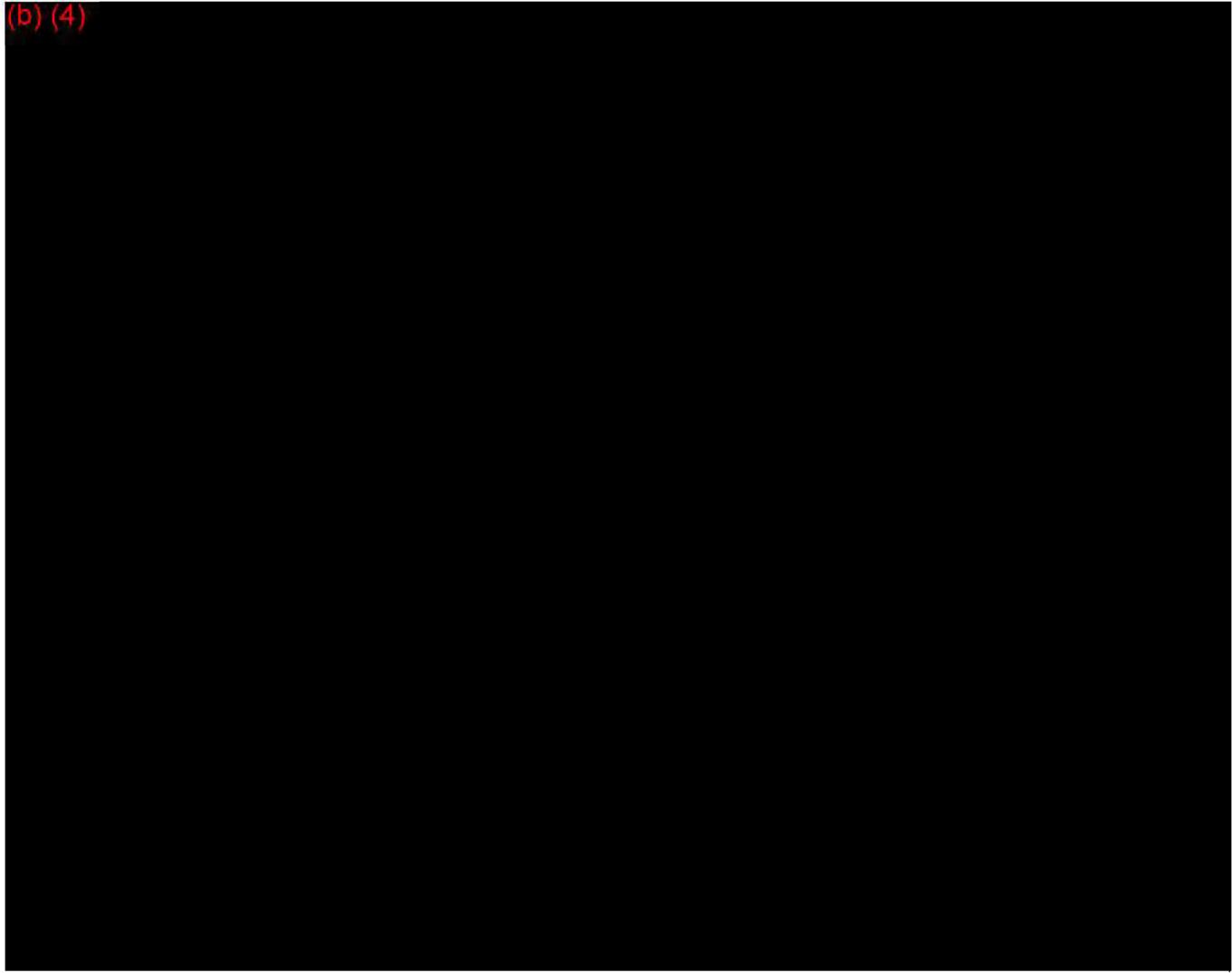
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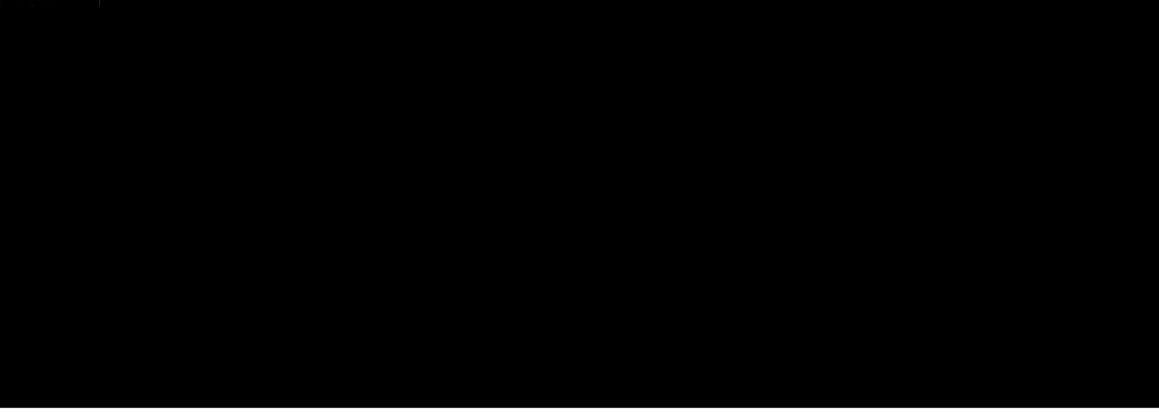
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#### 2.5.13 Elevator Failure Annunciation

Indication lights for the elevator system are located on the flight deck overhead panels, see Figure 2-6, Figure 2-7 and Figure 2-8. (b) (4)

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## 2.6 System Interfaces

### 2.6.1 Hydraulic System Interface

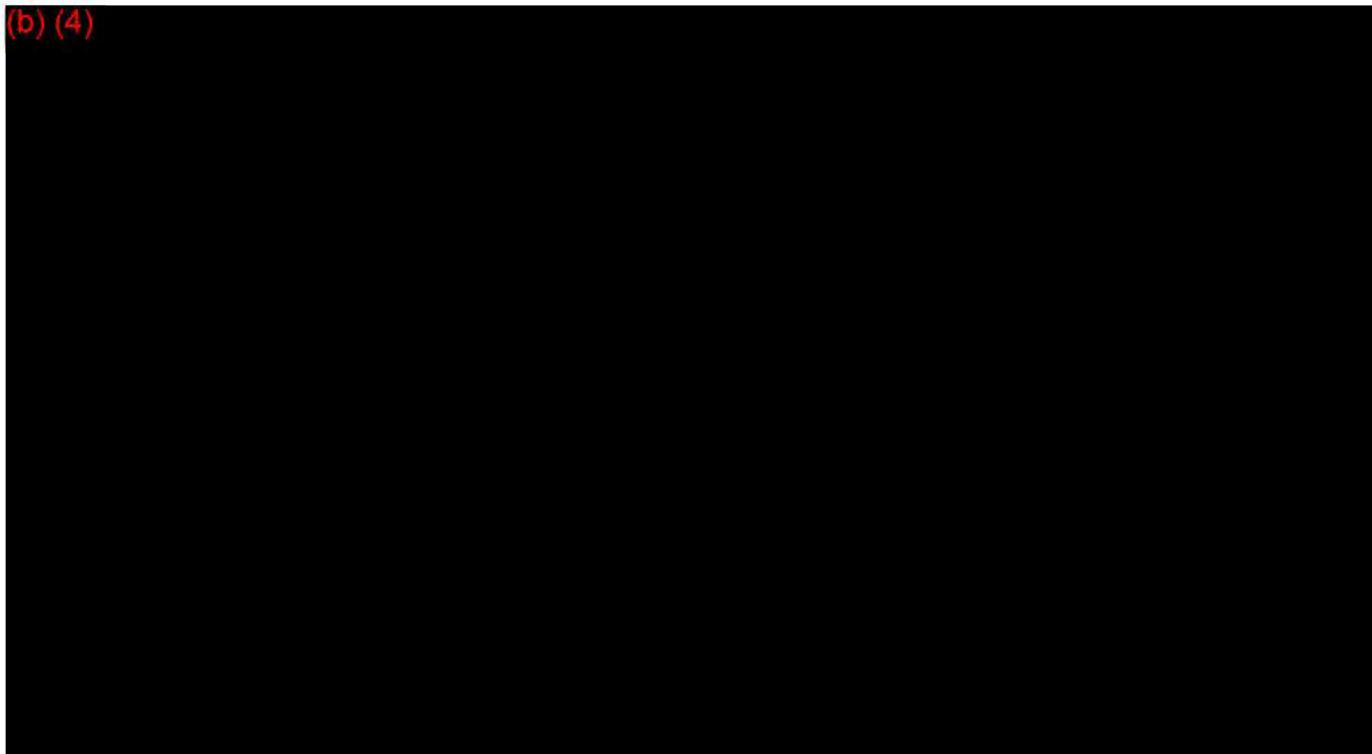
The right elevator PCU is powered by hydraulic system B and the left elevator PCU is powered by hydraulic system A.(b) (4)

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### 2.6.3 Flight Data Recorder Interface

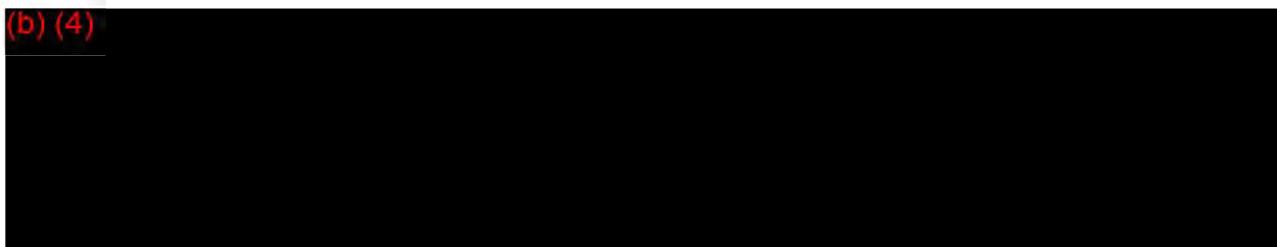
The following elevator system components are connected to the Digital Flight Data Acquisition Unit (DFDAU):

Parameter	(b) (4)
Captain Column Position	
First Officer Column Position	
Captain Column Force	
First Officer Column Force	
Left Elevator Position	
Right Elevator Position	
Autopilot Command	
Autopilot Servo Position	
Aft Quadrant Position	
Mach trim actuator command	
Mach trim actuator position	

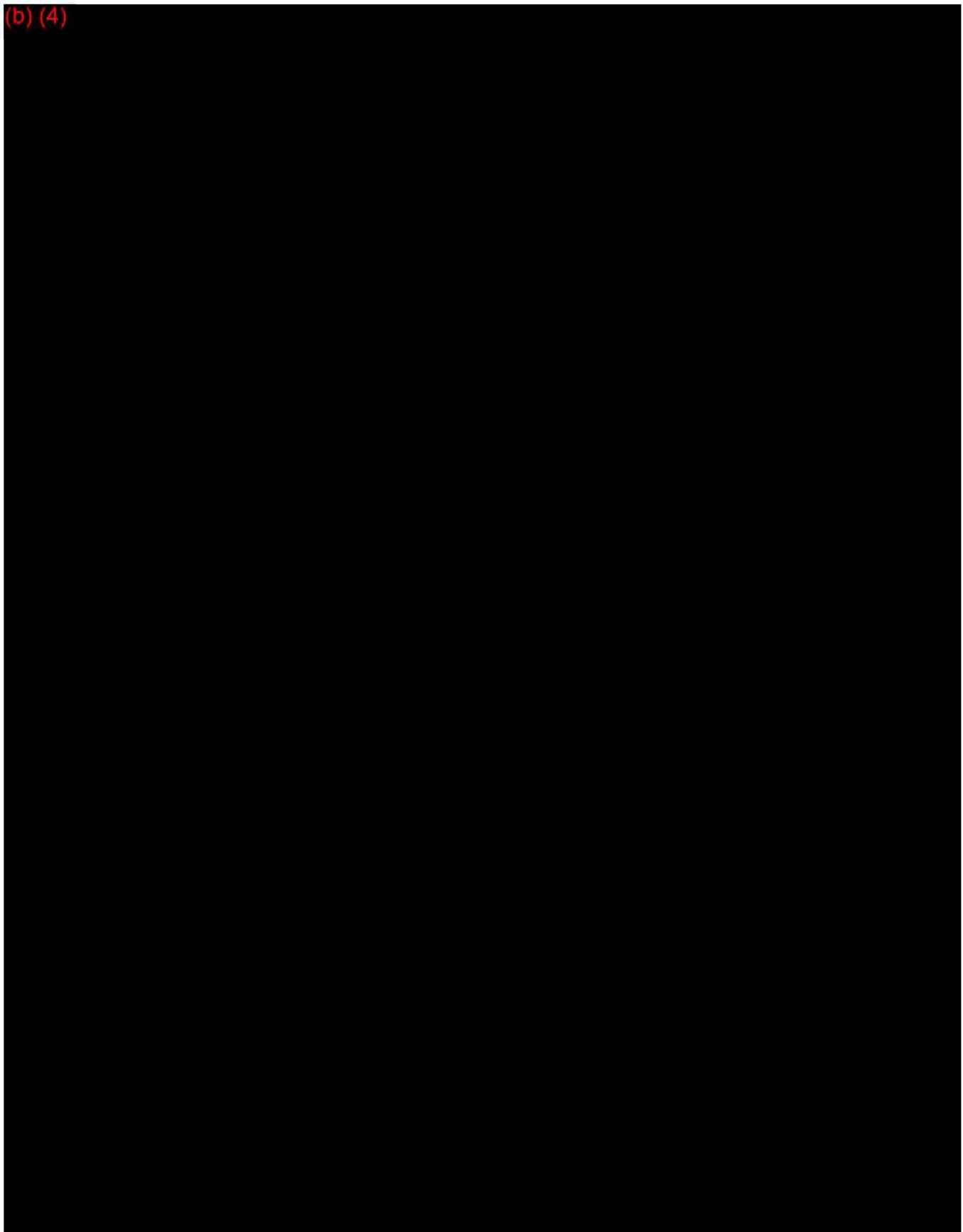
### 2.7 Differences From 737-700/800/900ER Models

This section describes the differences in the elevator control systems between the 737-7/-8/-9 MAX models and the 737-700/800/900ER Models.

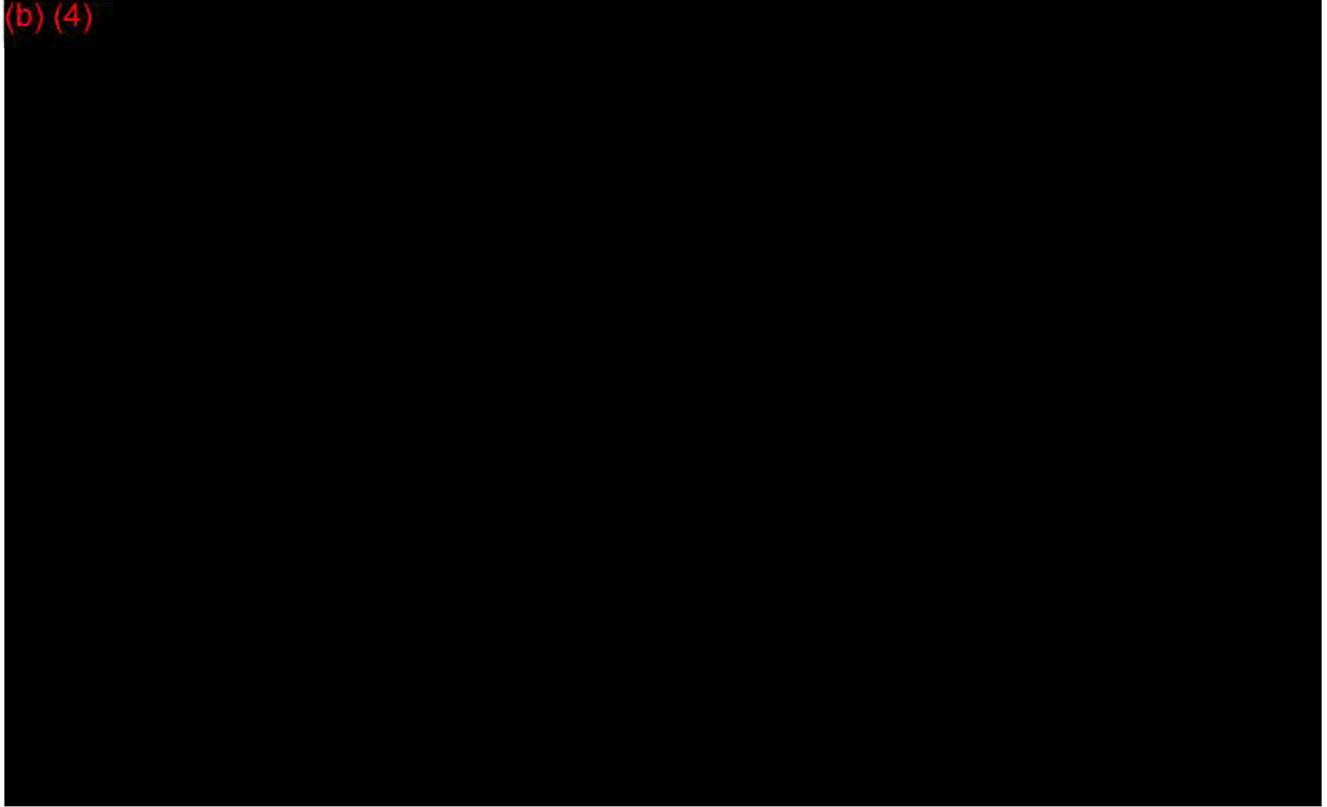
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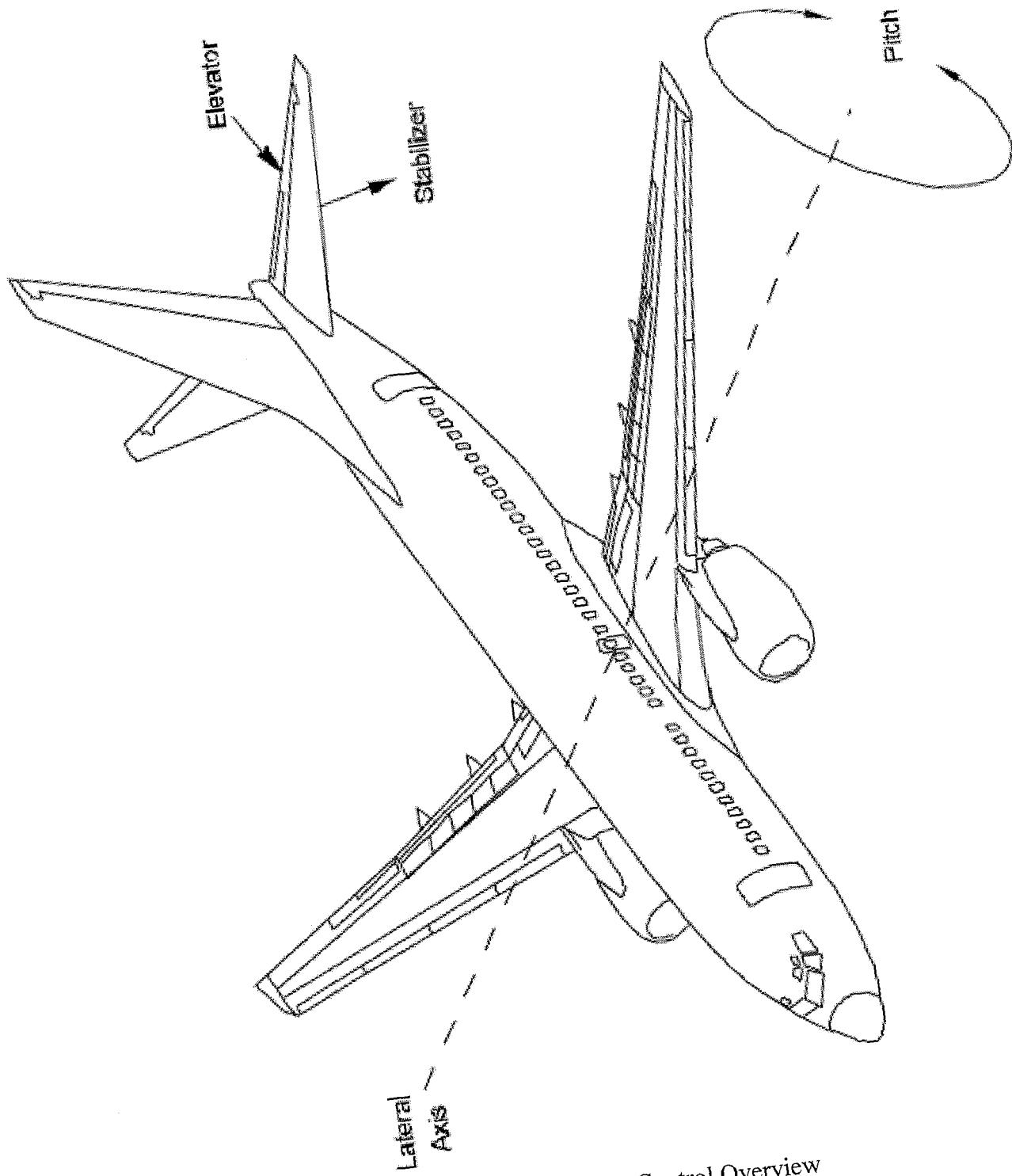
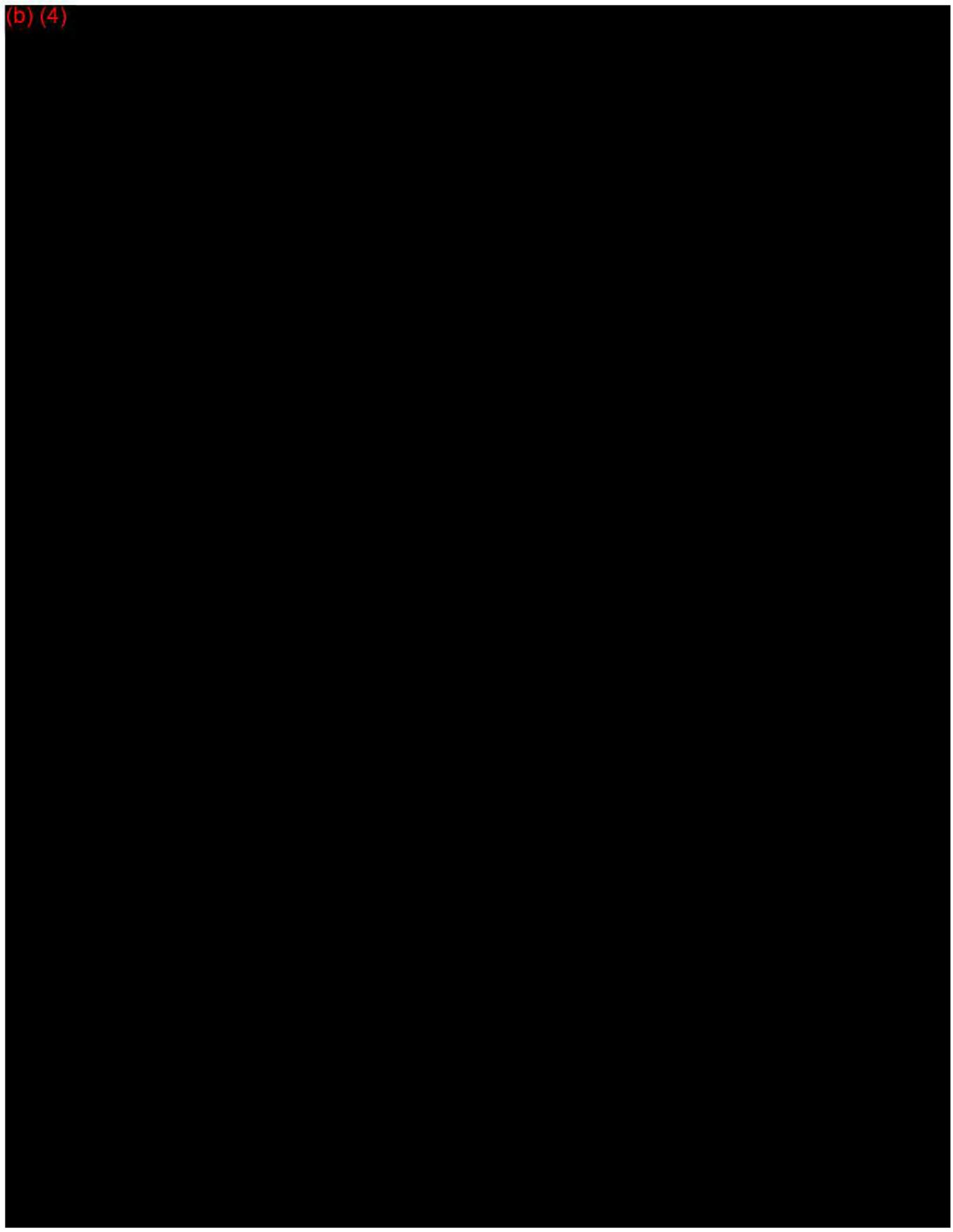
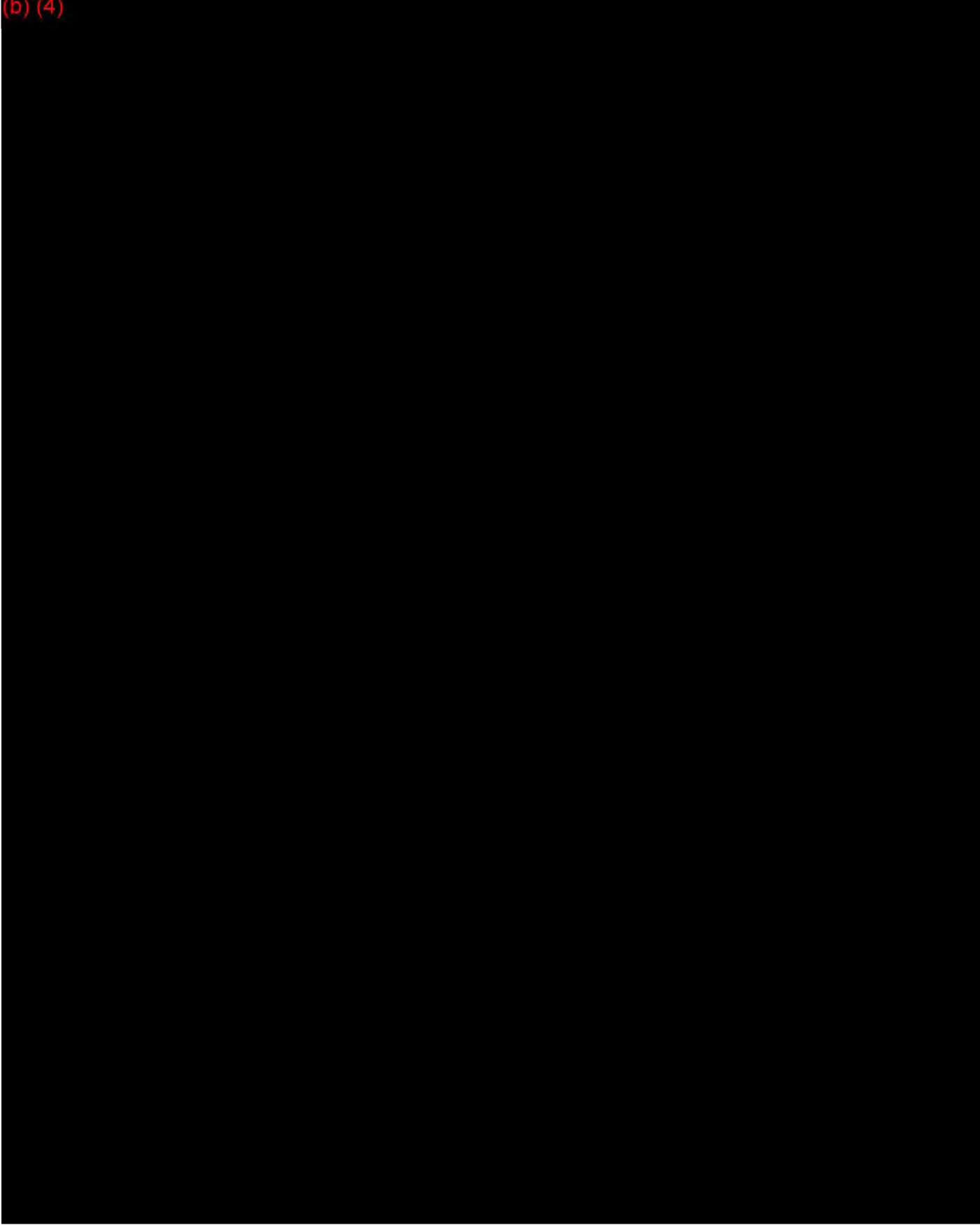


Figure 2-1 Elevator Pitch Control Overview

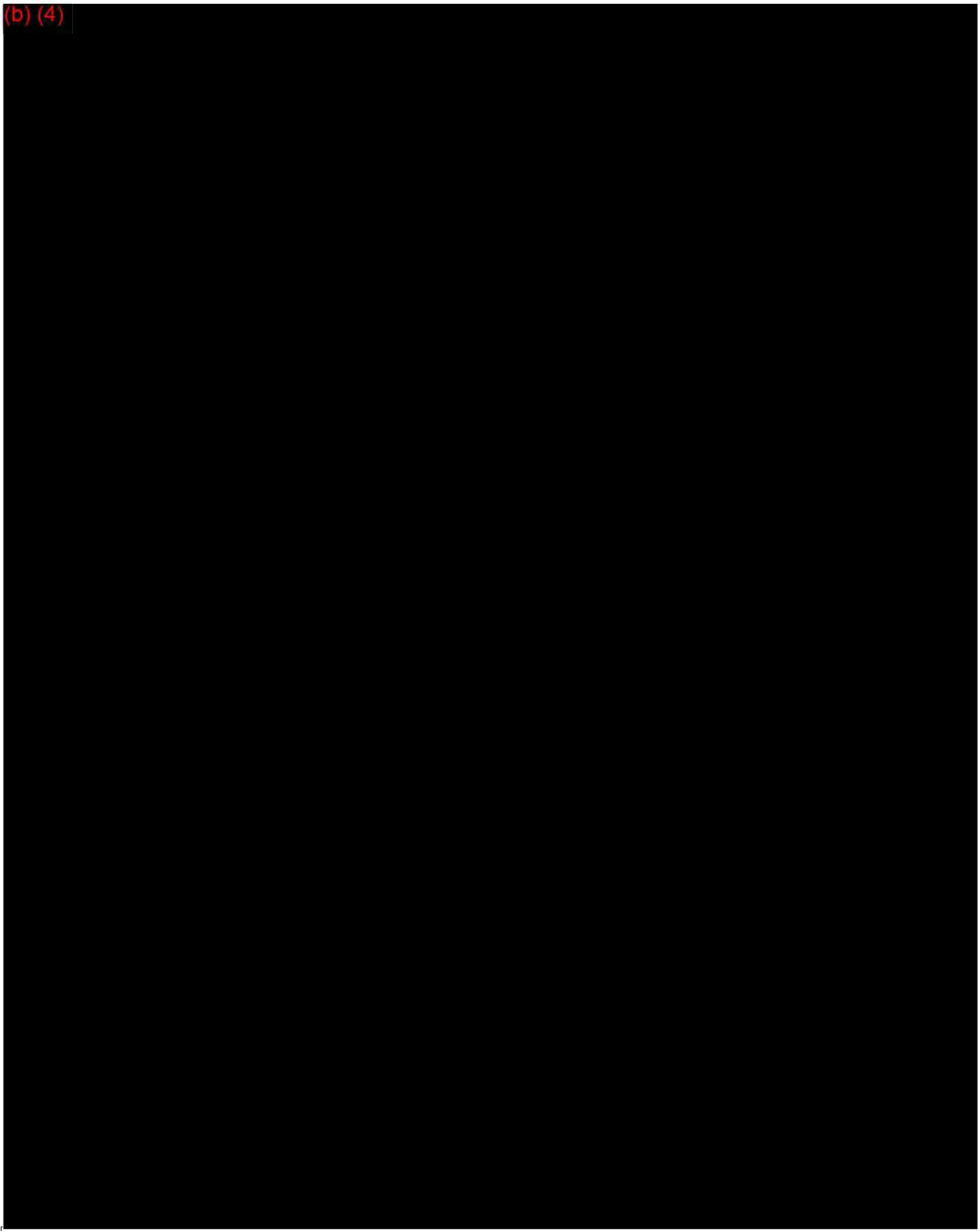
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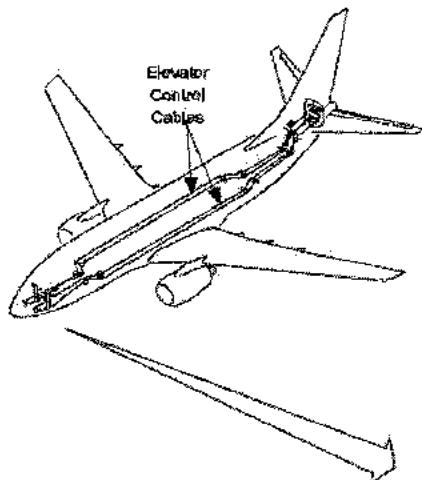


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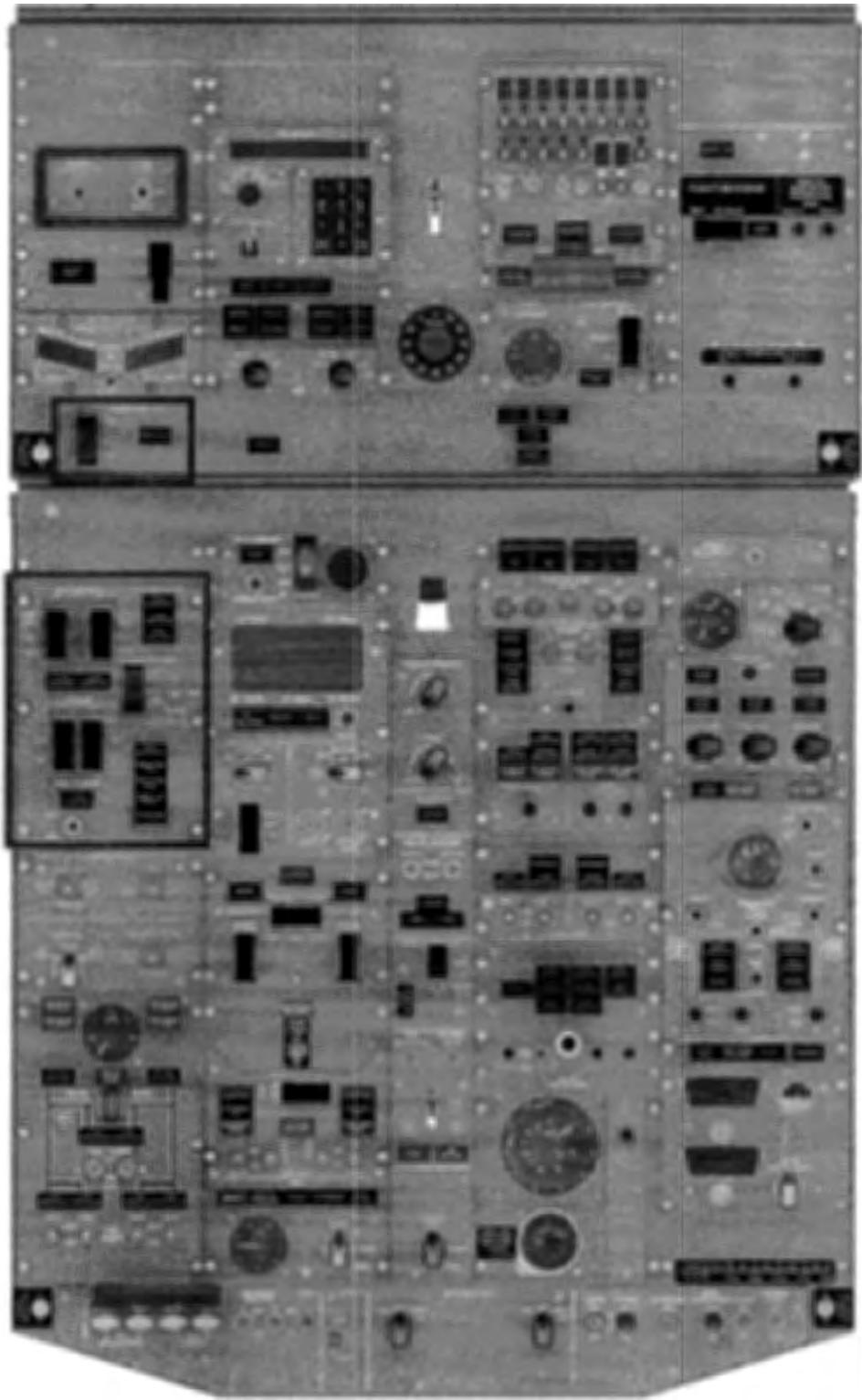


Figure 2-6 737 MAX Overhead Panel

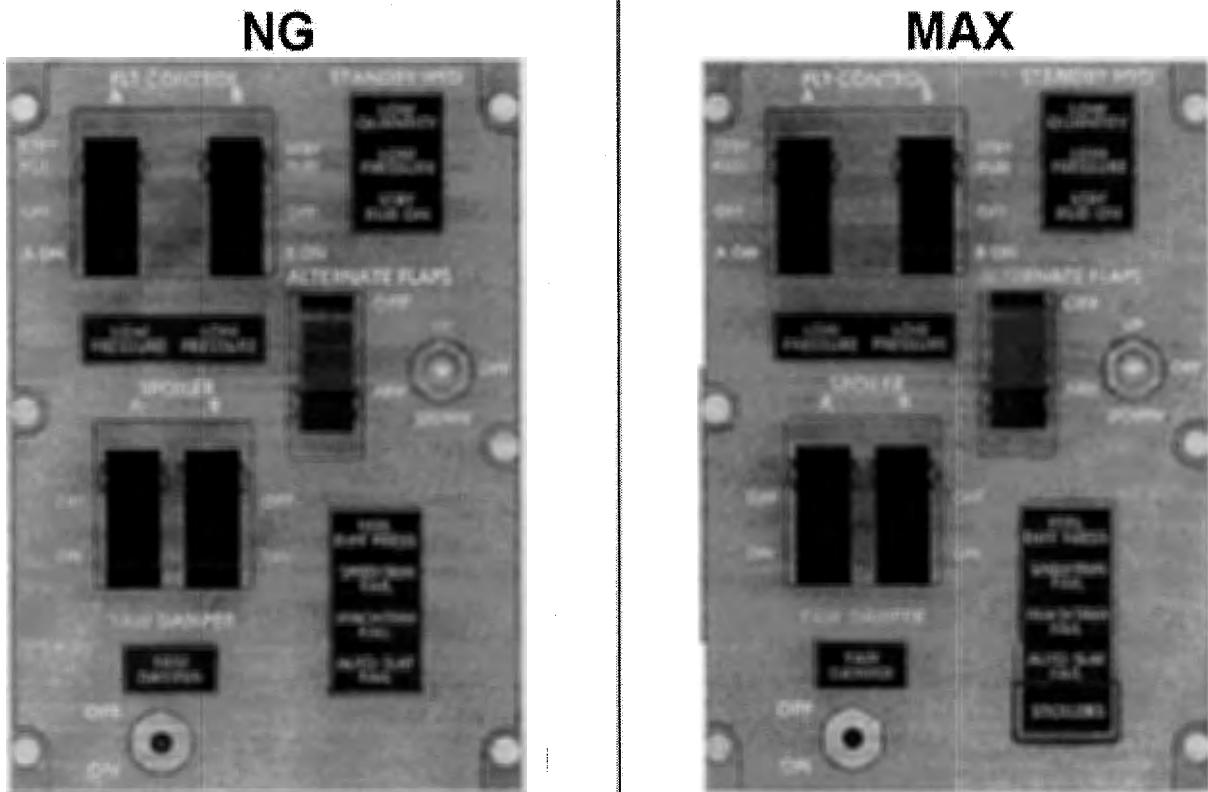


Figure 2-7 Forward Overhead Flight Controls Panel Differences Between NG and MAX

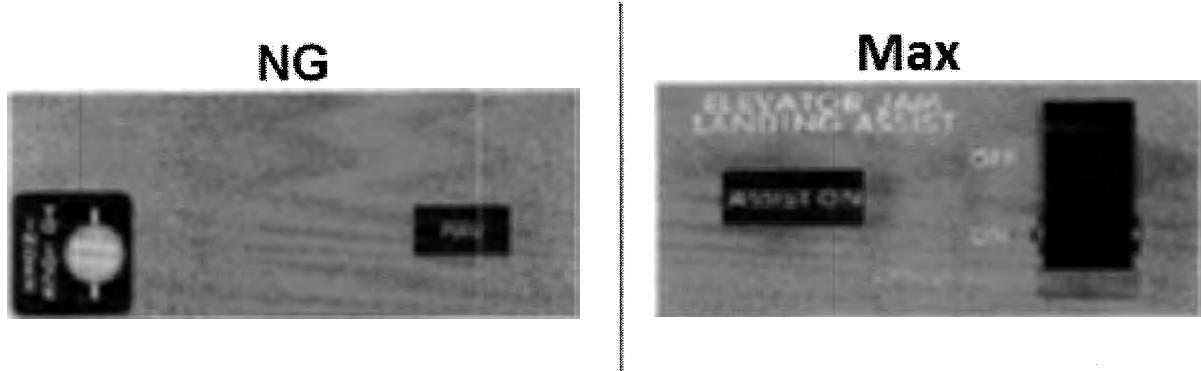
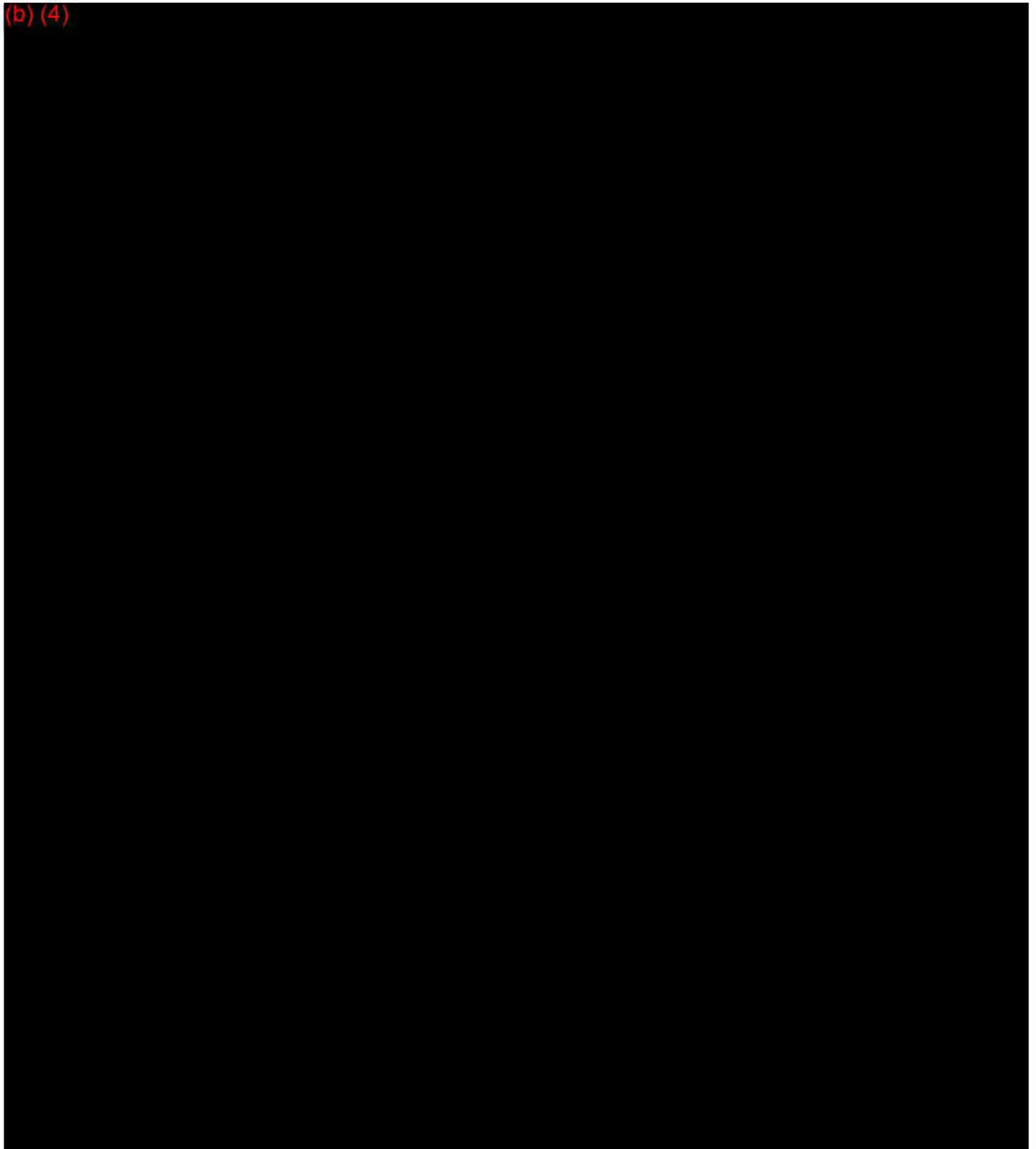


Figure 2-8 P5-3 New Elevator Jam Landing Assist Switch - Aft Overhead Panel

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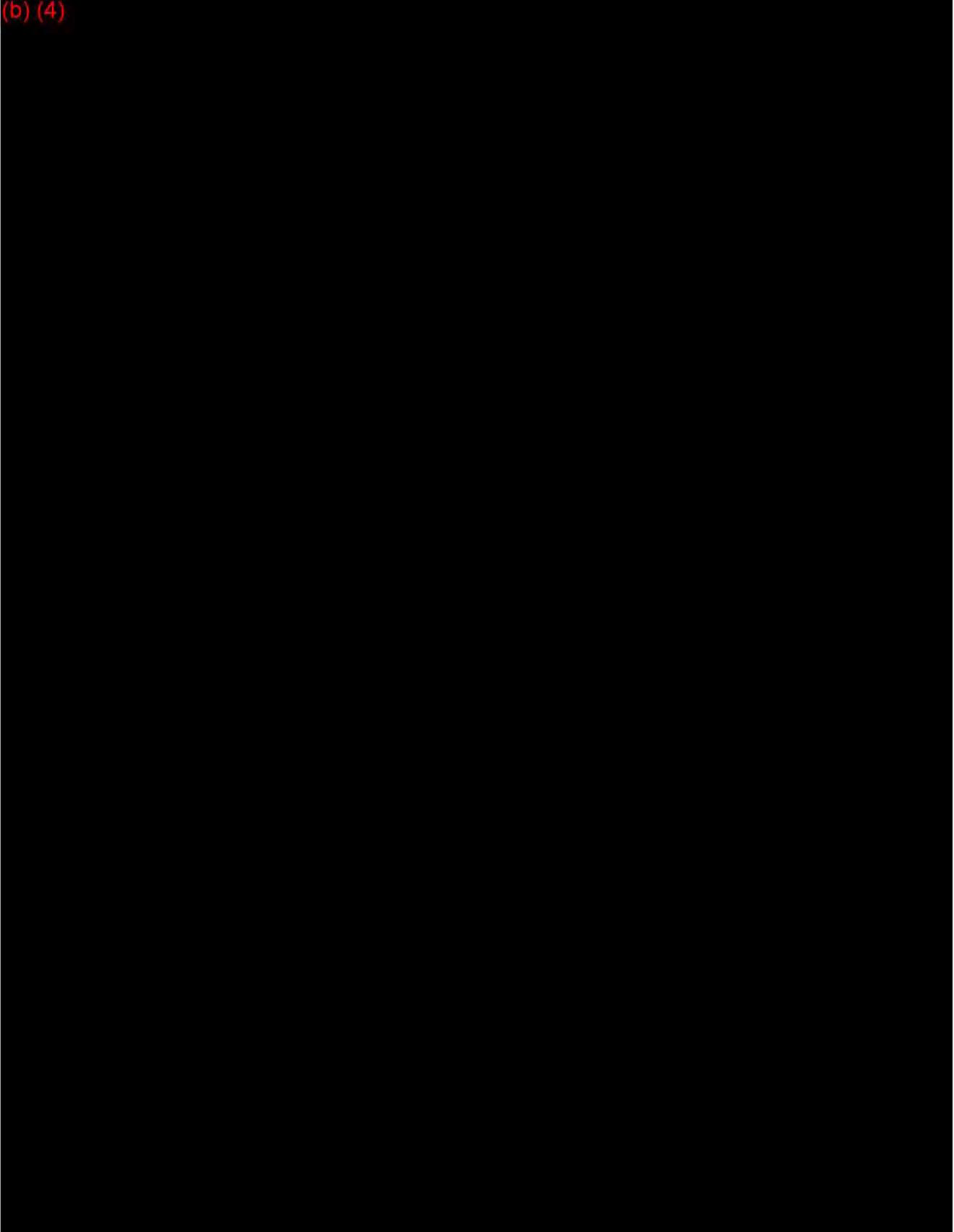


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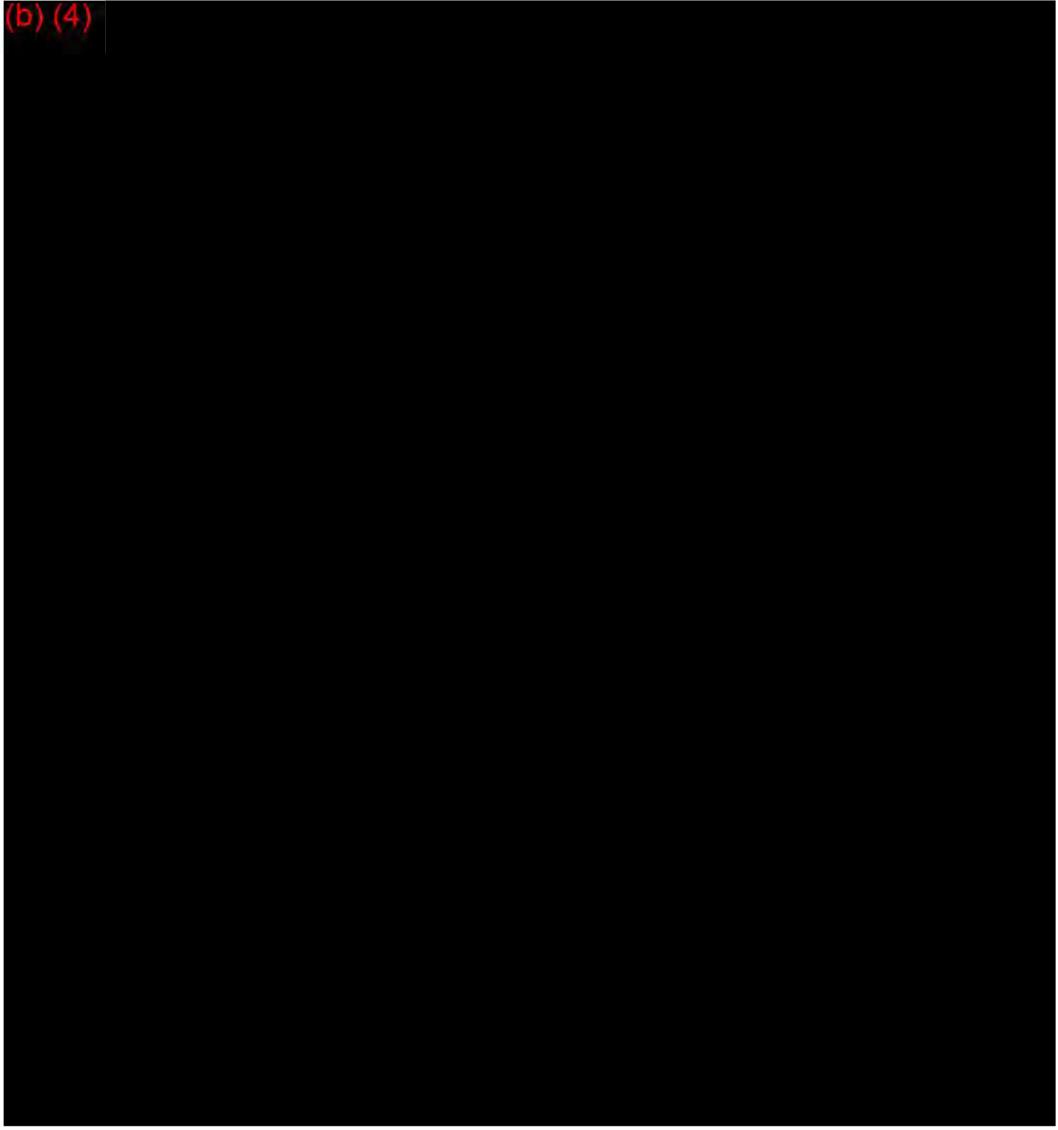


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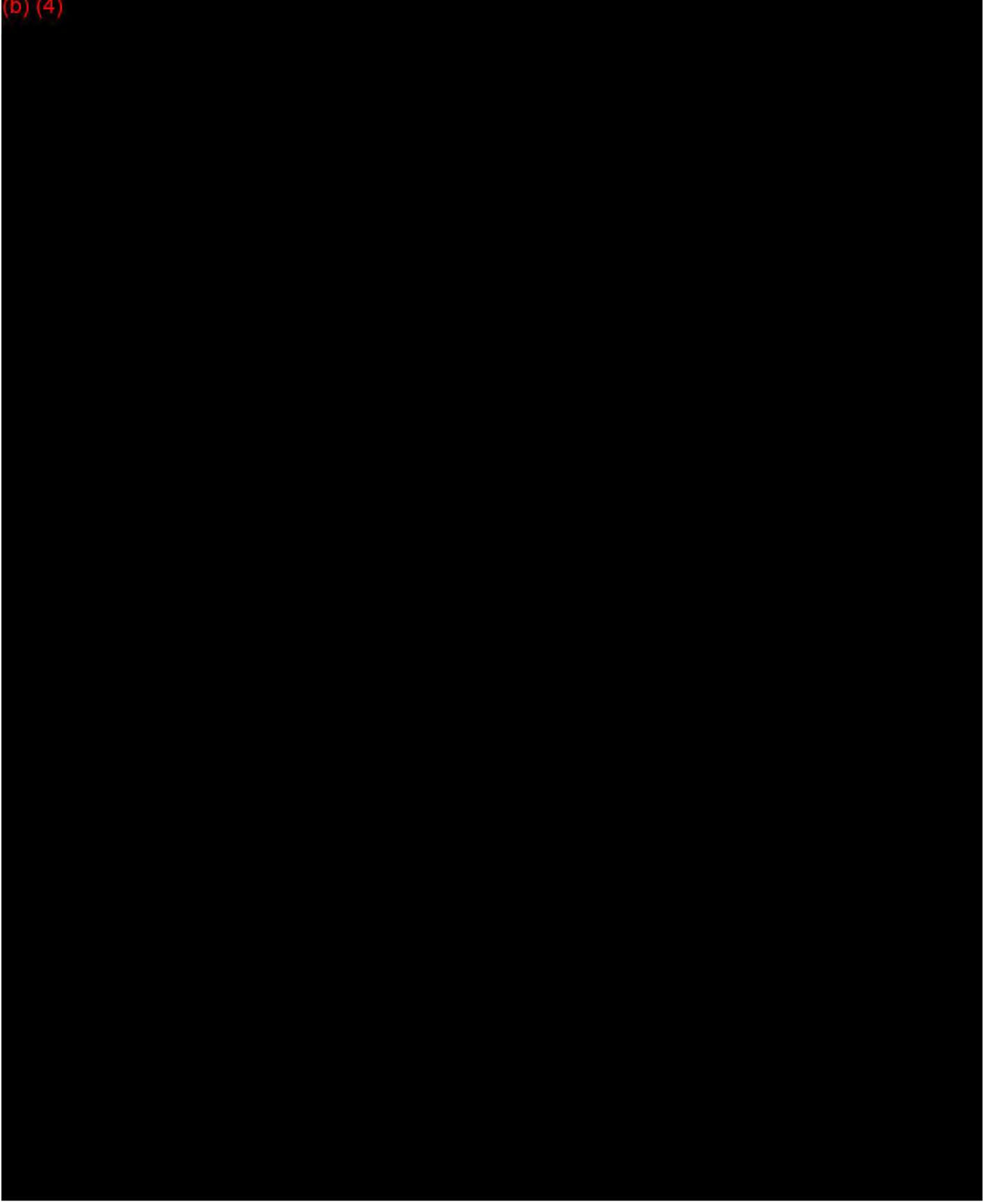


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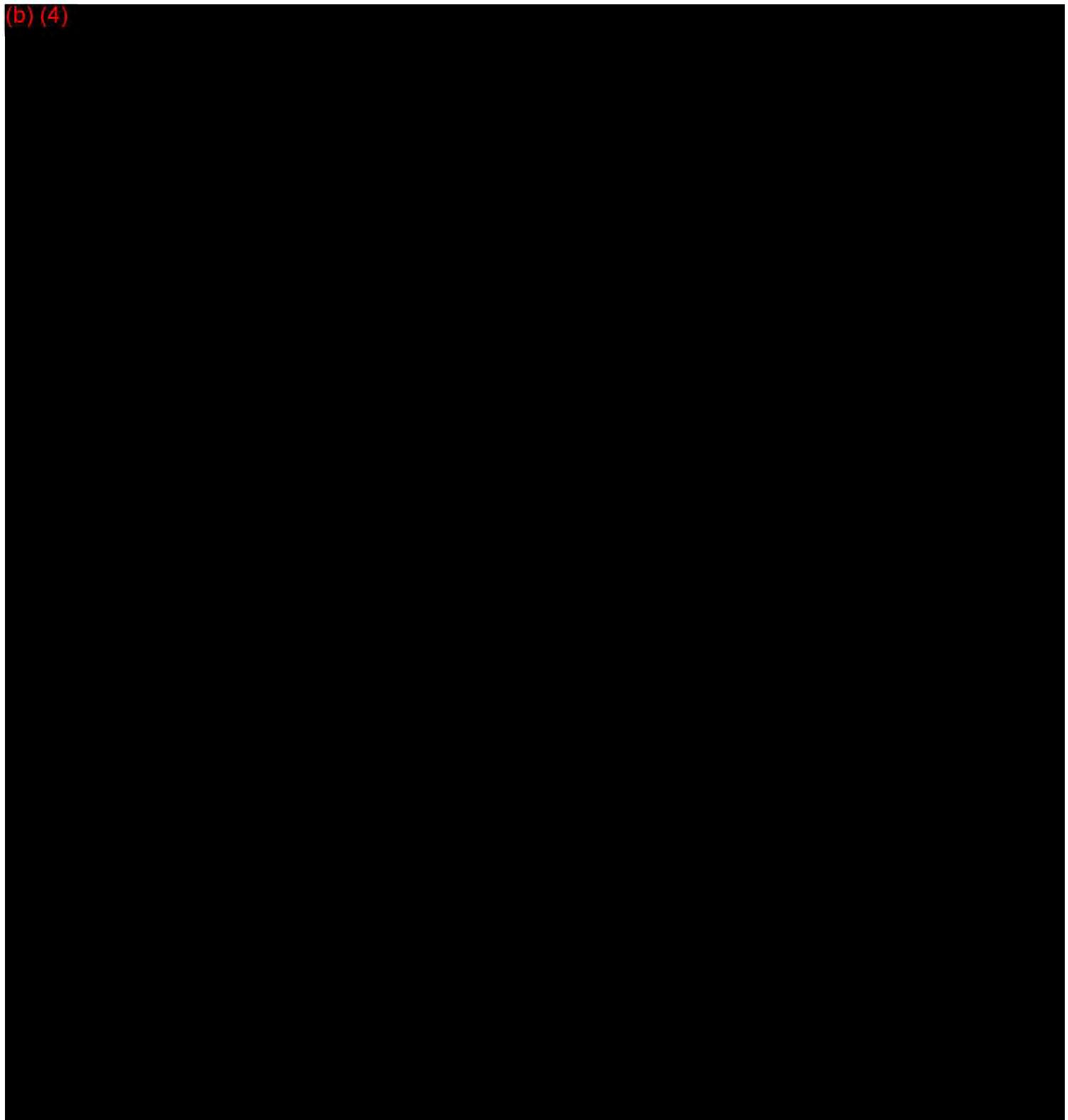




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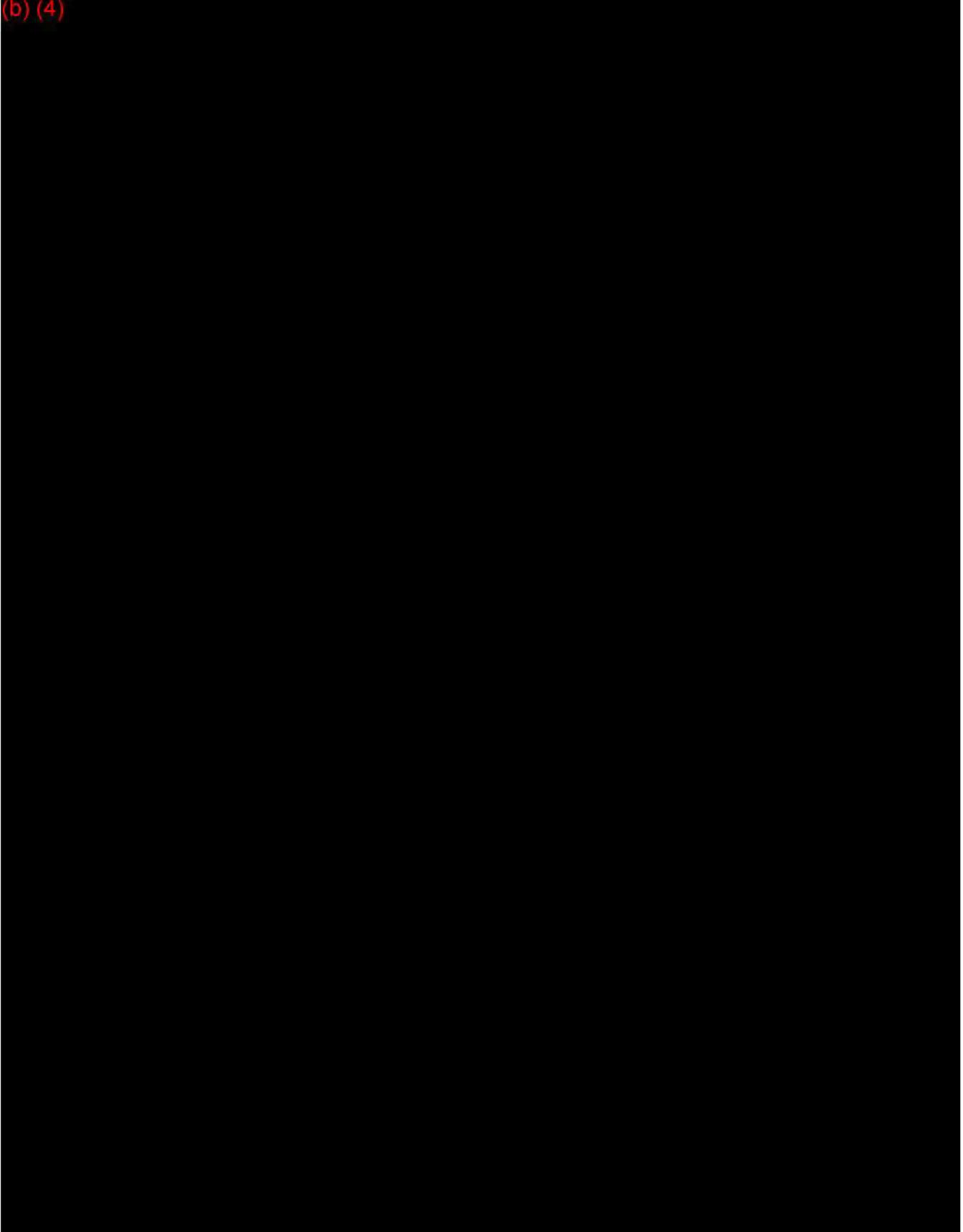
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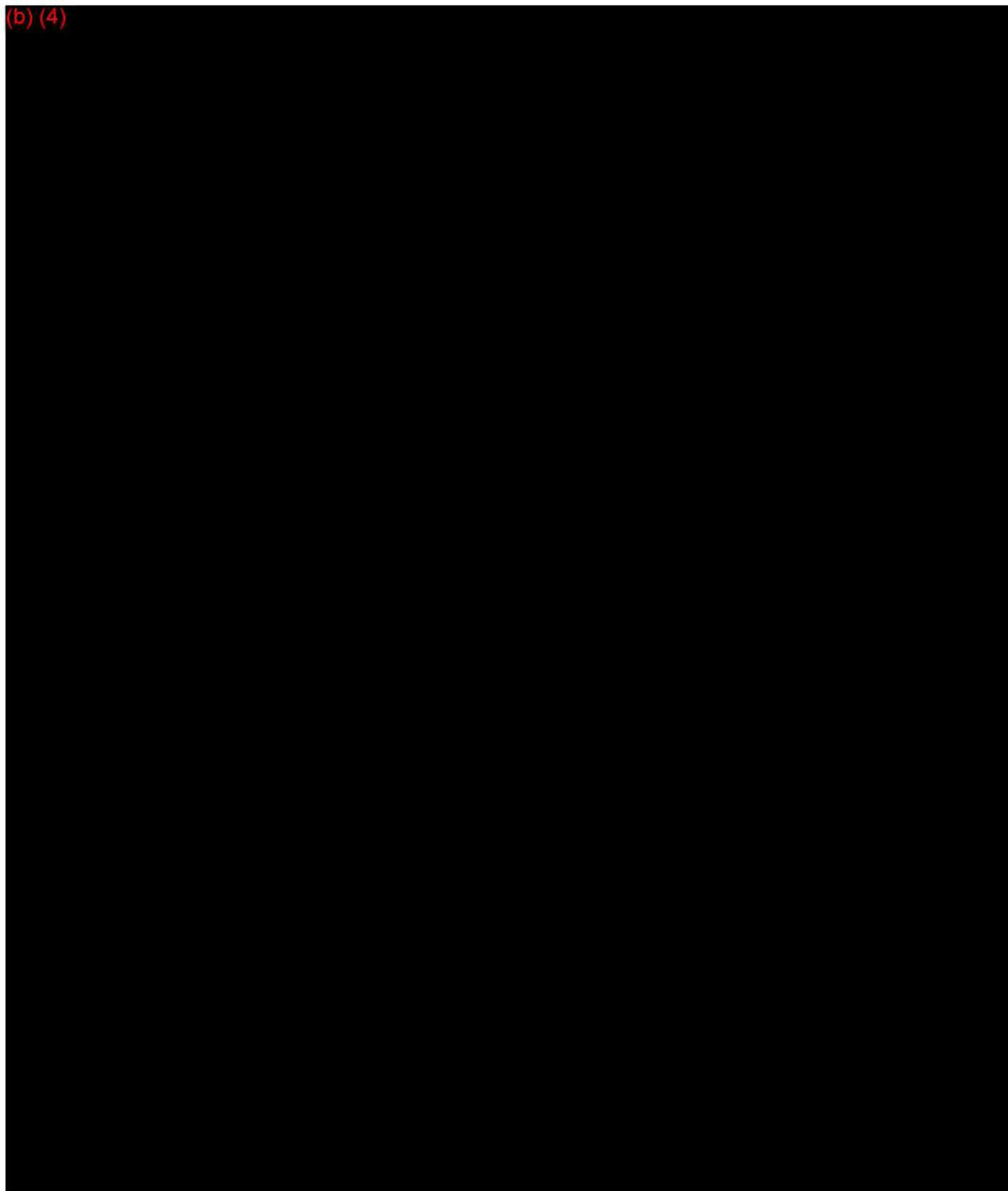
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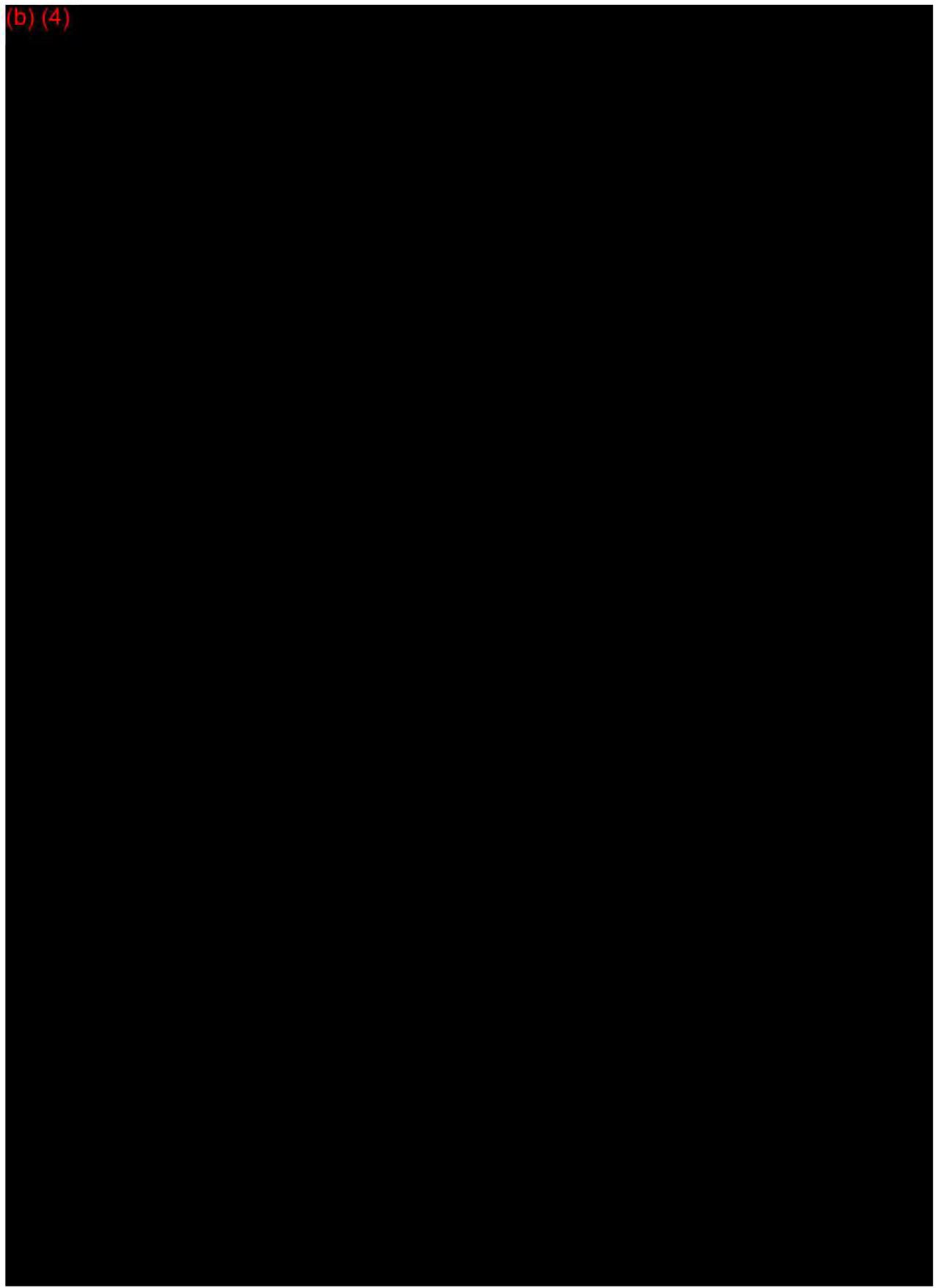
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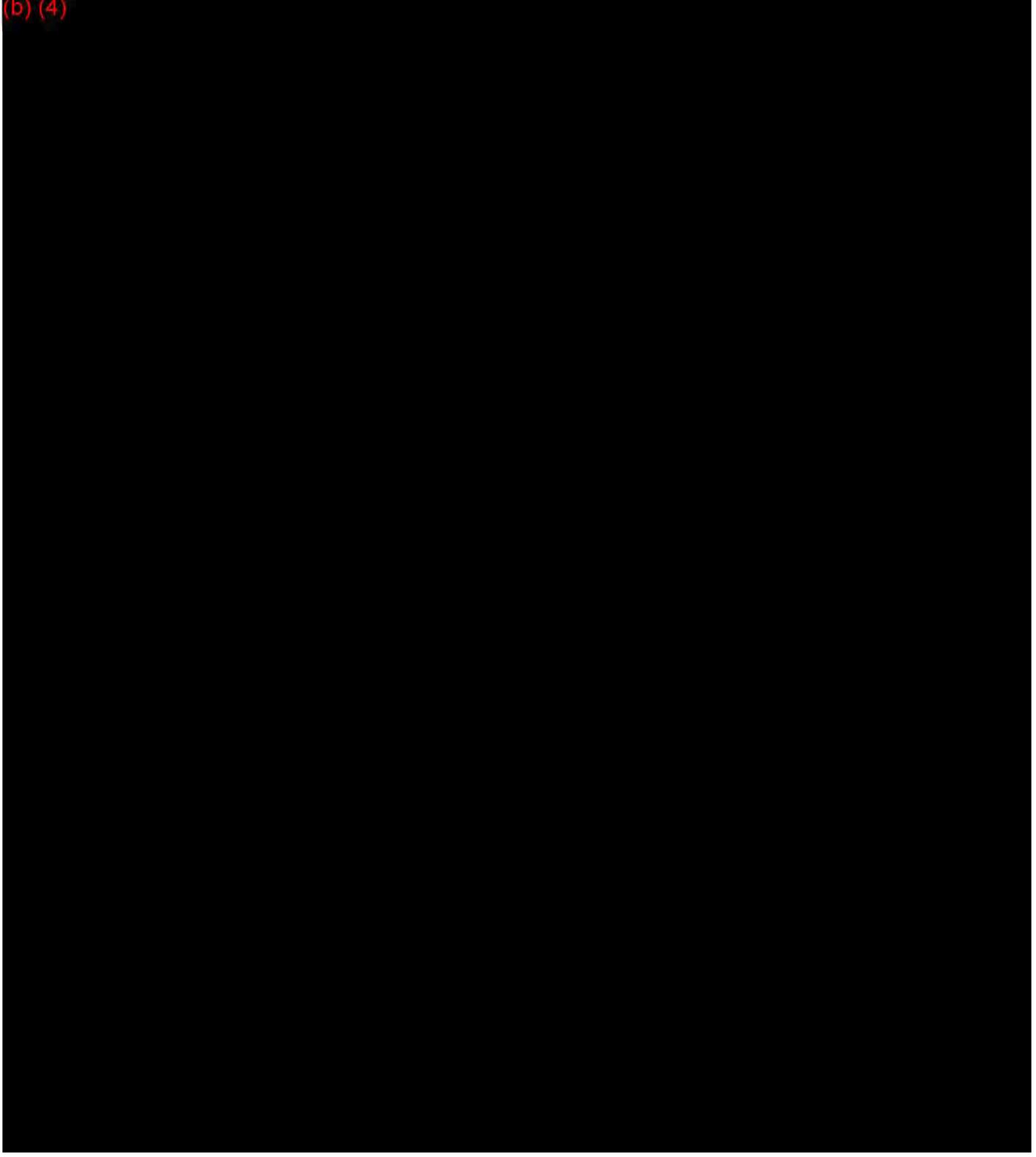
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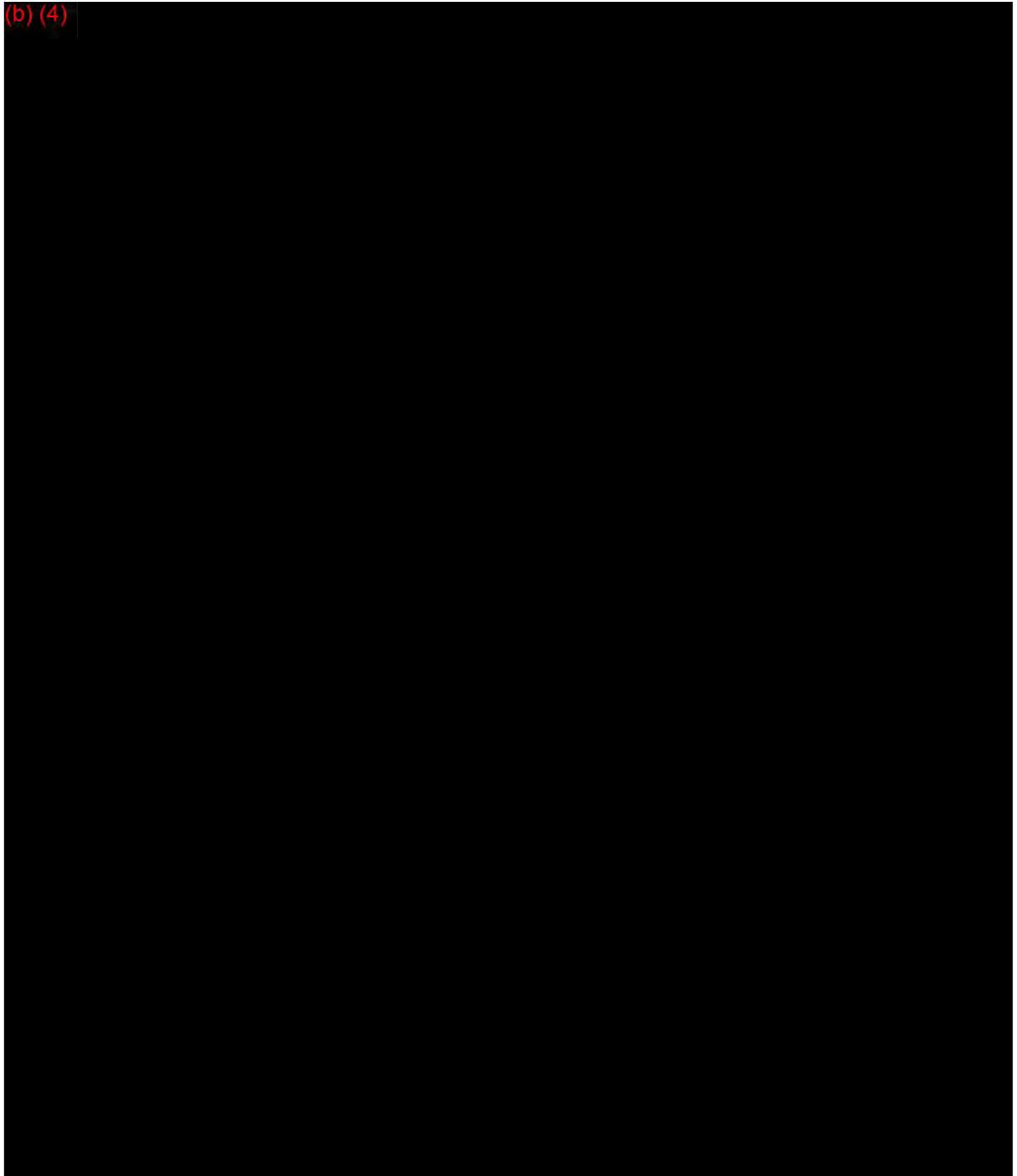
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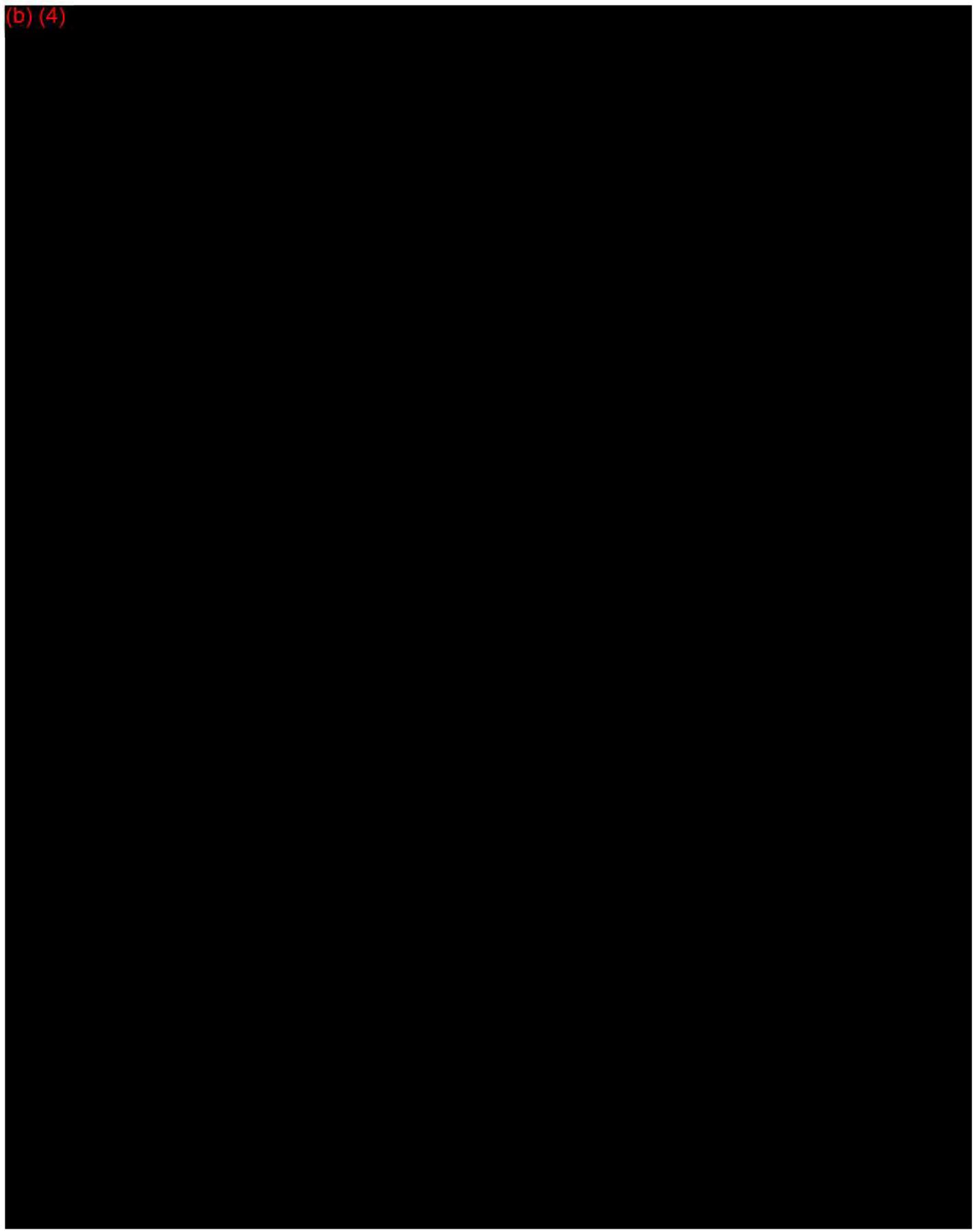
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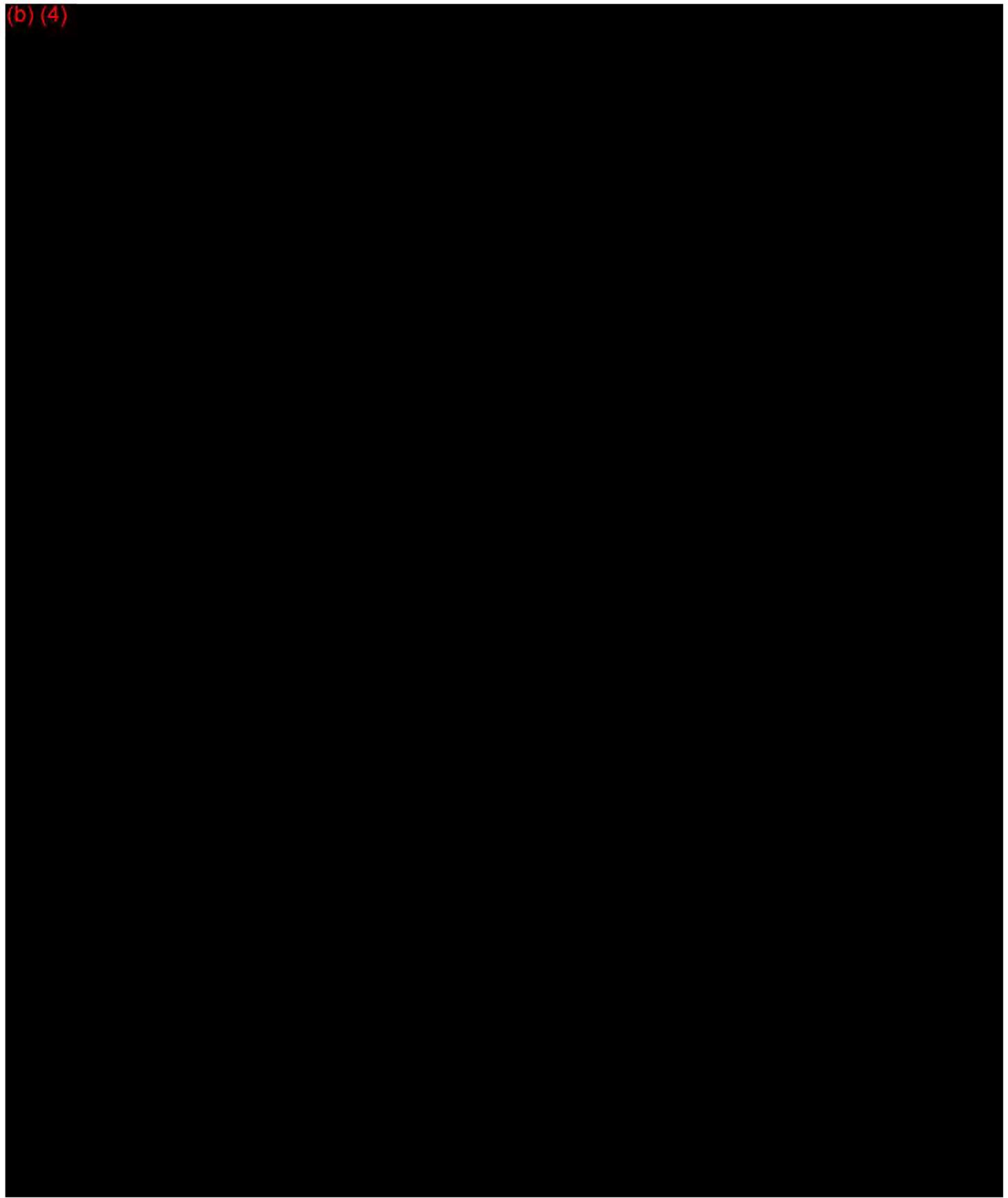
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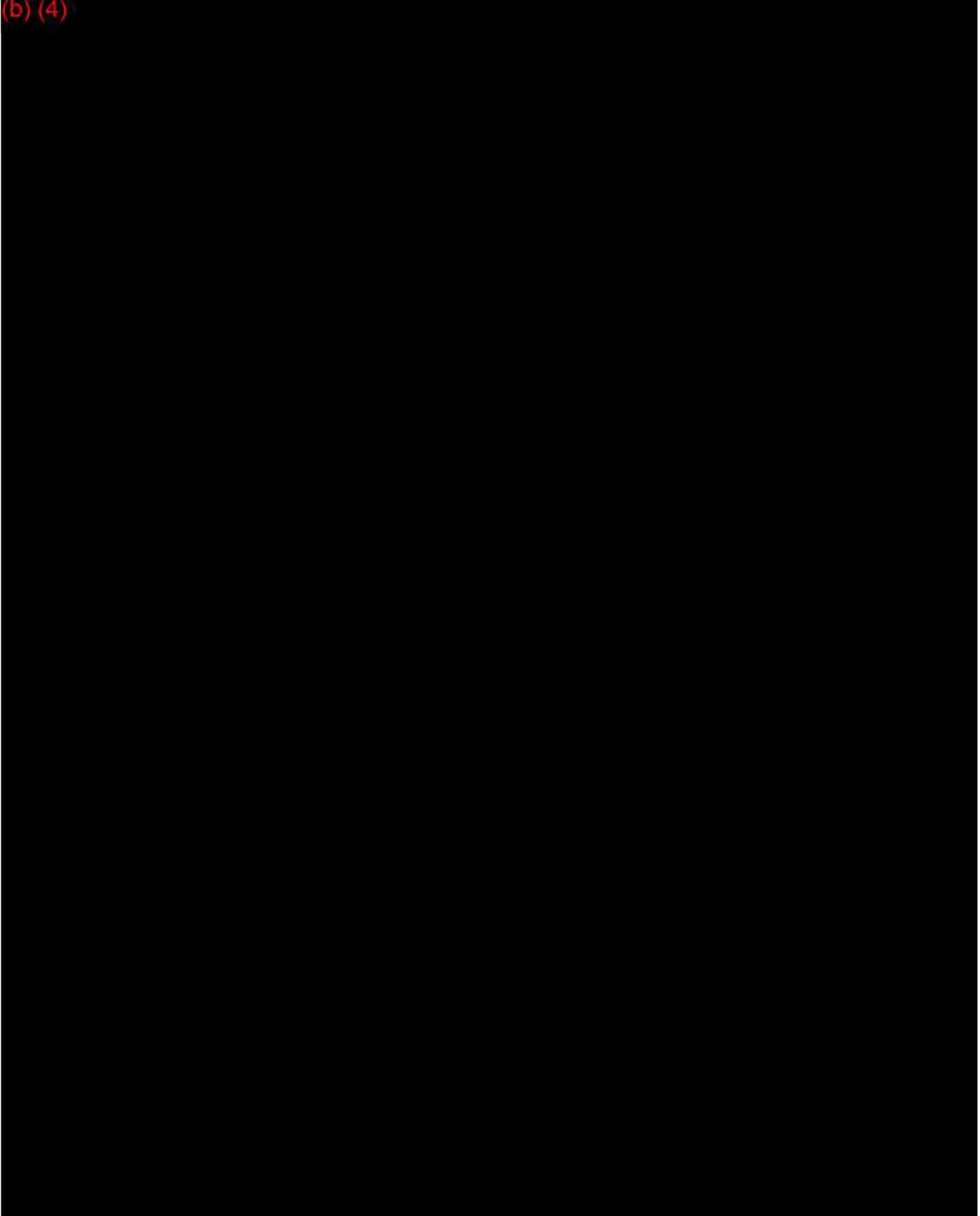
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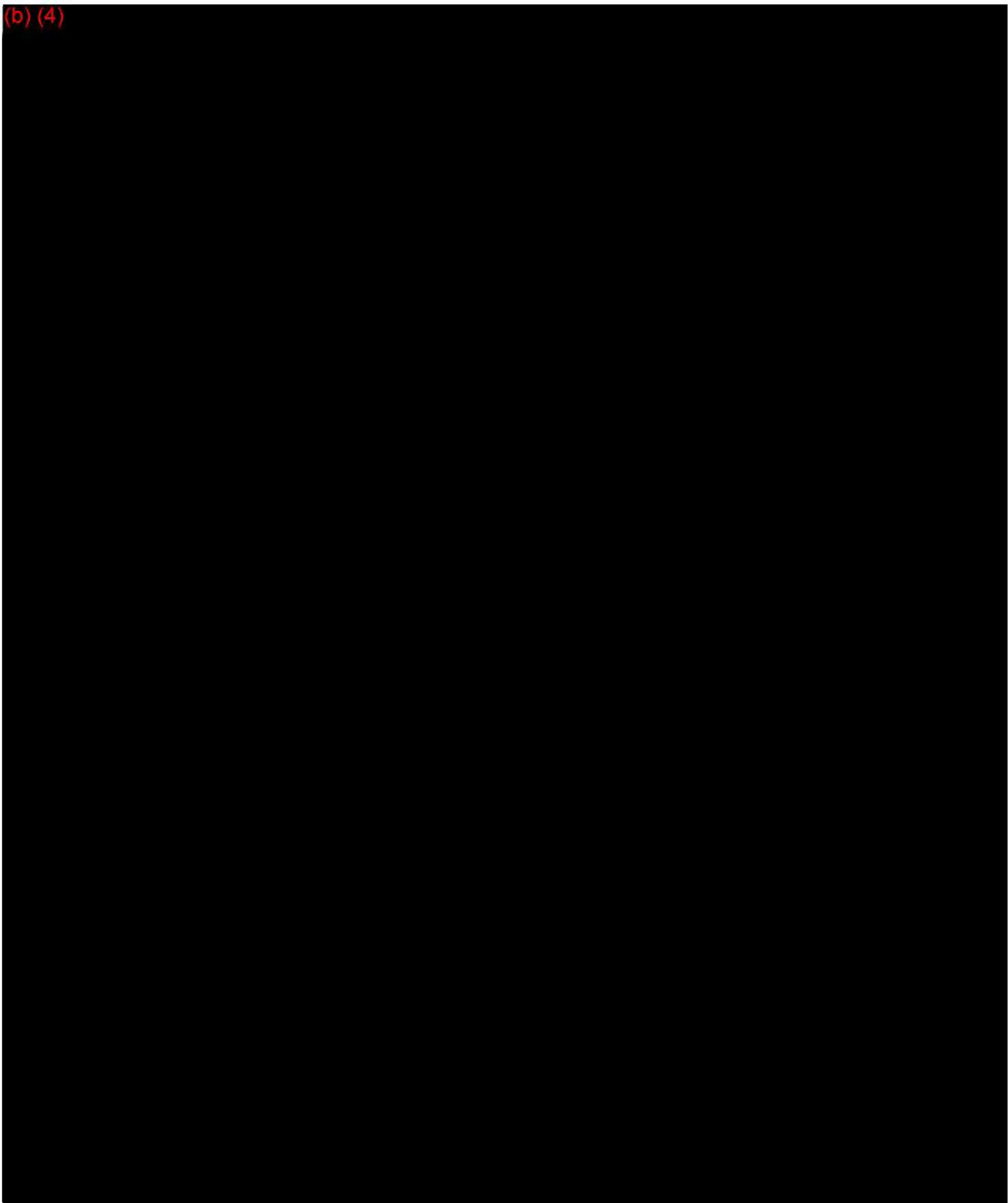
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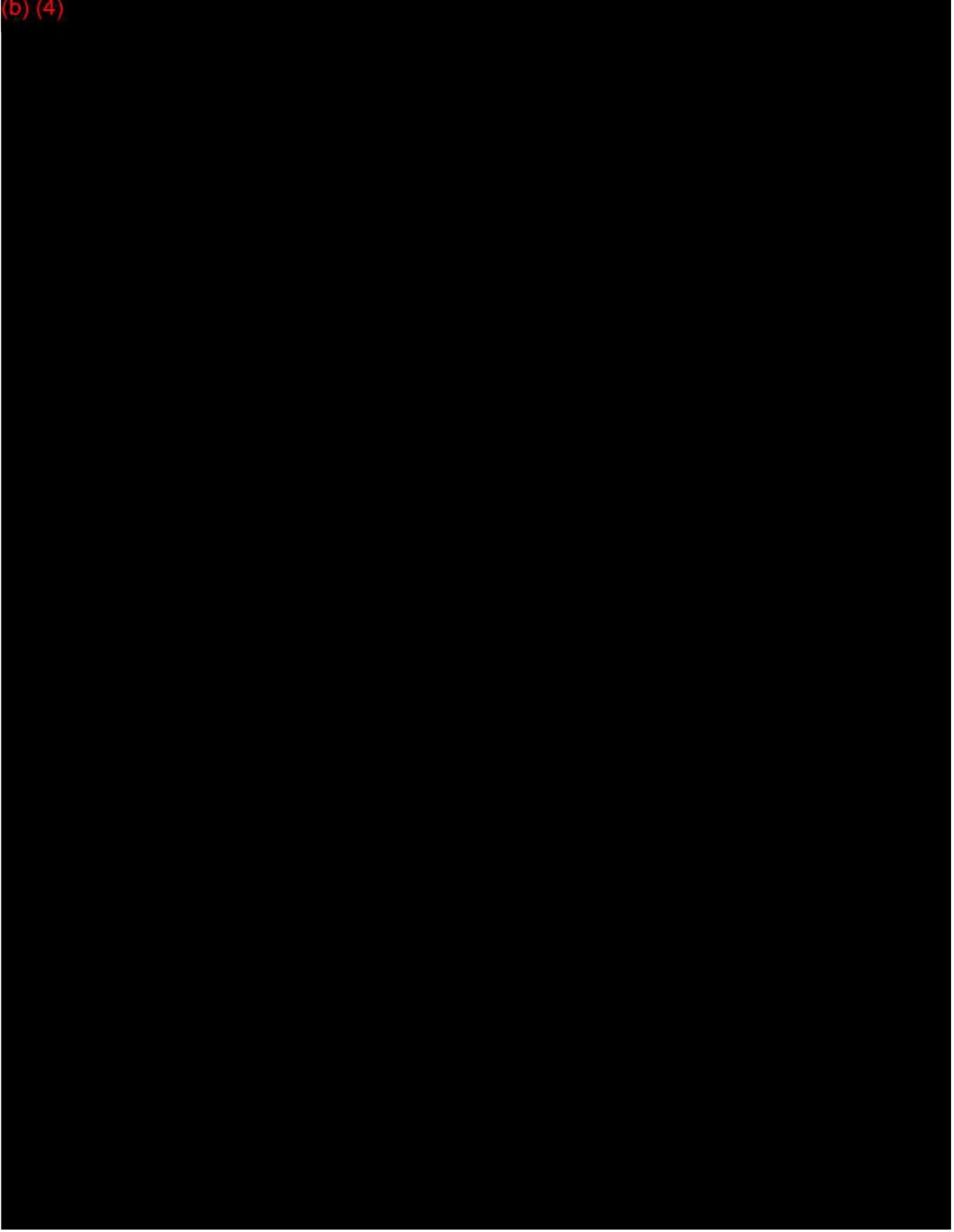
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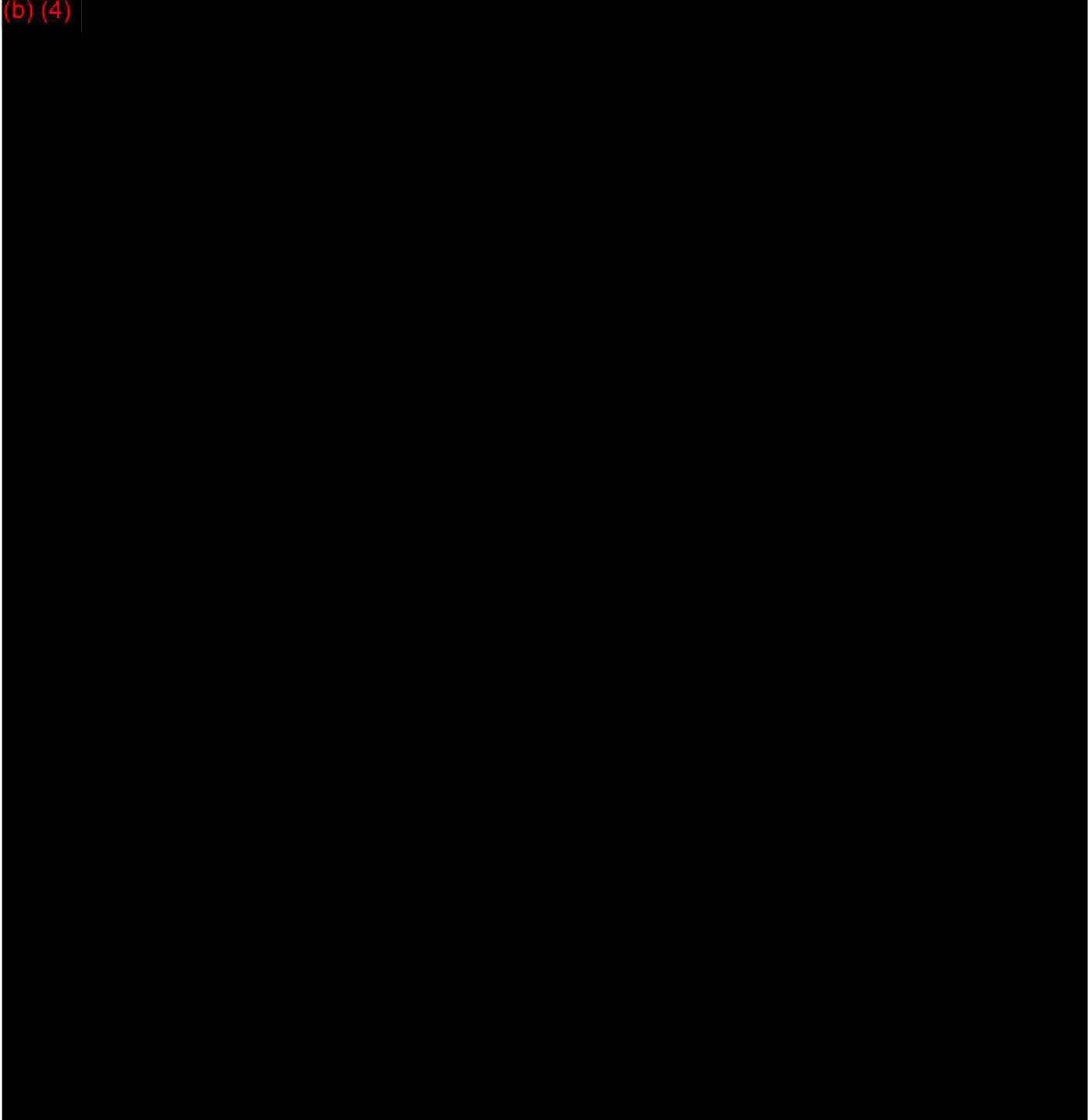
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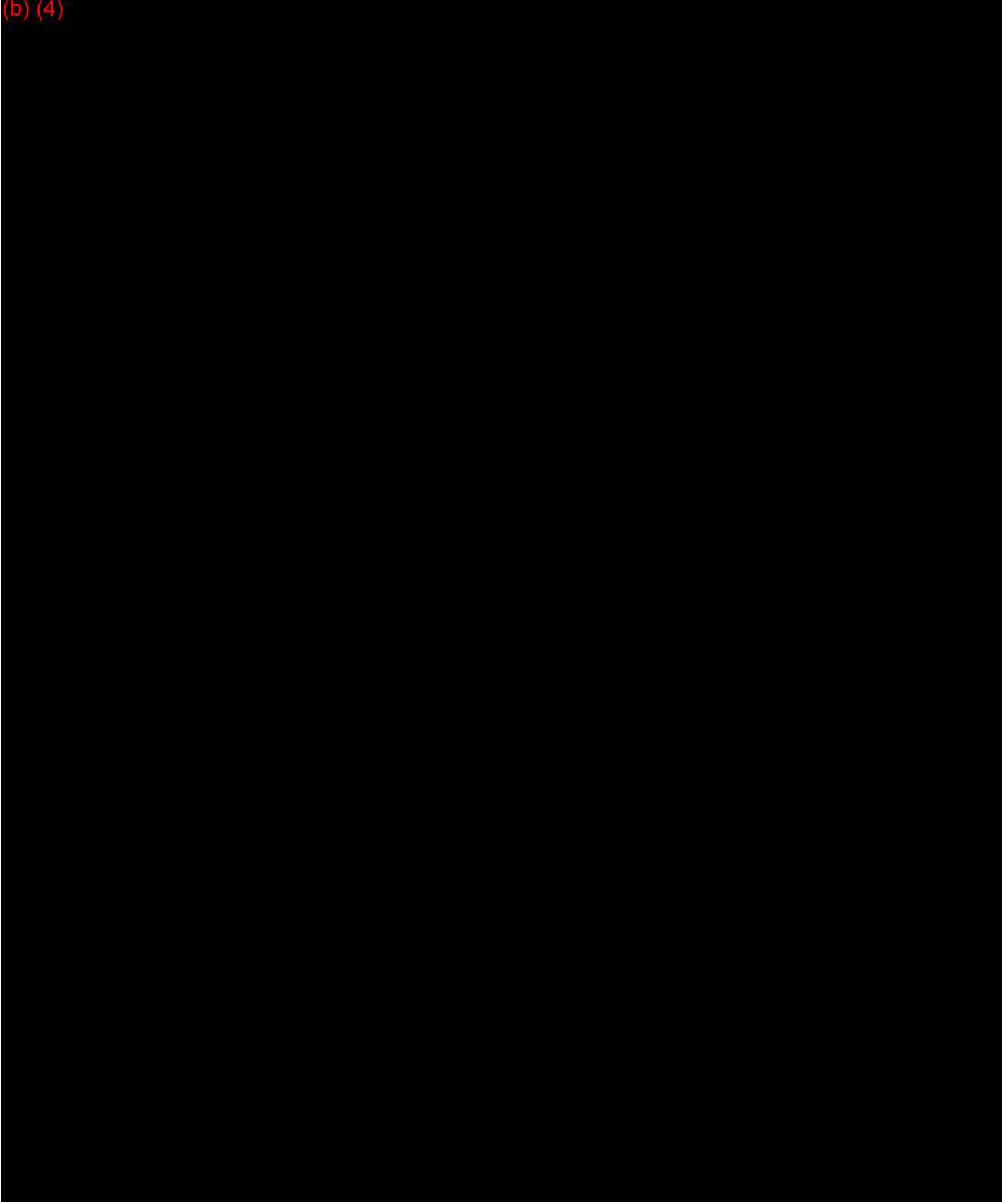
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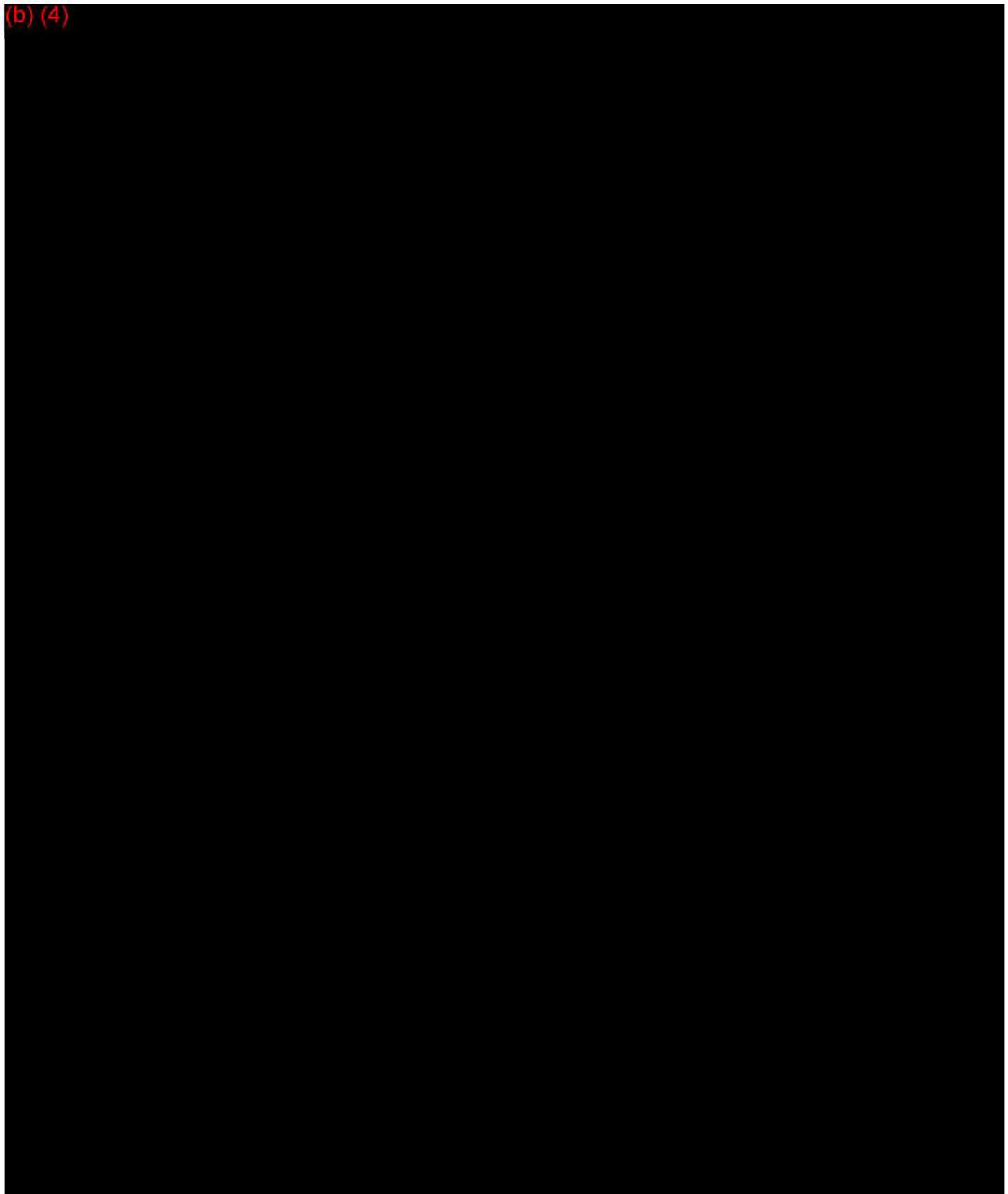
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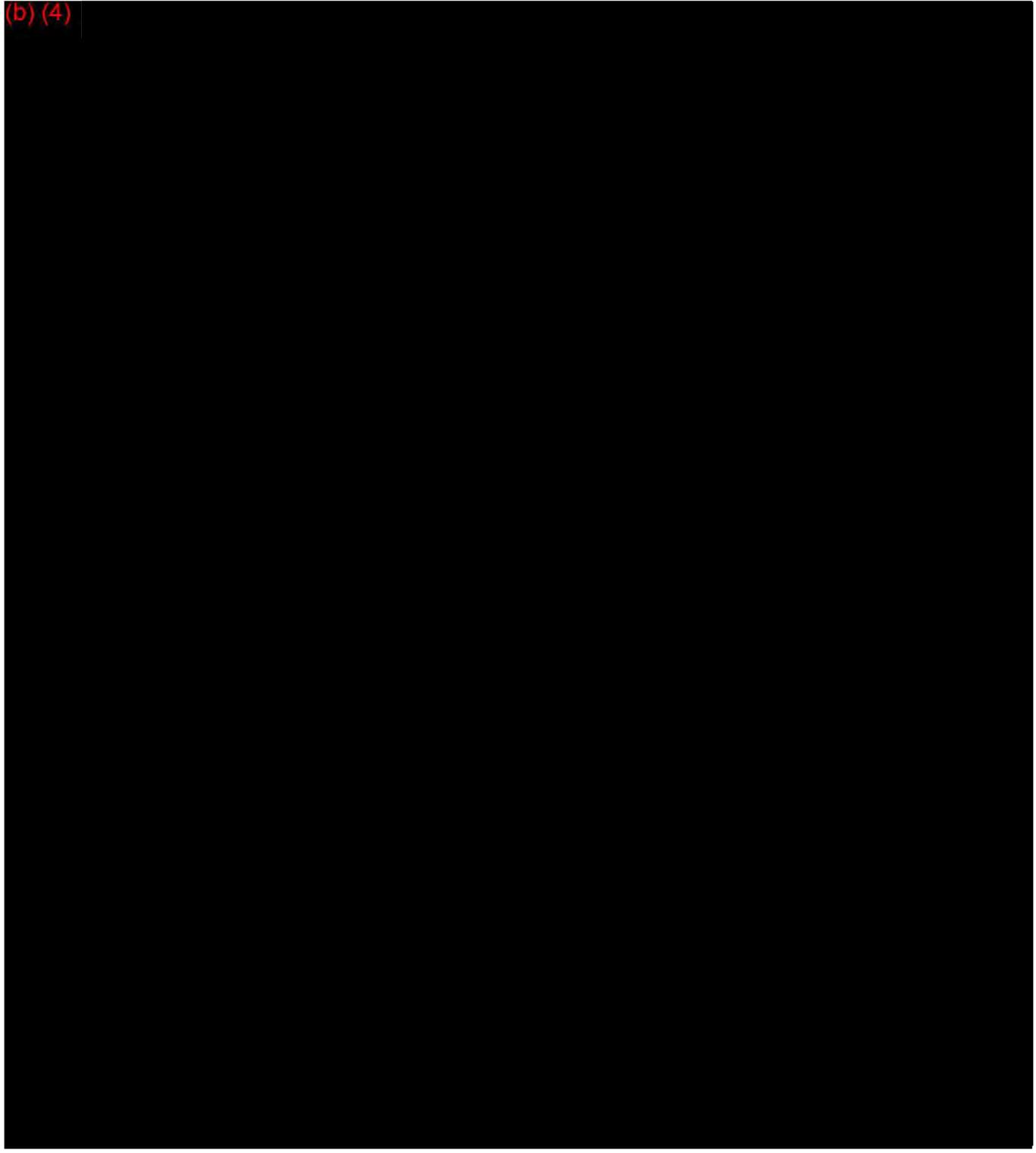
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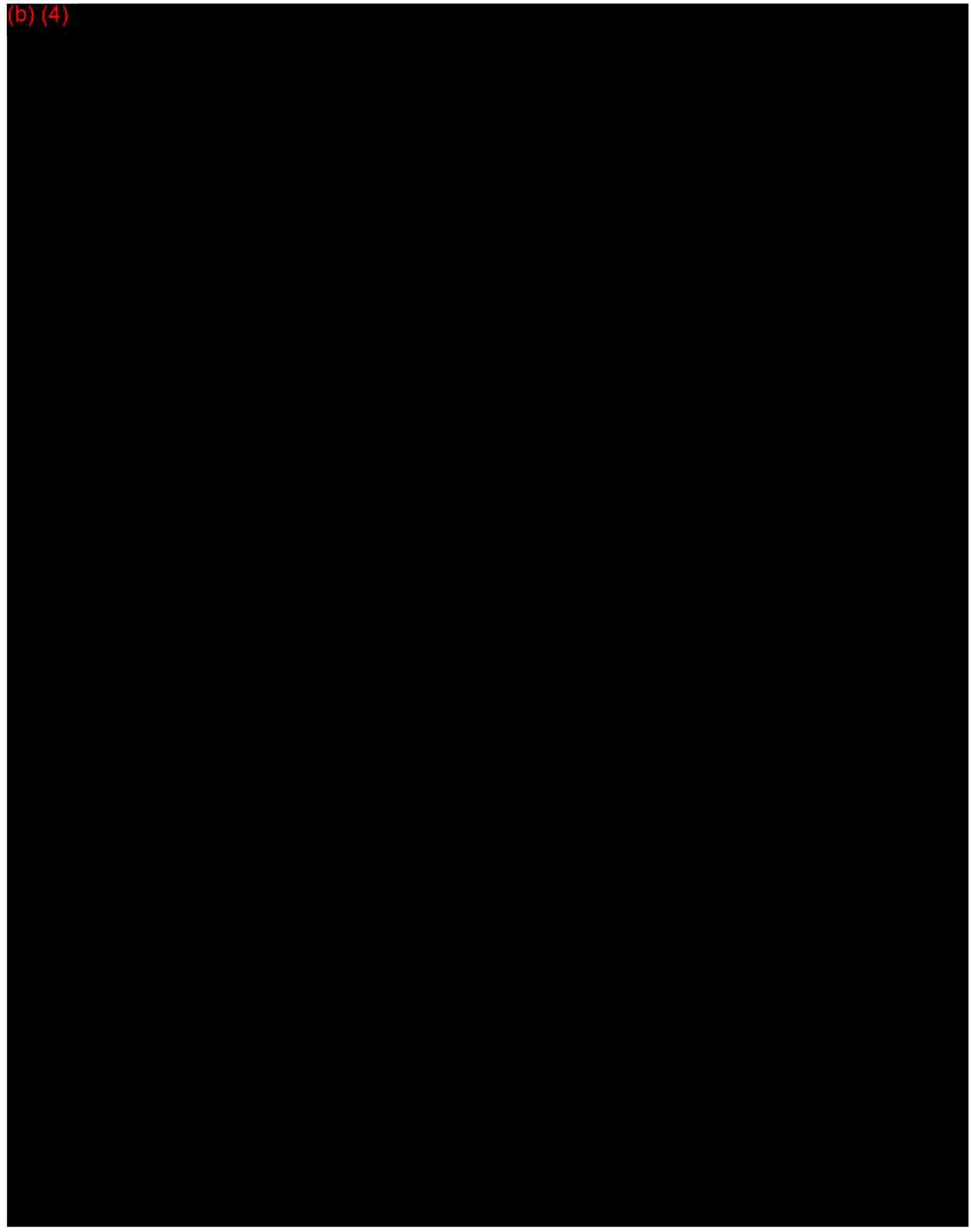
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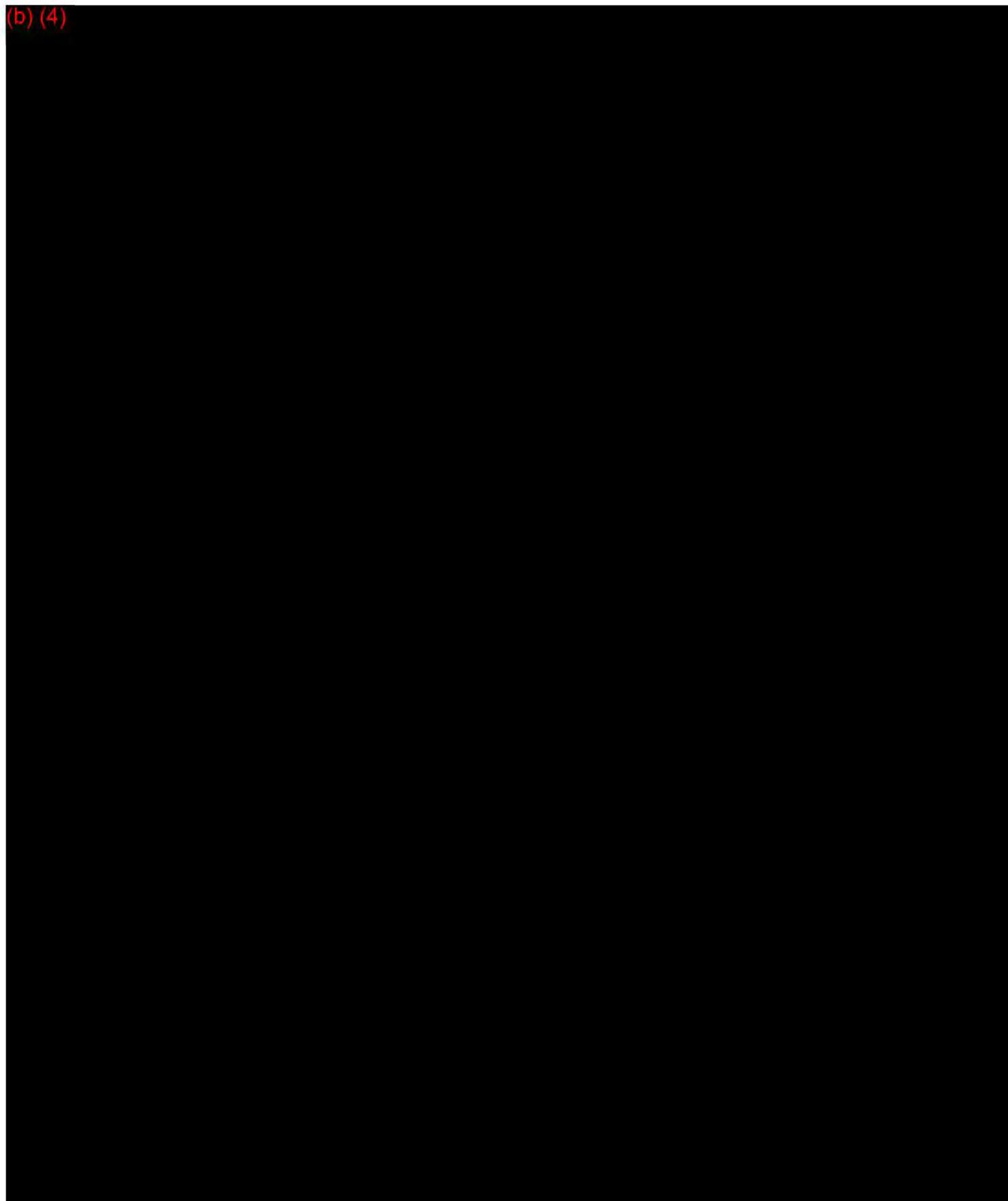
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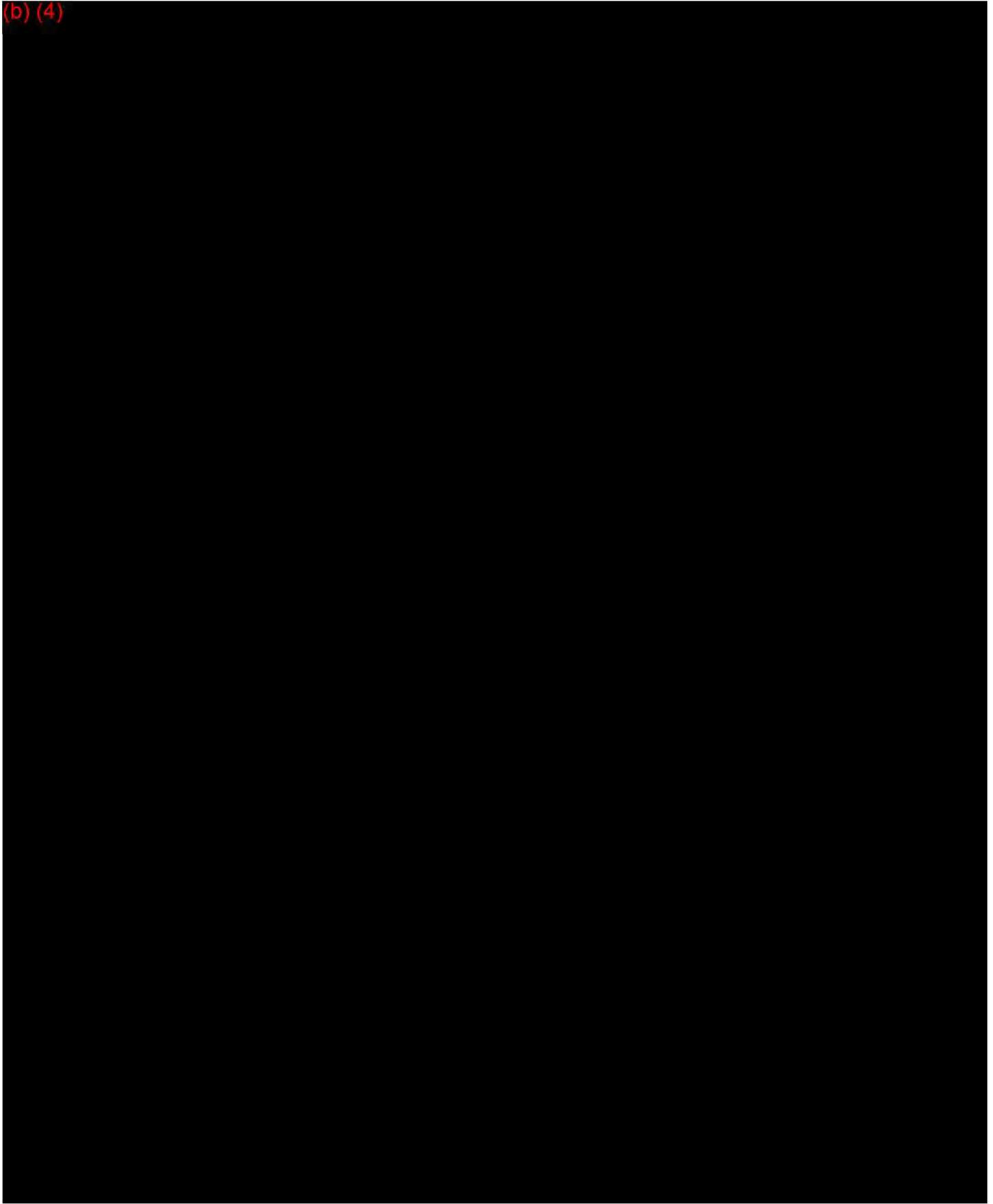
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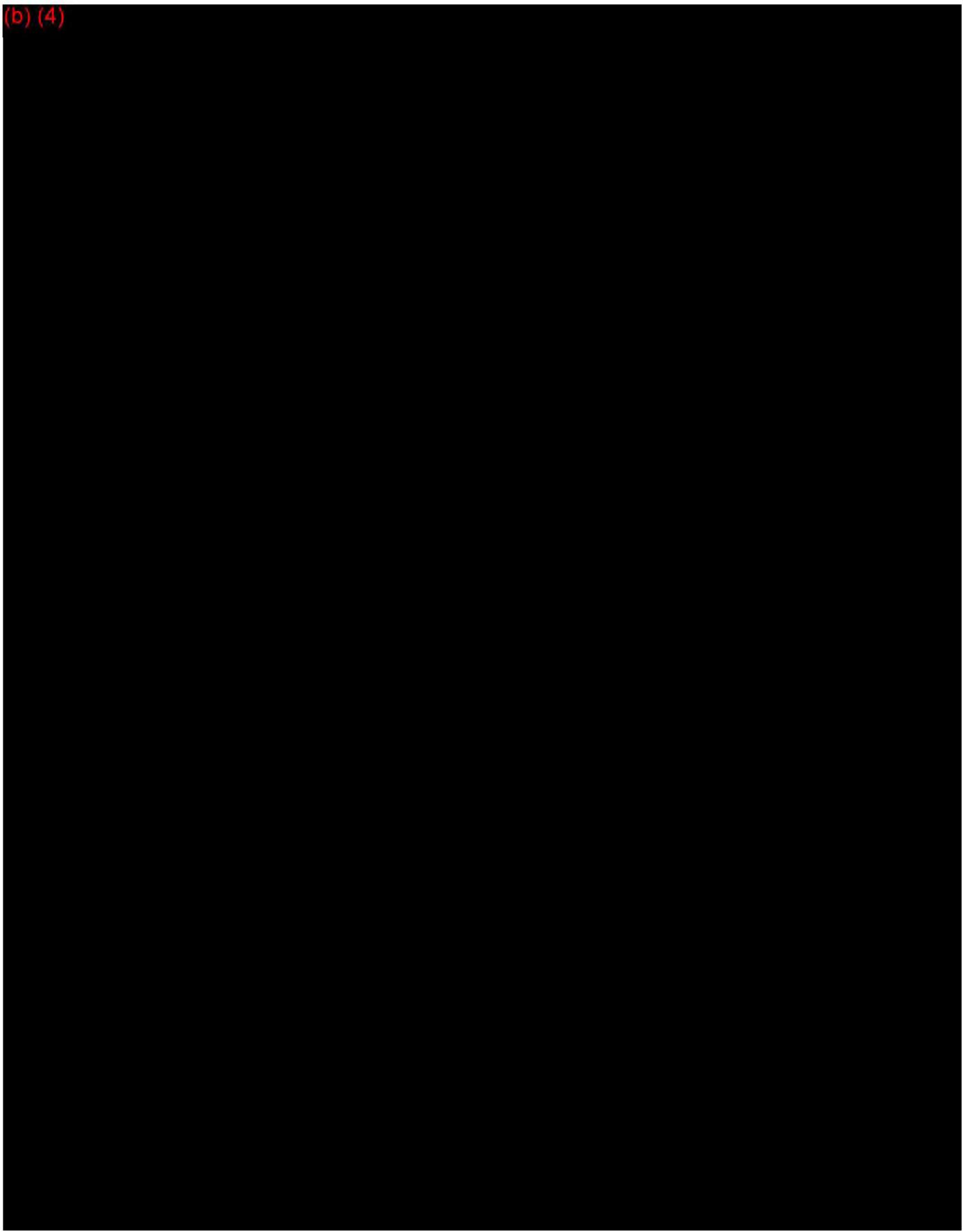
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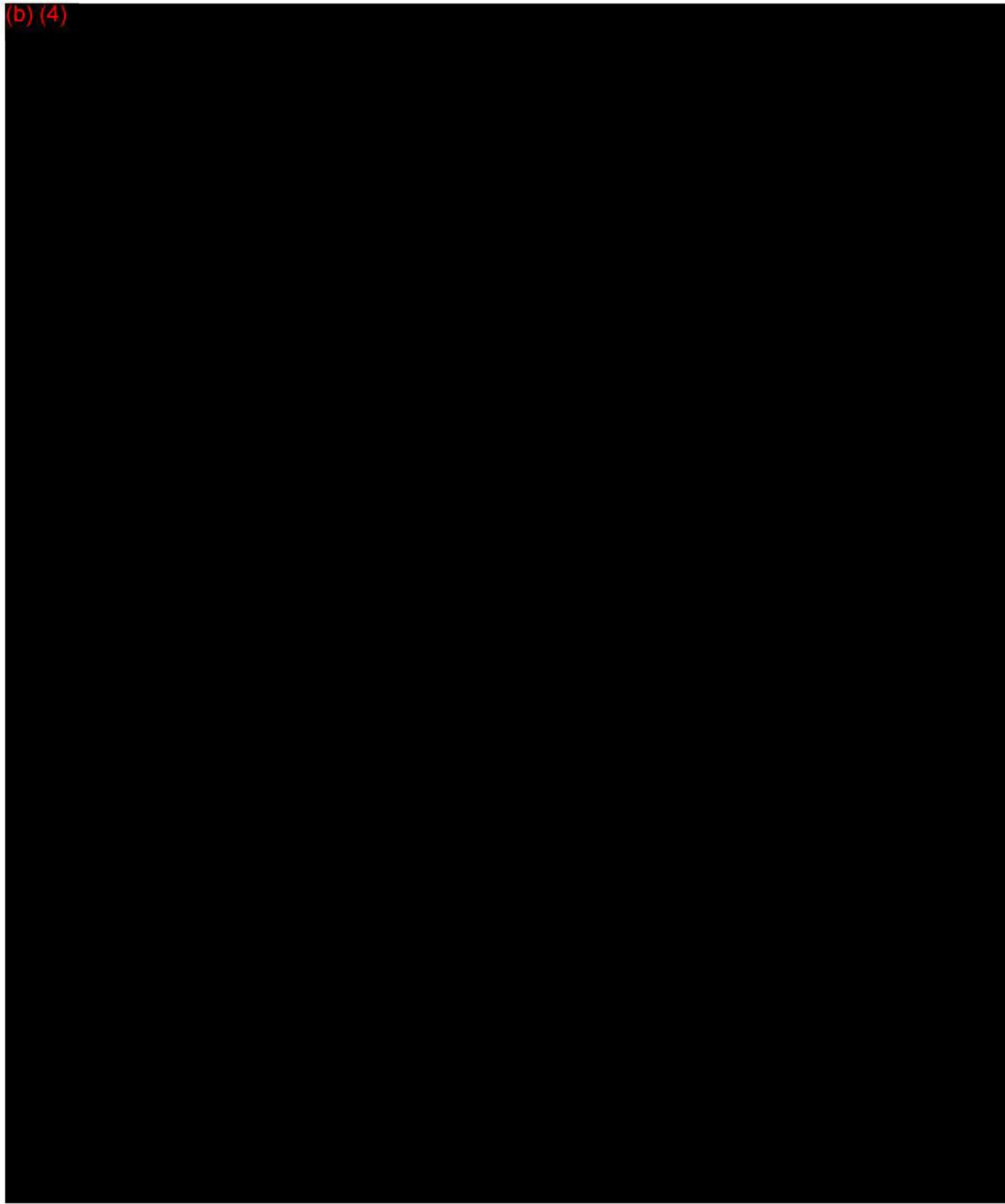
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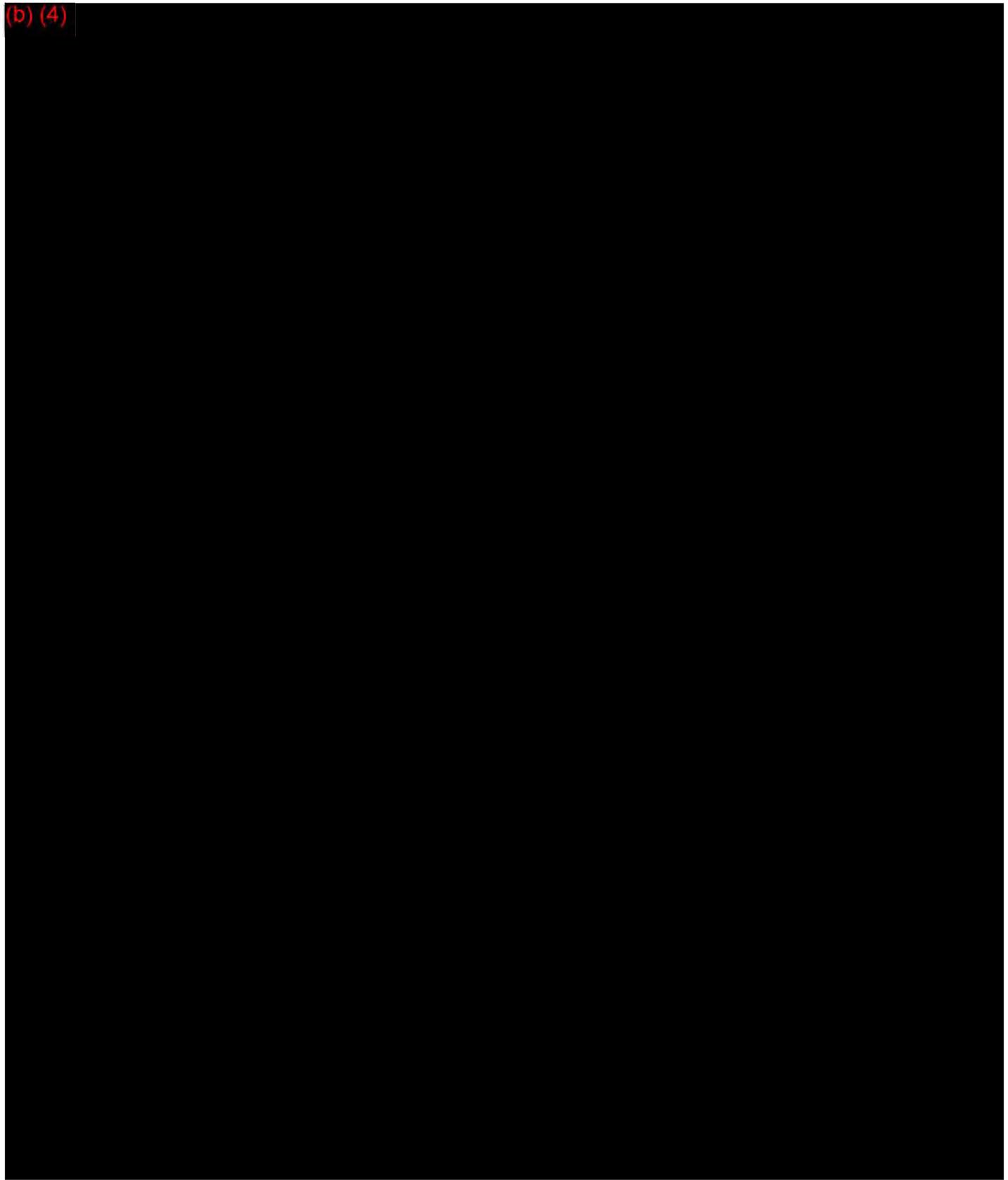
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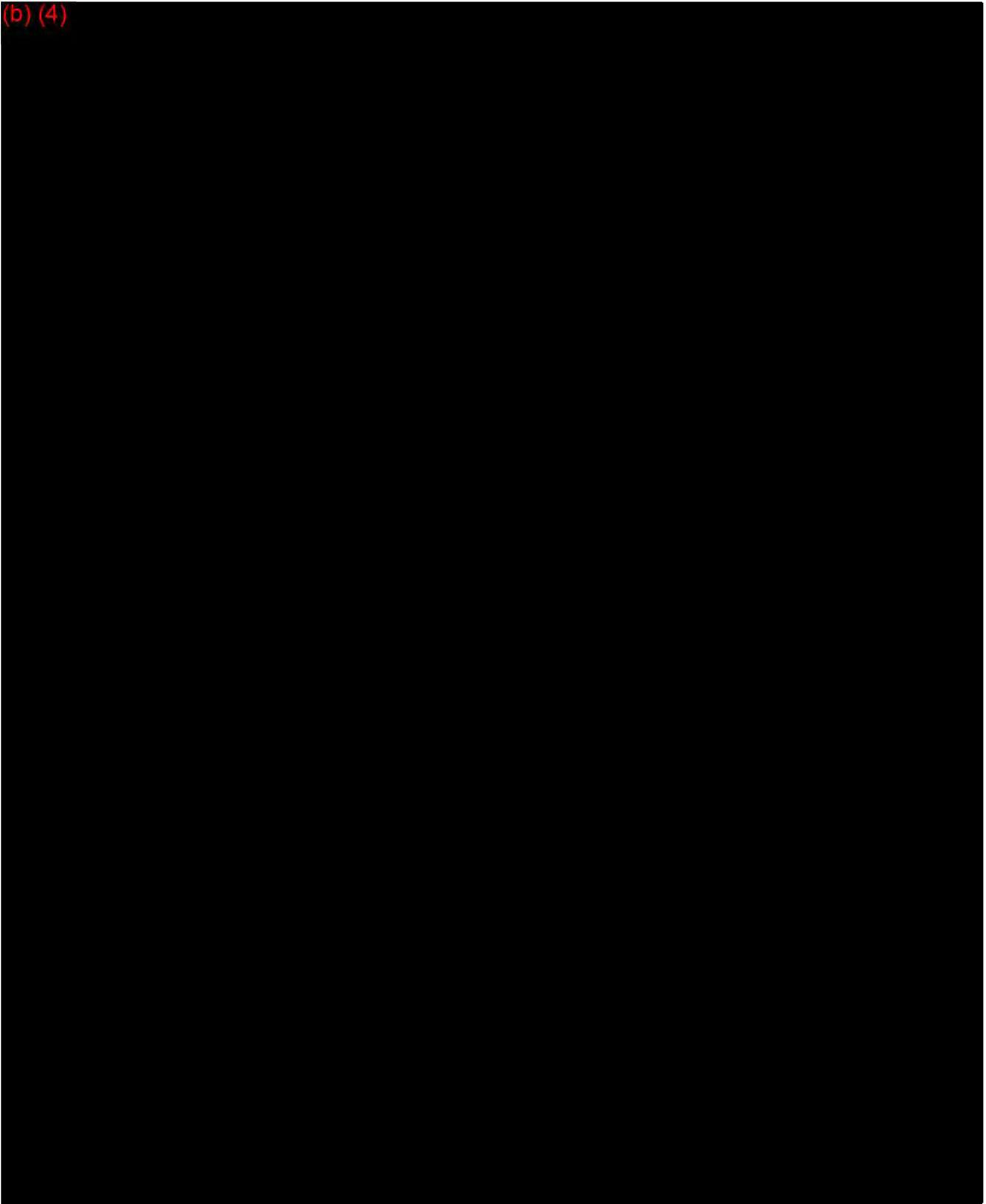
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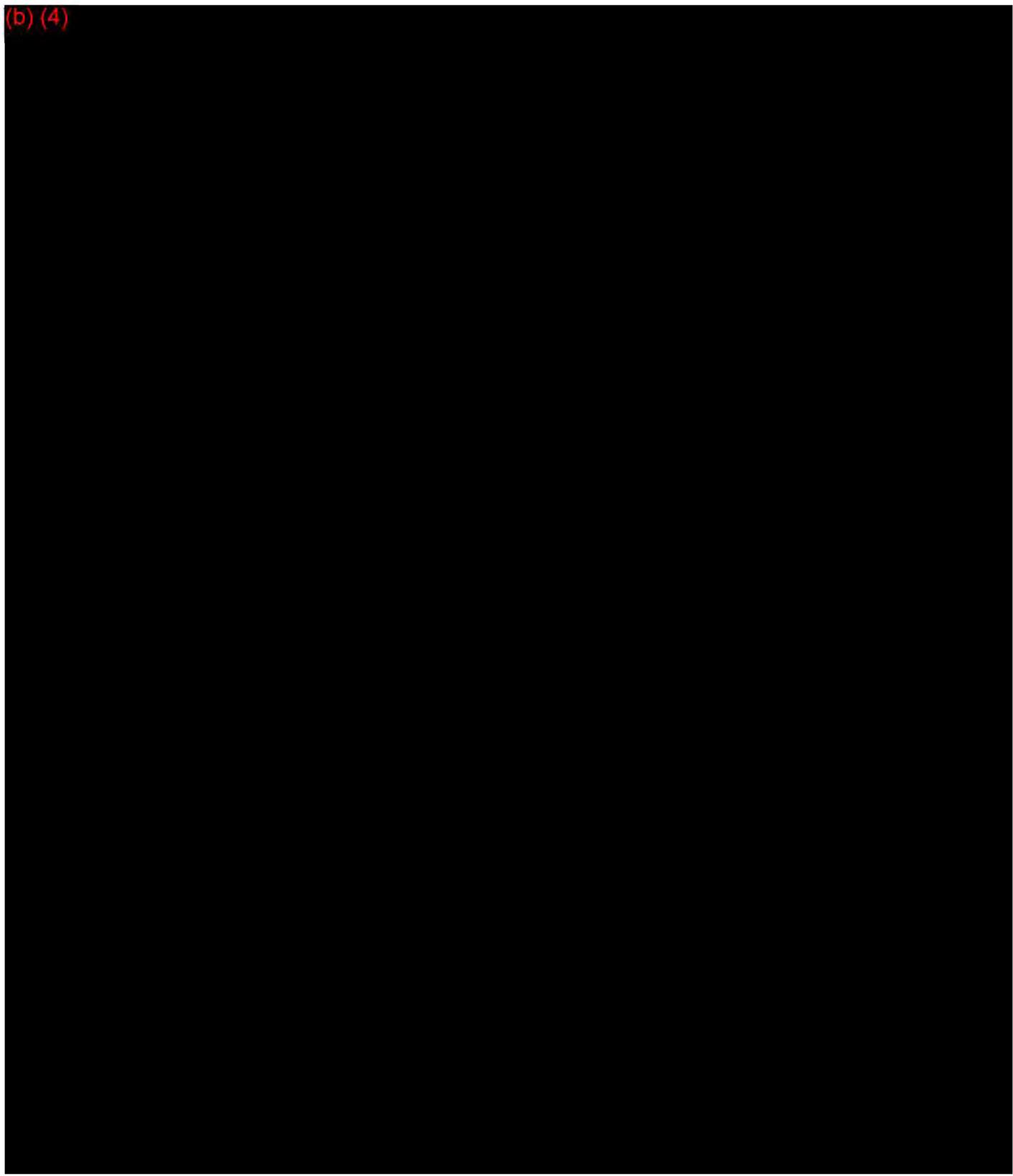
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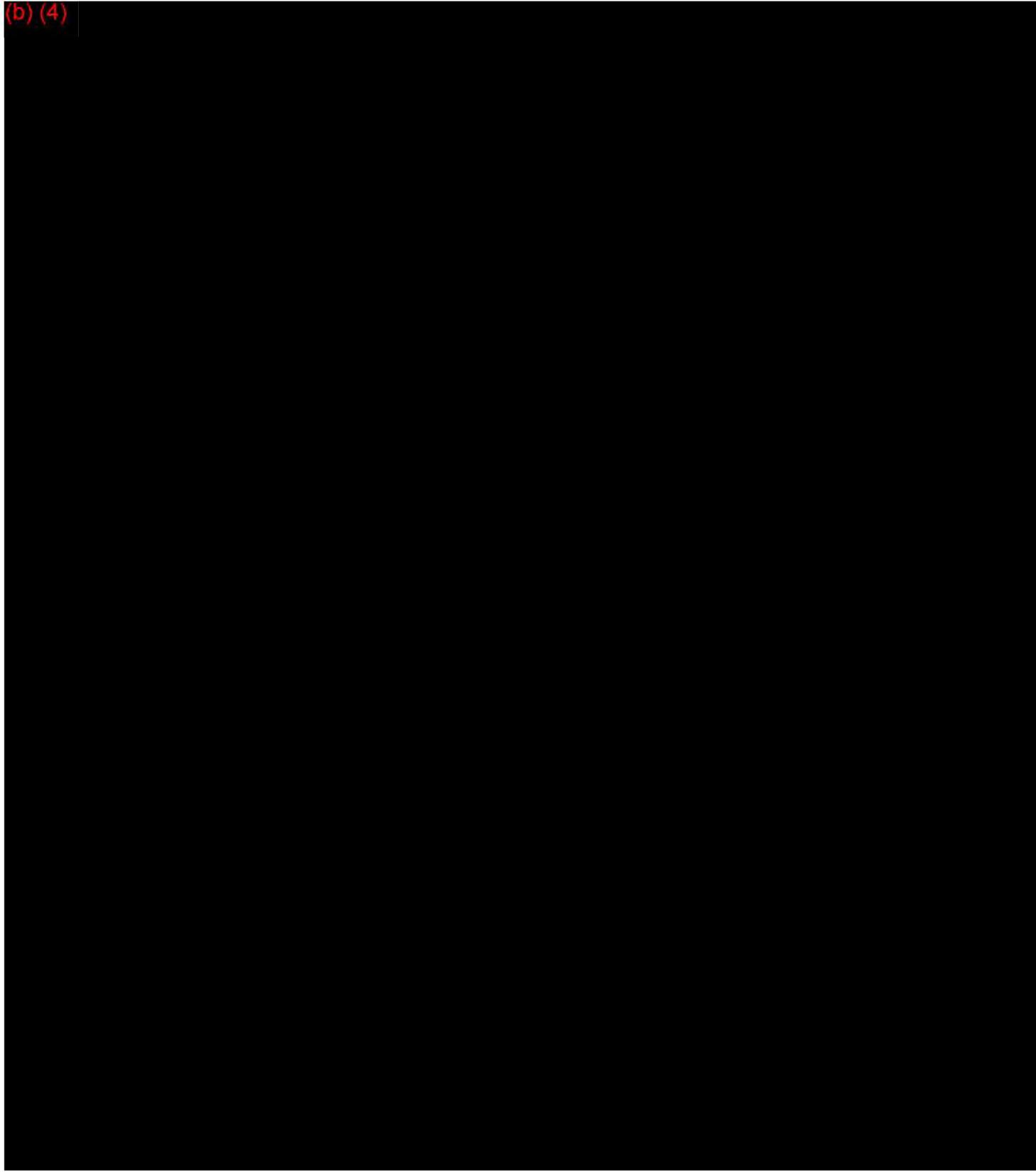
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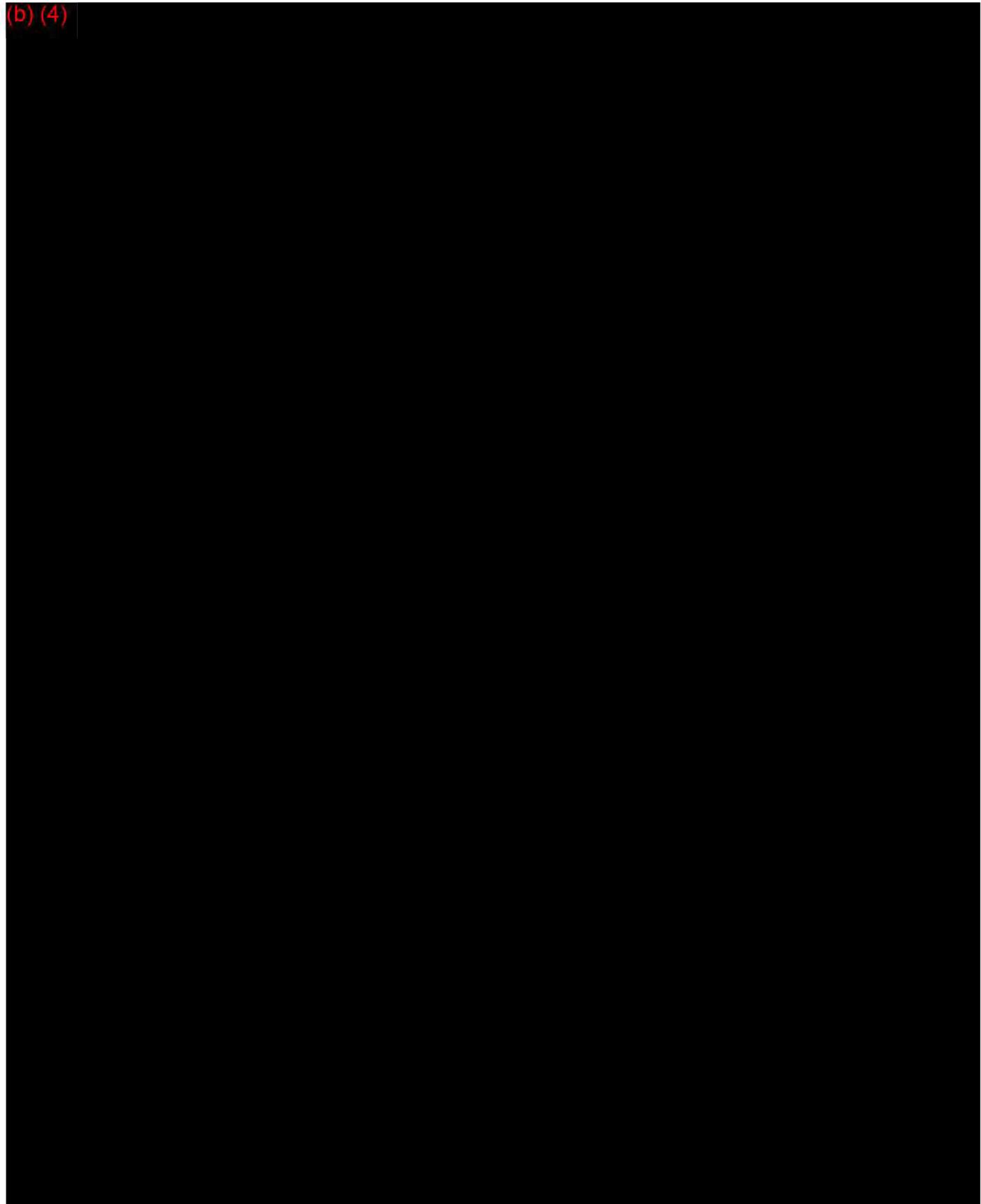
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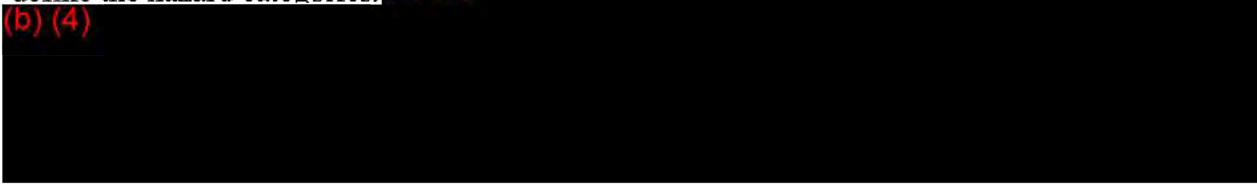


## 4.0 Functional Hazard Assessment

This section summarizes the Functional Hazard Assessment (FHA) that was performed as part of the 737 MAX 7/8/9 Elevator system safety analysis. The FHA is a systematic top-down examination of system functions to determine potential hazards that system malfunctions can cause to aircraft operation. An FHA is concerned with the functions and vulnerabilities of the system rather than with detailed hardware analysis. The FHA addresses each system function and the result of loss of function or erroneous operation. The analysis considered phases of flight, interfacing systems, and established effect categories for each failure condition.

Performance analysis, piloted simulations, or engineering judgment were used as needed to help define the hazard categories. (b) (4)

(b) (4)



The failure conditions defined by the FHA provide the basis for the top level events analyzed by the Fault Tree Analysis (FTA) to demonstrate compliance with CFR 25.671(c)(2) and 25.1309(b)(1). Table 4-1 shows the criticality categories used in developing the FHA and the corresponding acceptable probabilities of occurrence. The FHA results are presented in Table 4-3. A fault tree analysis was performed on each failure condition determined to be either Catastrophic or Hazardous and is shown in Section 6.0.

The FHA combined with detailed Failure Modes and Effects Analysis (FMEA) describing system and subsystem failures provides most of the framework for the fault tree analyses. (b) (4)

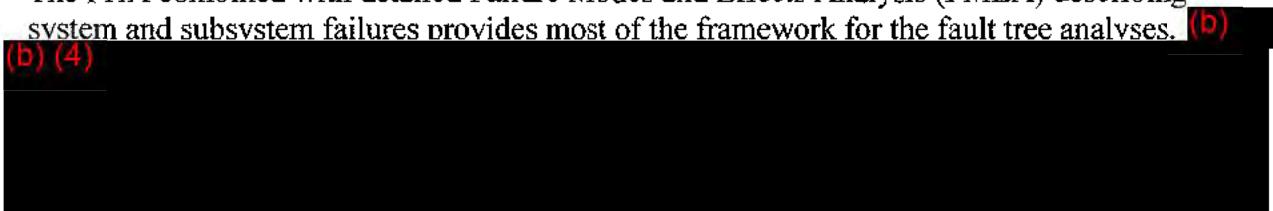
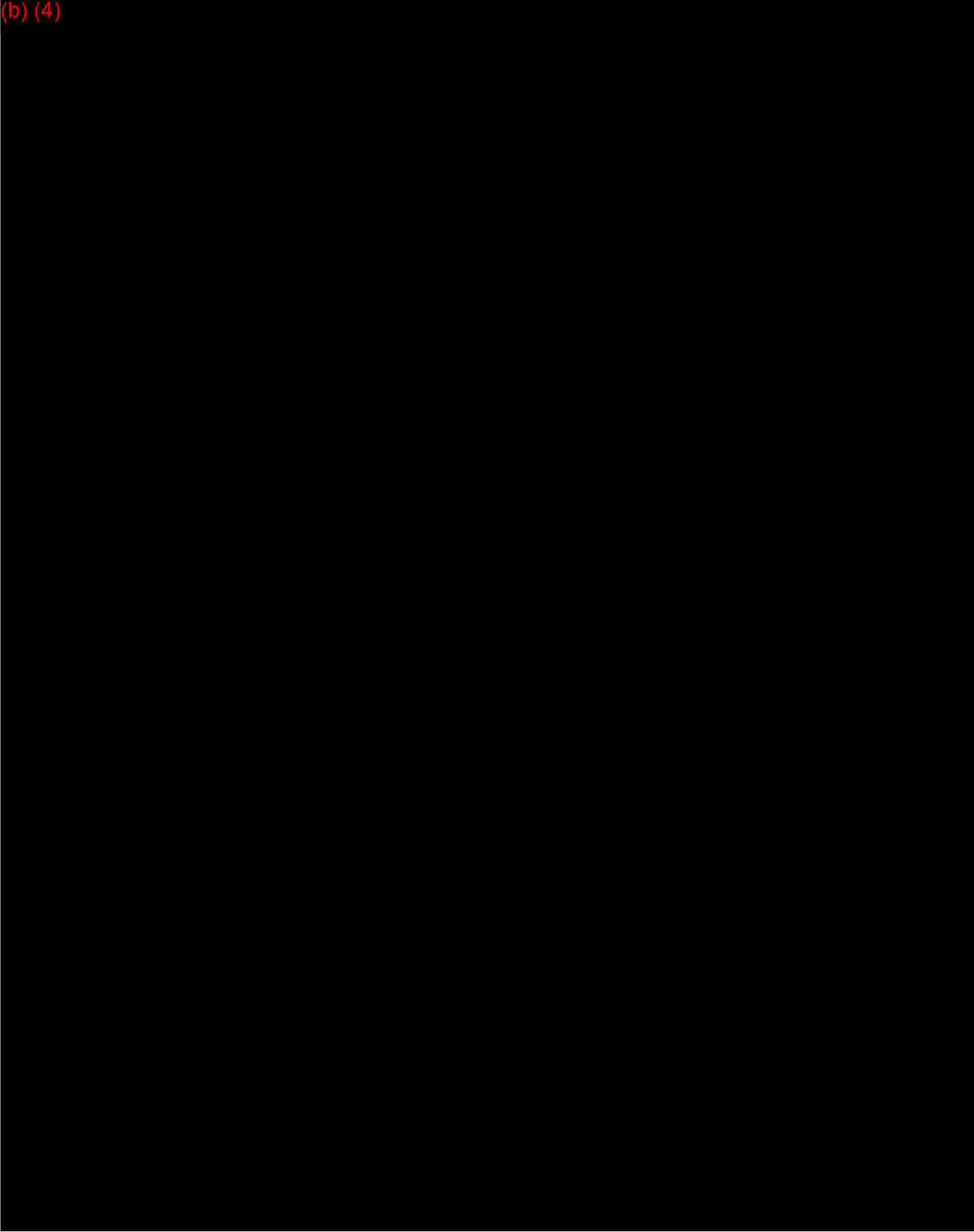


Table 4-1: CFR / CS Failure Effect Category Definitions

	<b>FAR - AC 25.1309-1A definitions</b>	No significant degradation of aircraft capability. Crew actions well within their capabilities.	Reduction of the aircraft capability or of the crew ability to cope with adverse operating conditions.		Prevention of continued safe flight and landing of the aircraft.
<b>Effects on aircraft and occupants of the identified failure condition.</b>	<b>AMJ No.1 of CS 25.1309 definitions.</b>	Slight reduction of safety margins,  Slight increase in work load, (e.g. routine changes in flight plan), or  Physical effects but no injury to occupants.	Significant reduction in safety margins,  Reduction in the ability of the flight crew to cope with adverse operating conditions impairing their efficiency, or  Injury to occupants.	Large reduction in safety margins, Physical distress or workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely, or Serious injury to or death of a relatively small portion of the occupants.	Loss of the aircraft and/or fatalities.
<b>FAR effect category AC 25.1309-1A.</b>	<b>Minor</b>		<b>Major</b>		<b>Catastrophic</b>
<b>CS effect category AMJ No. 1 of 25.1309</b>	<b>Minor</b>		<b>Major</b>	<b>Hazardous</b>	<b>Catastrophic</b>
<b>Criticality category RTCA DO-178A</b>	<b>Non-essential (Level 3 software)</b>		<b>Essential (Level 2 software)</b>		<b>Critical (Level 1 software)</b>
<b>Criticality category RTCA DO-178B</b>	<b>Minor (Level D software)</b>		<b>Major (Level C software)</b>	<b>Hazardous (Level B software)</b>	<b>Catastrophic (Level A software)</b>
<b>FAR qualitative probability terms.</b>	<b>Probable</b>		<b>Improbable.</b>		<b>Extremely Improbable</b>
<b>CS qualitative probability terms.</b>	<b>Frequent</b>	<b>Reasonably Probable</b>	<b>Remote</b>	<b>Extremely Remote</b>	<b>Extremely Improbable</b>
<b>FAR and CS quantitative probability ranges.</b>	10 <sup>-3</sup> 10 <sup>-5</sup> 10 <sup>-7</sup> 10 <sup>-9</sup> Probability of Failure Condition (for one flight hour or flight if less than one hour).				

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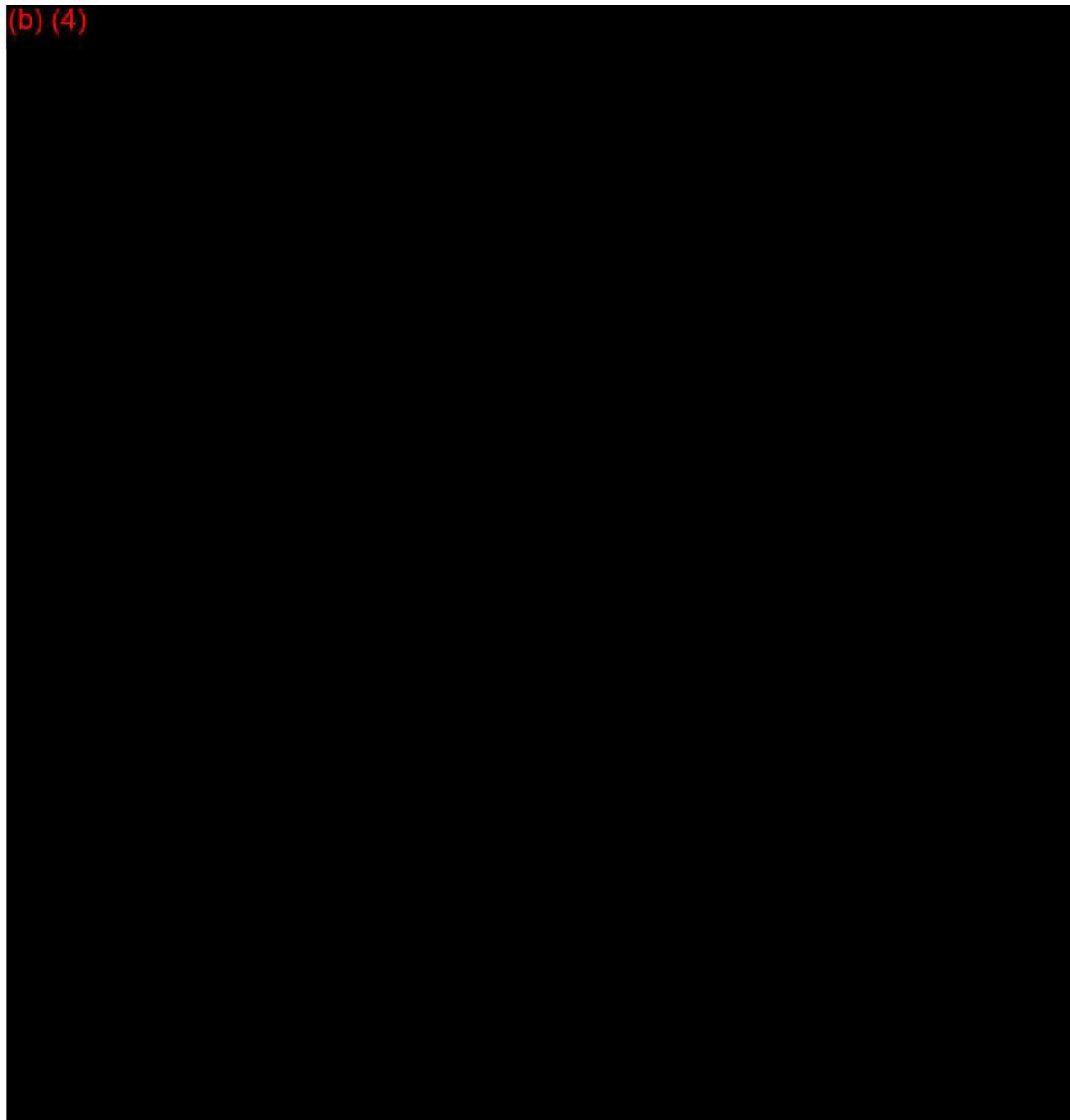
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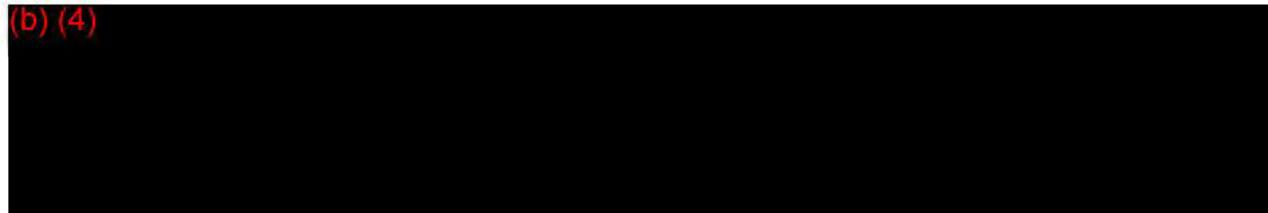


## 5. FAILURE MODES AND EFFECTS ANALYSIS

The Failure Modes and Effects Analysis (FMEA) provides a "bottom up" analysis of the Elevator Control System. For each identifiable functional failure of a component in the system, the following airplane level effects were evaluated:

- System or airplane level effects relevant to aircraft operation and flight crew workload
- Annunciation or other means of indication to the flight crew
- Hazard level of the failure
- In the case of a latent failure, the latency and relevant maintenance task is also addressed

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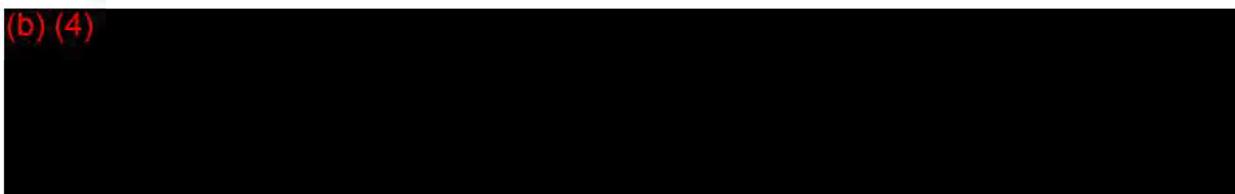


### 5.1 FMEA Map

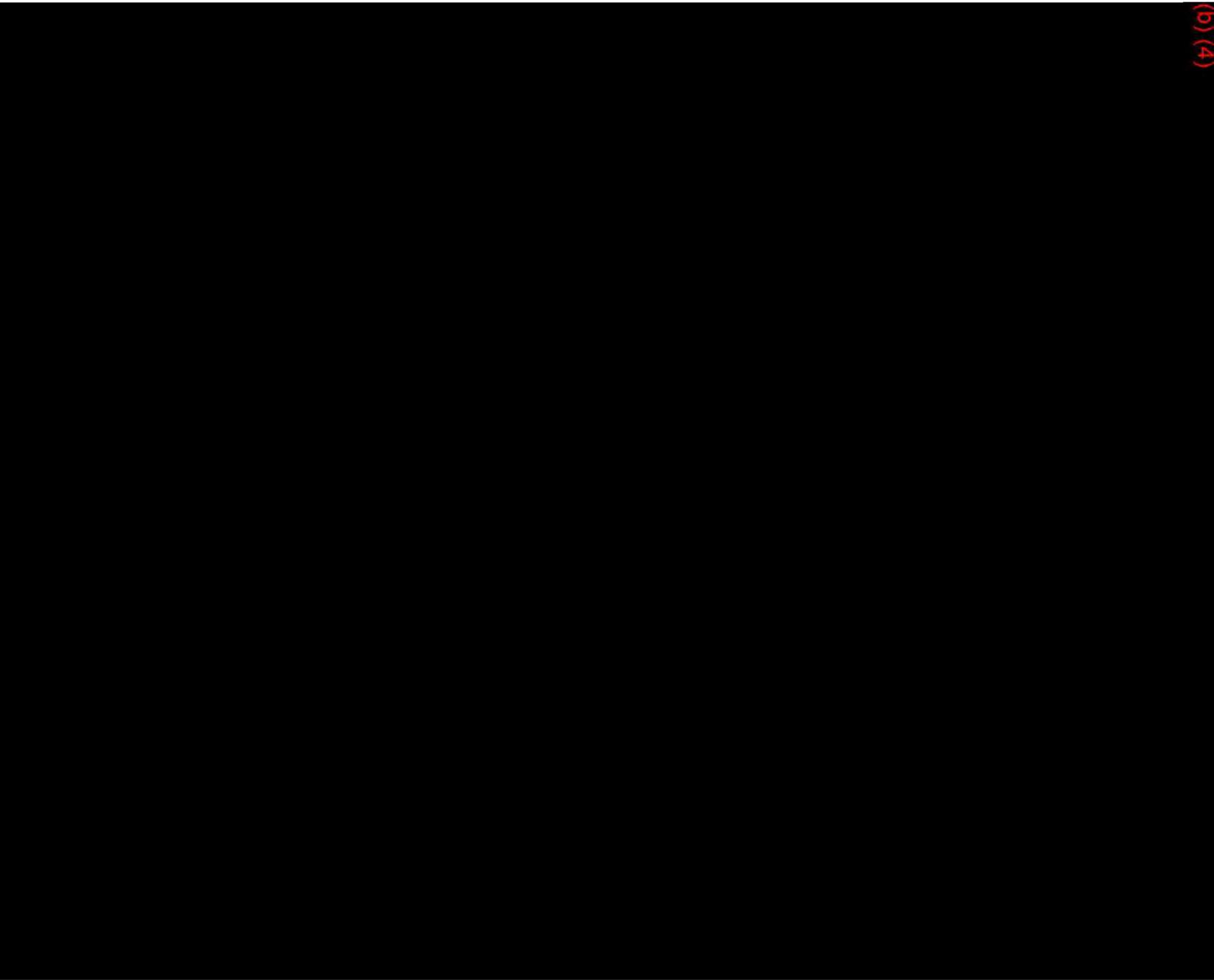
The FMEA Map is a graphical representation of the functional relationships in the Elevator Control System and it is intended to aid in the understanding of FMEA results. Each component in the Elevator Control System has been assigned a reference number according to the outline map. These reference numbers are used in column one of the FMEA table to track each component.

The figures below show the reference numbers for various components and sub-components as follows:

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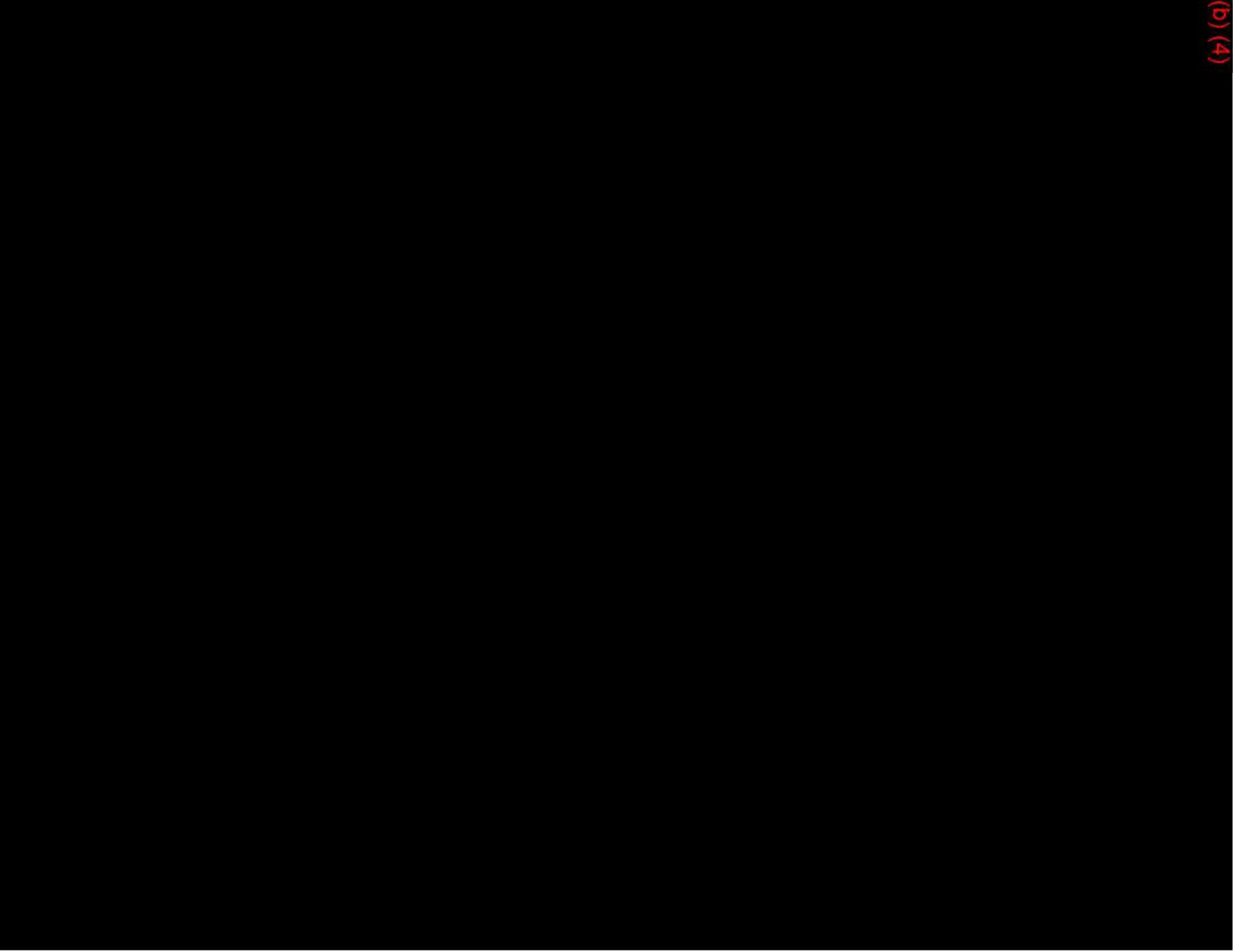
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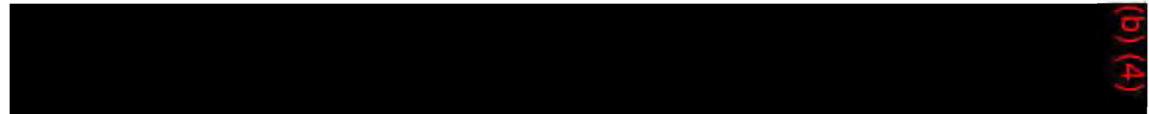
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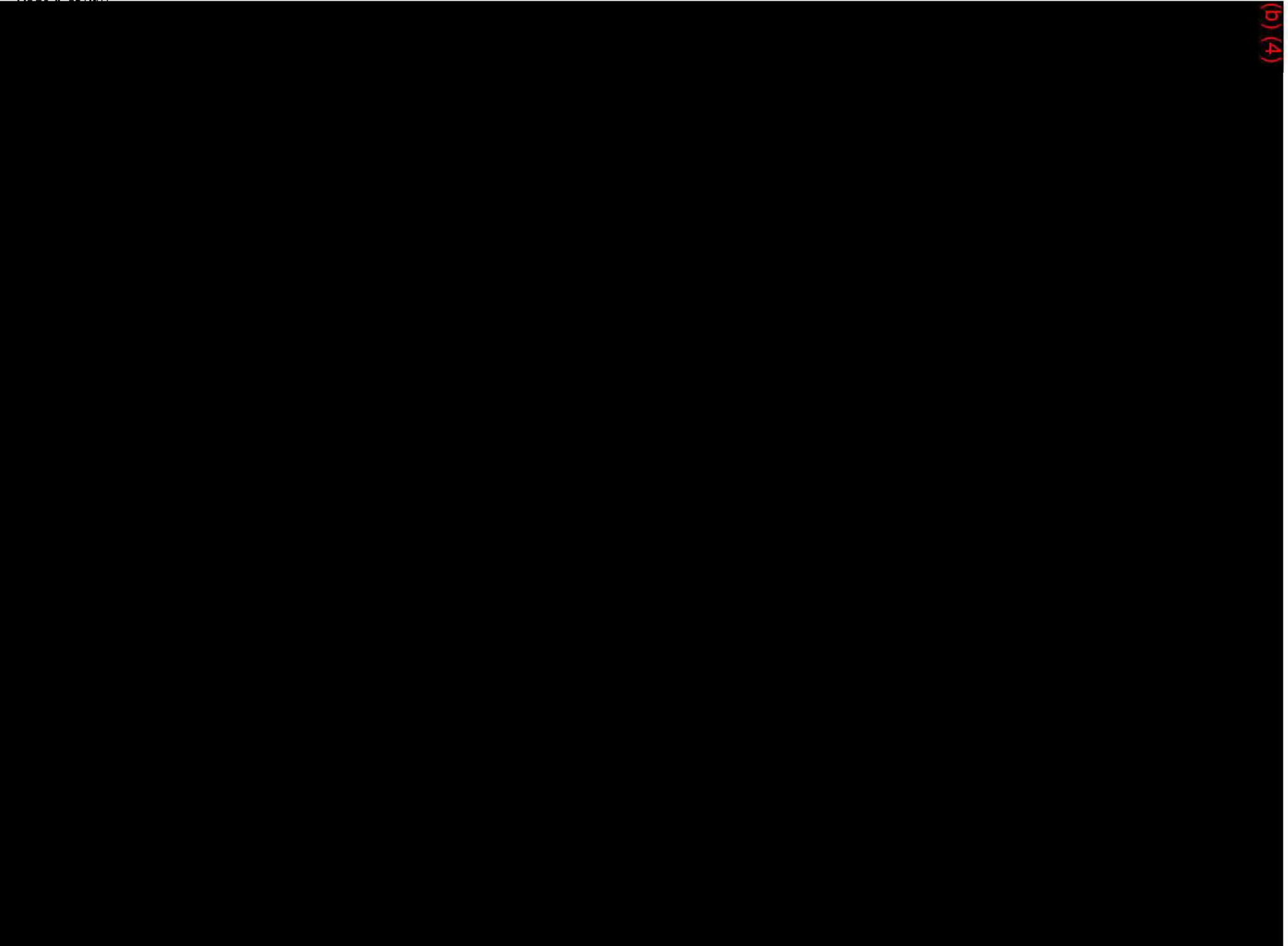
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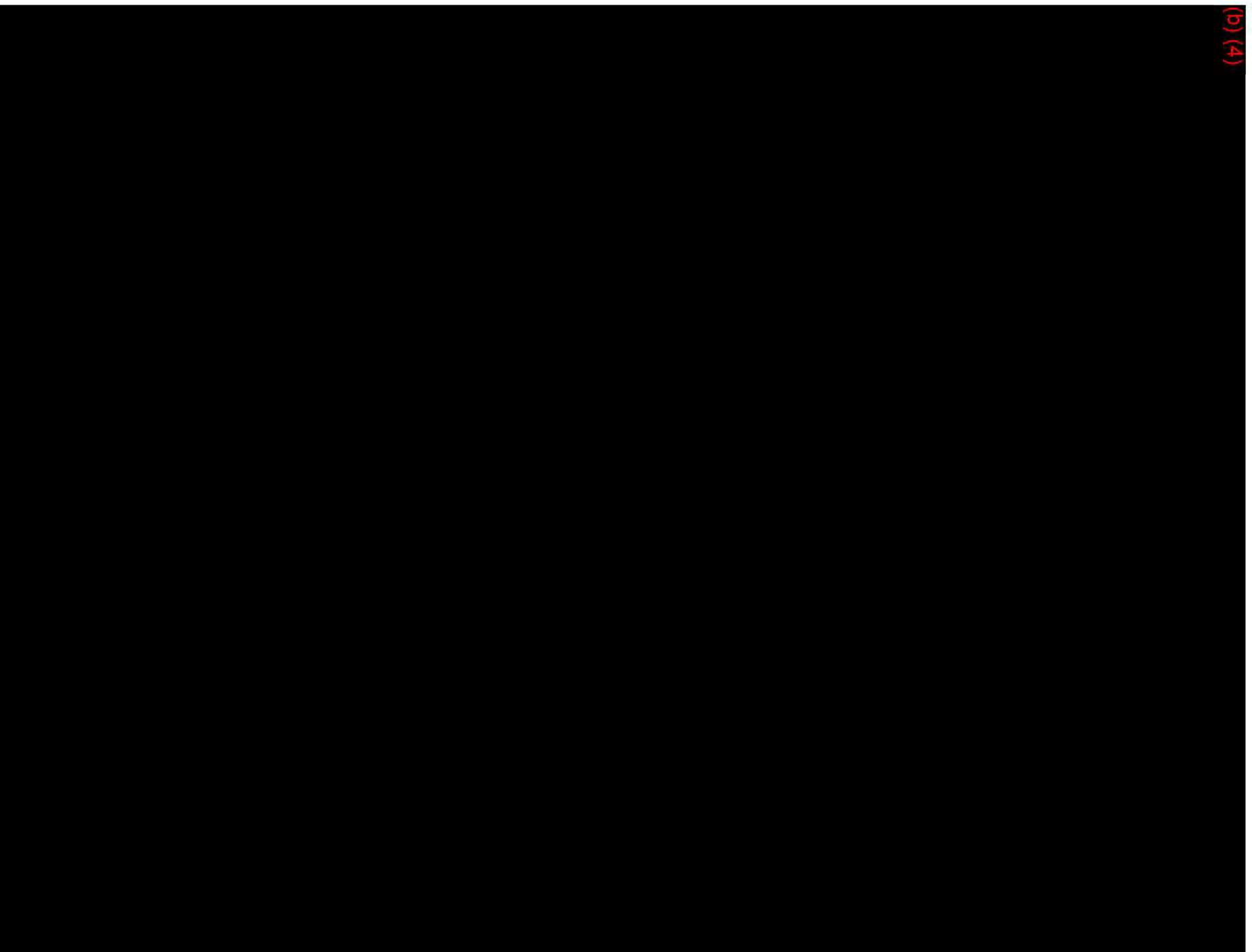
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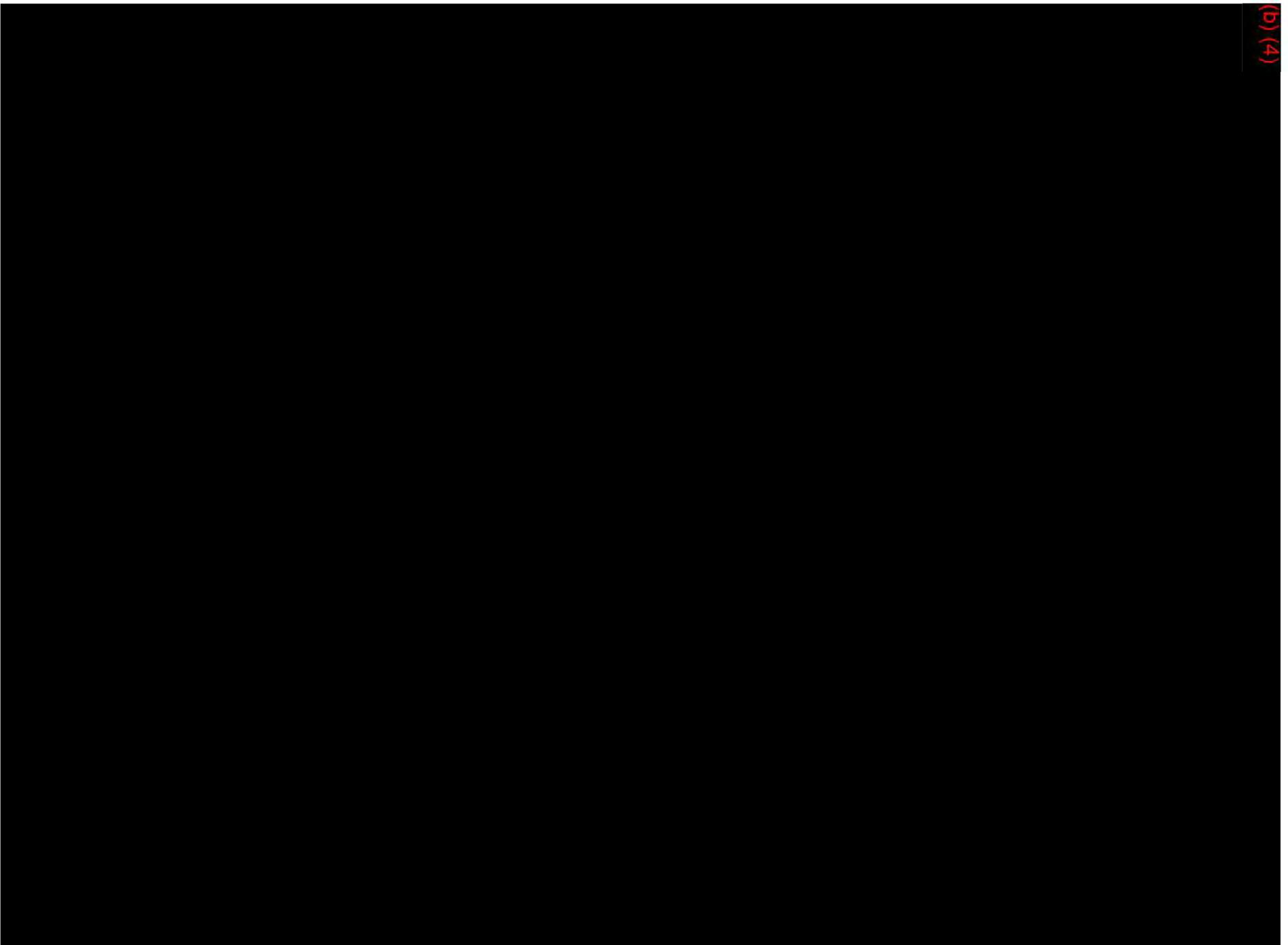
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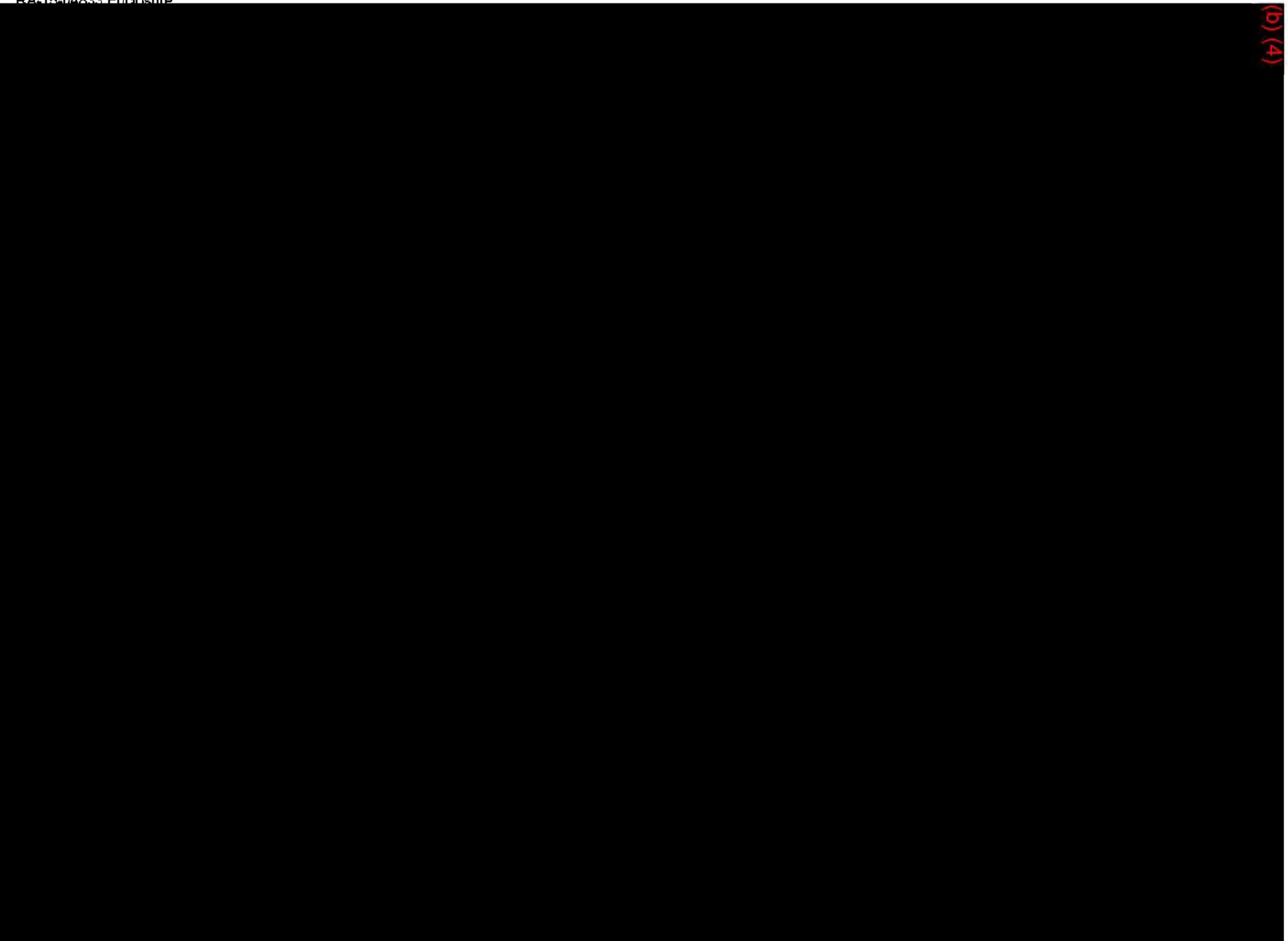
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## 6.0 Fault Tree Analysis

This section presents the Fault Tree Analysis (FTA) that was developed as part of the Elevator Control Systems safety analysis. The FTA is a tool that is used to quantitatively determine the numerical probability of a certain combination of failures. The failure conditions defined by the FHA provide the basis for the top level events analyzed by the fault tree analysis to demonstrate compliance with CFR 25.671(c)(2), (c)(3) and 25.1309(b)(1).

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### 6.1 Fault Tree Symbols

The following symbols are used in the fault trees:



AND gate



OR gate



Basic Event



Undeveloped Event

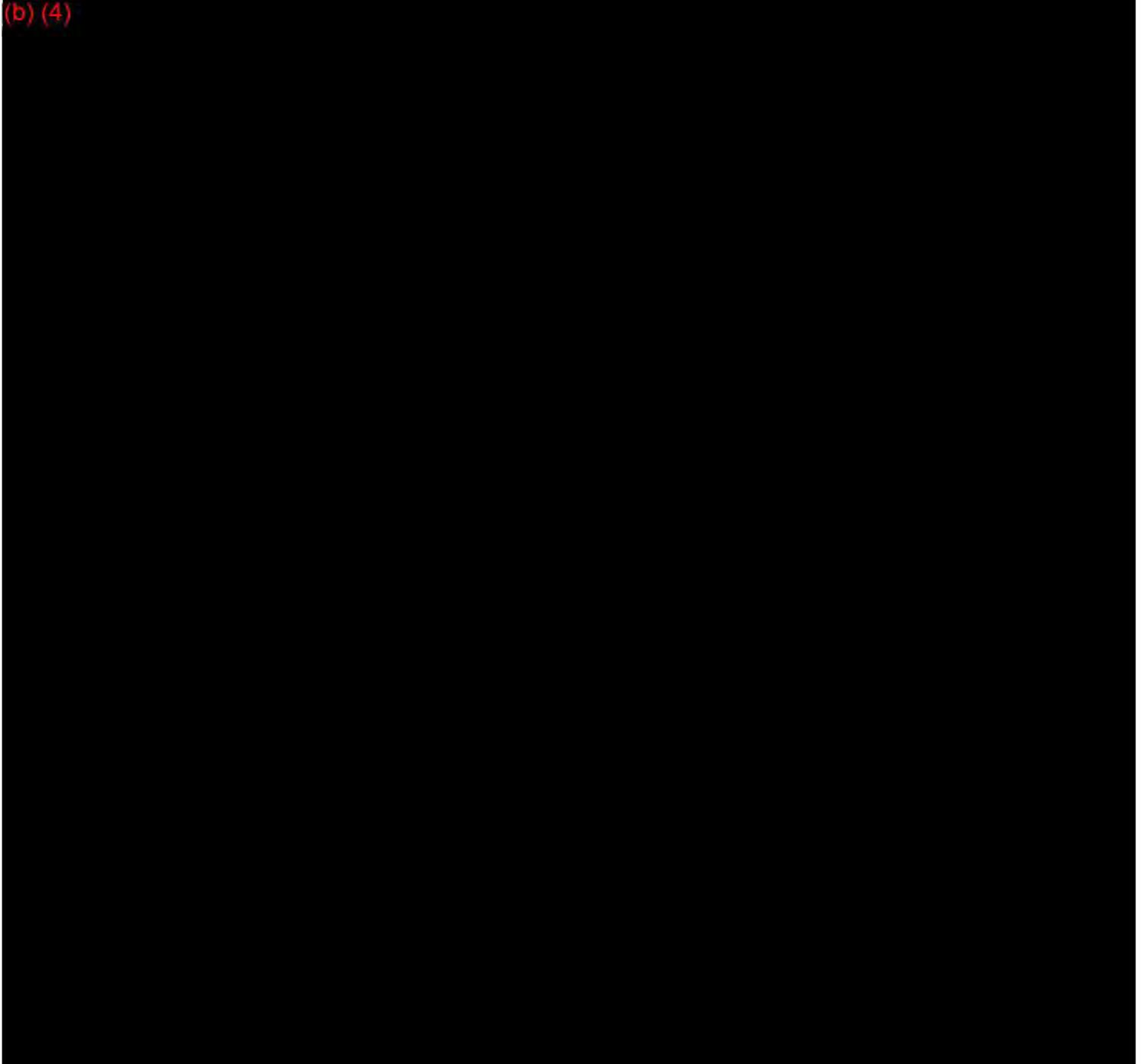


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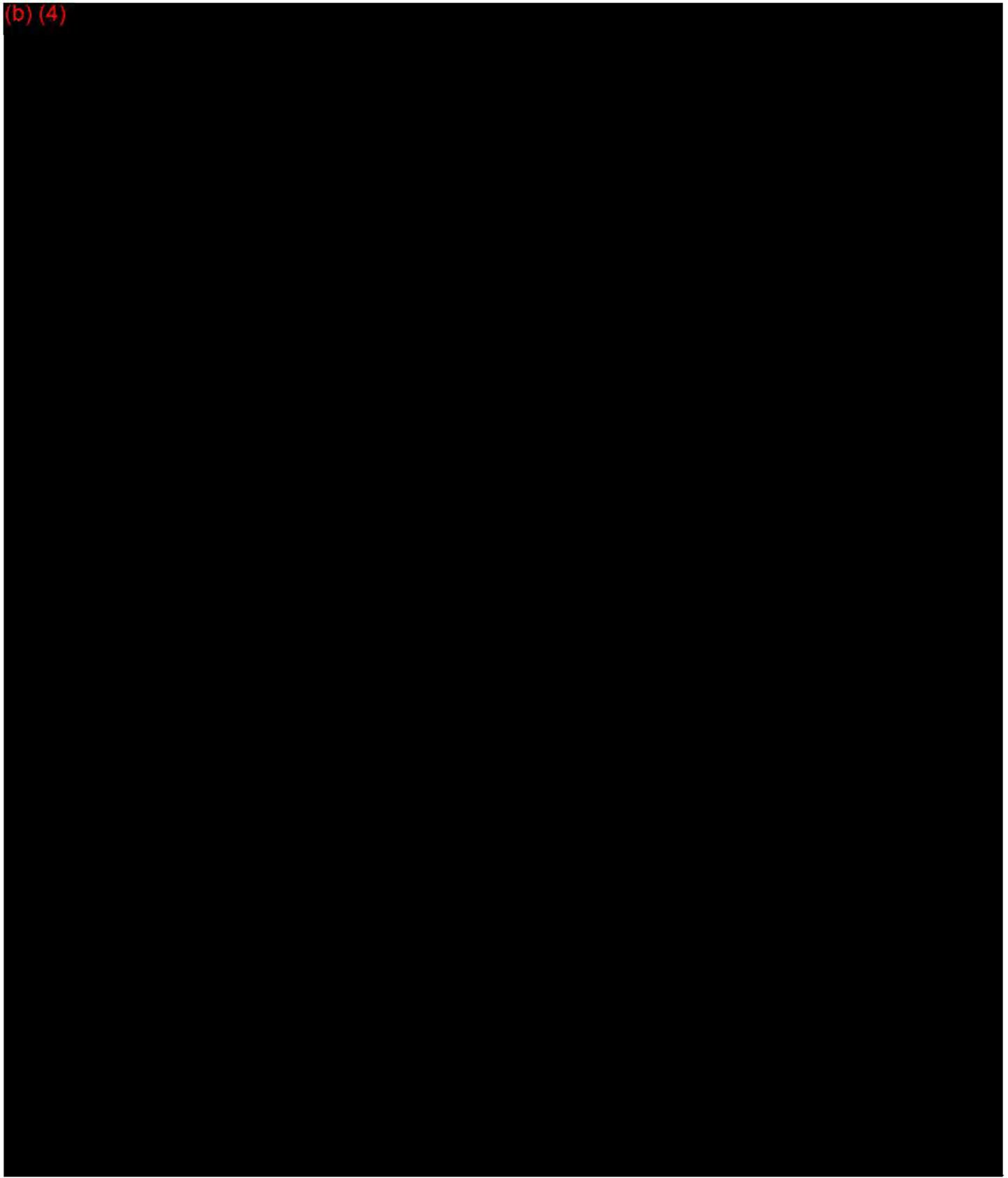


Combination gate

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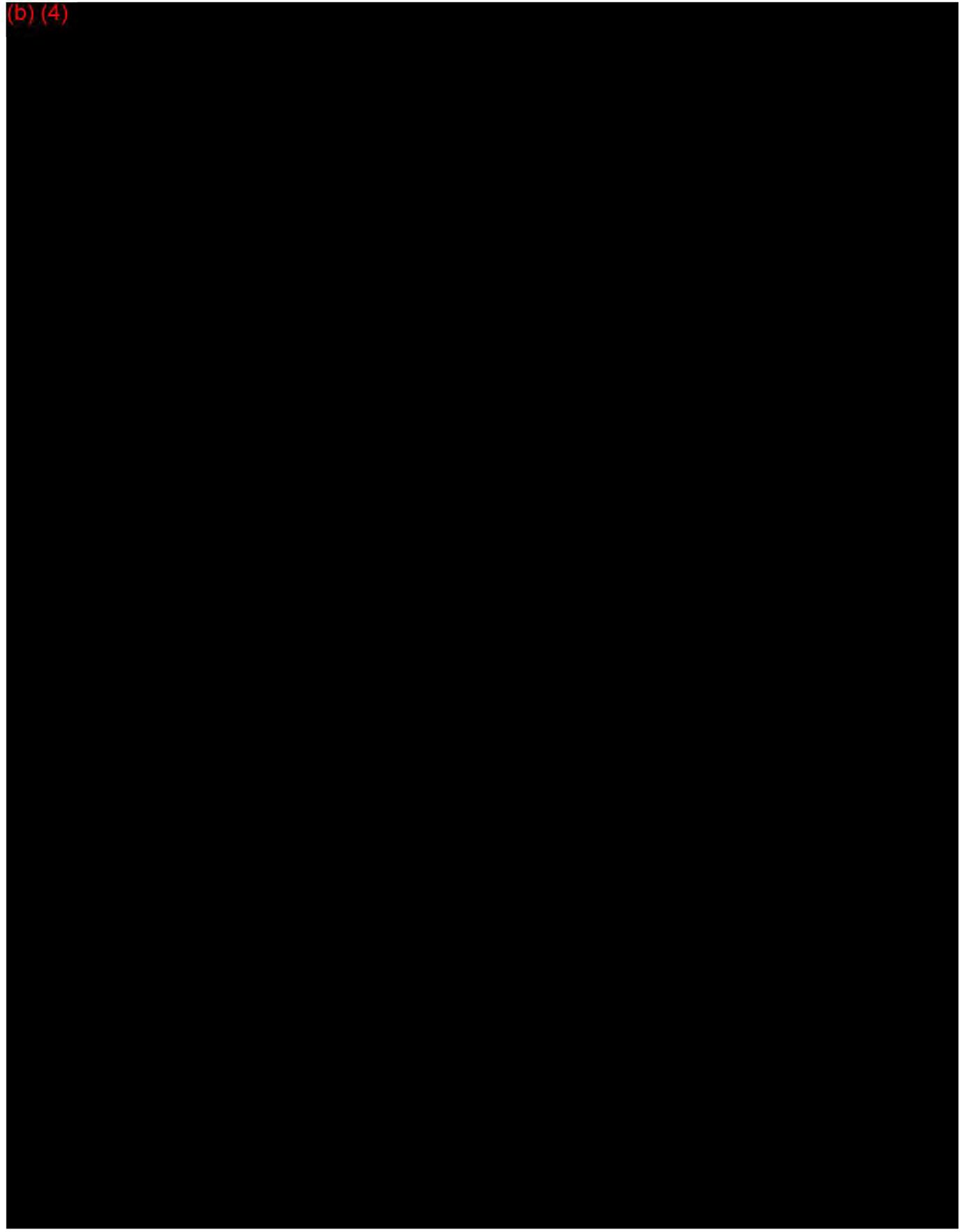
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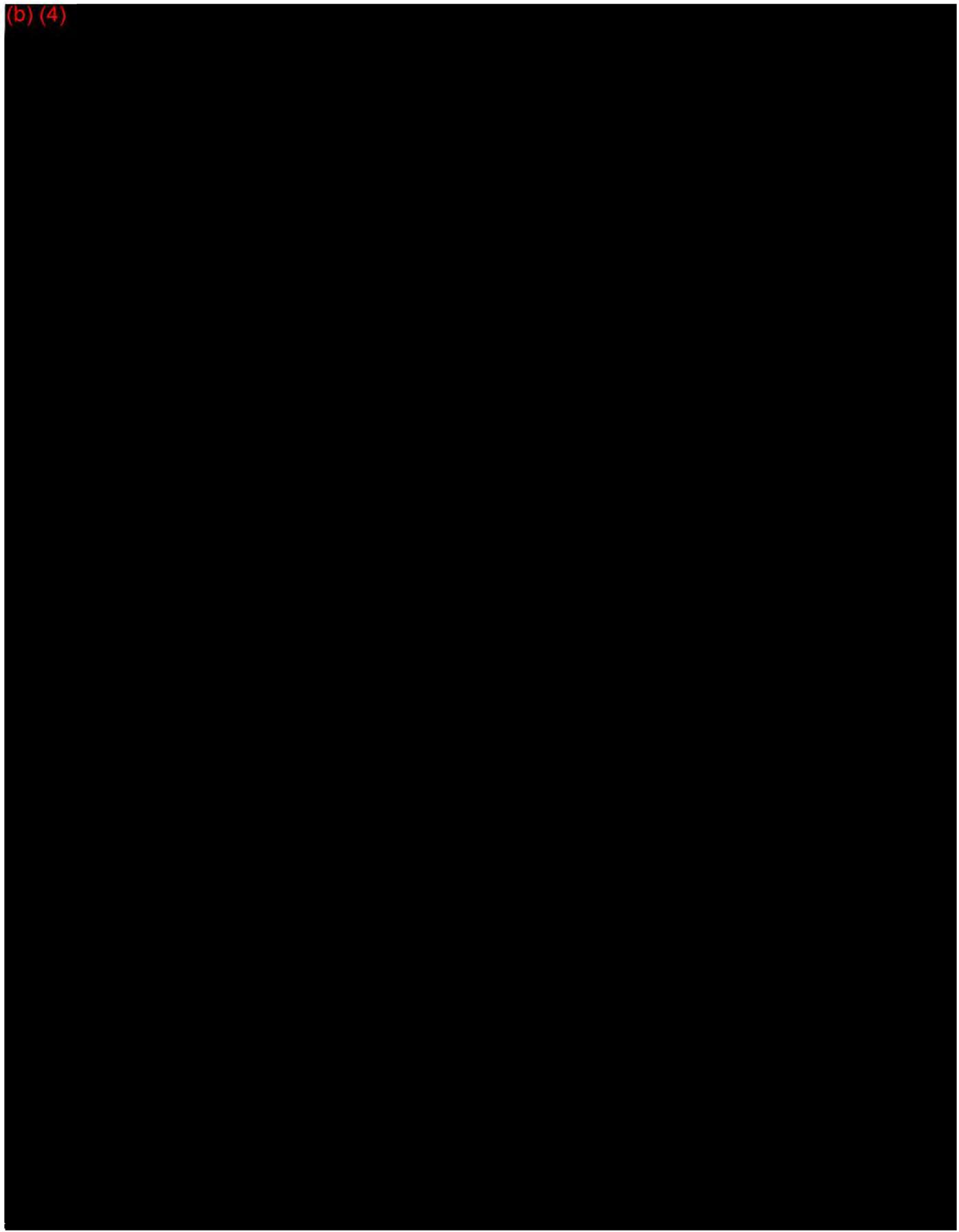
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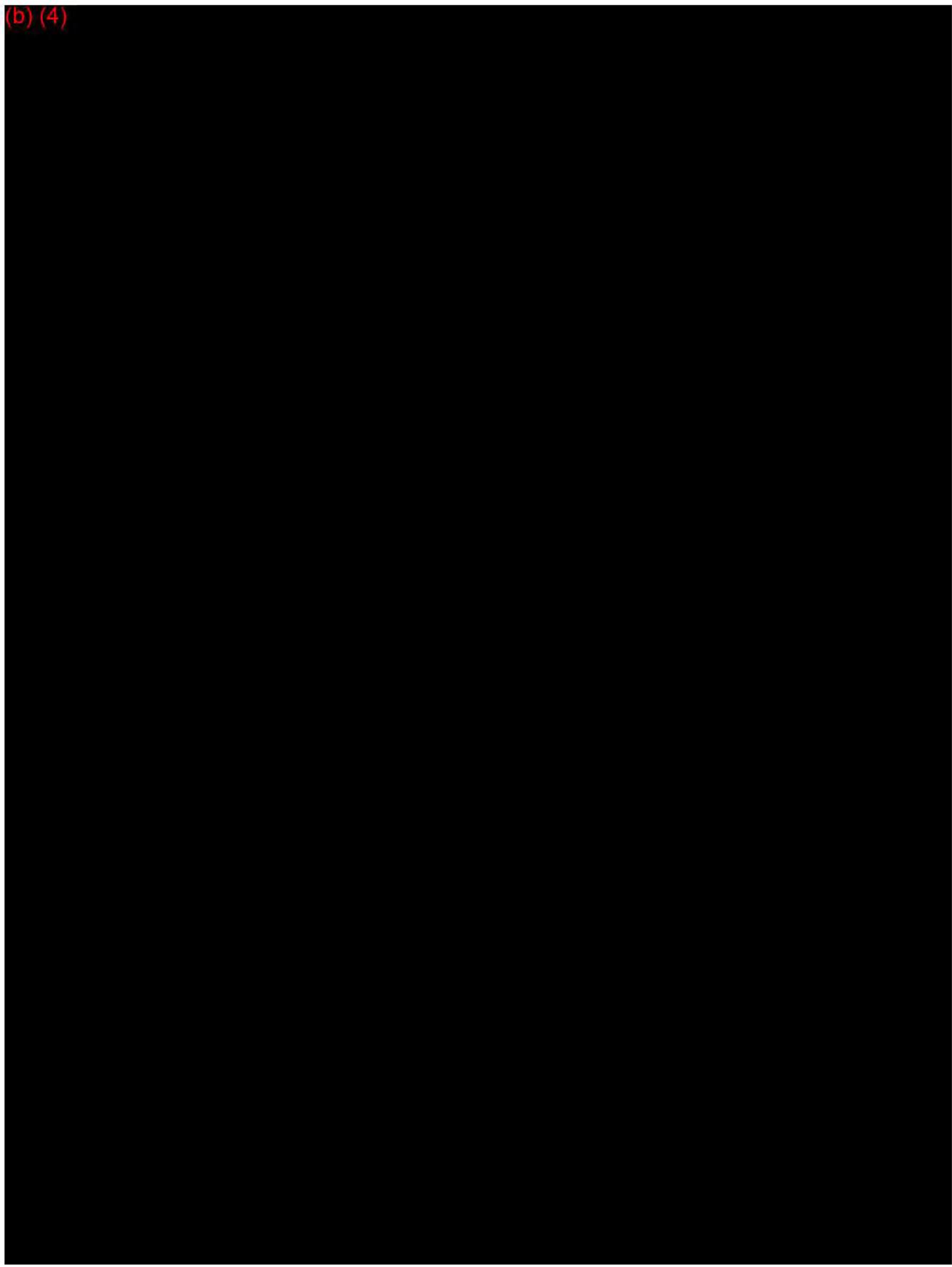
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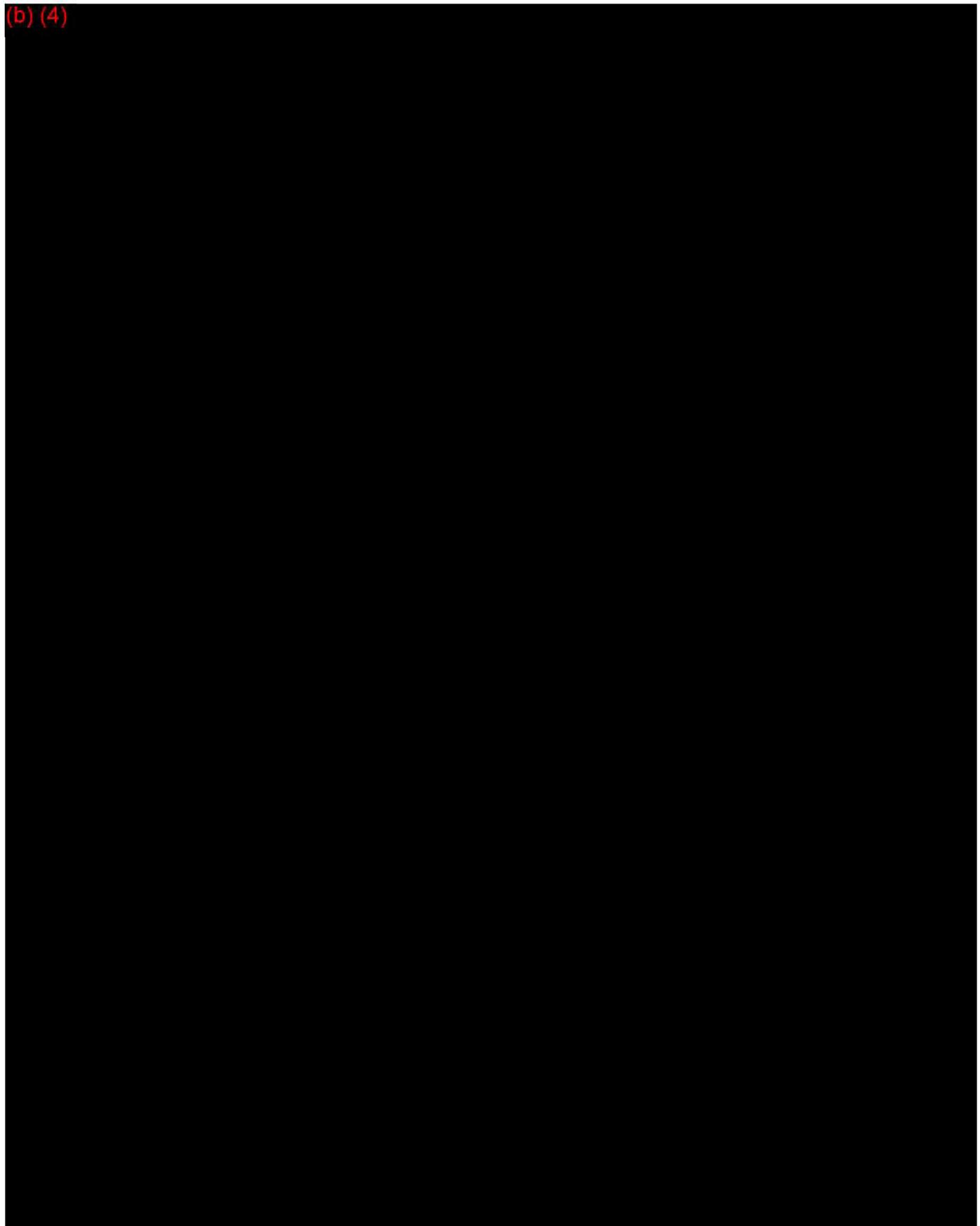
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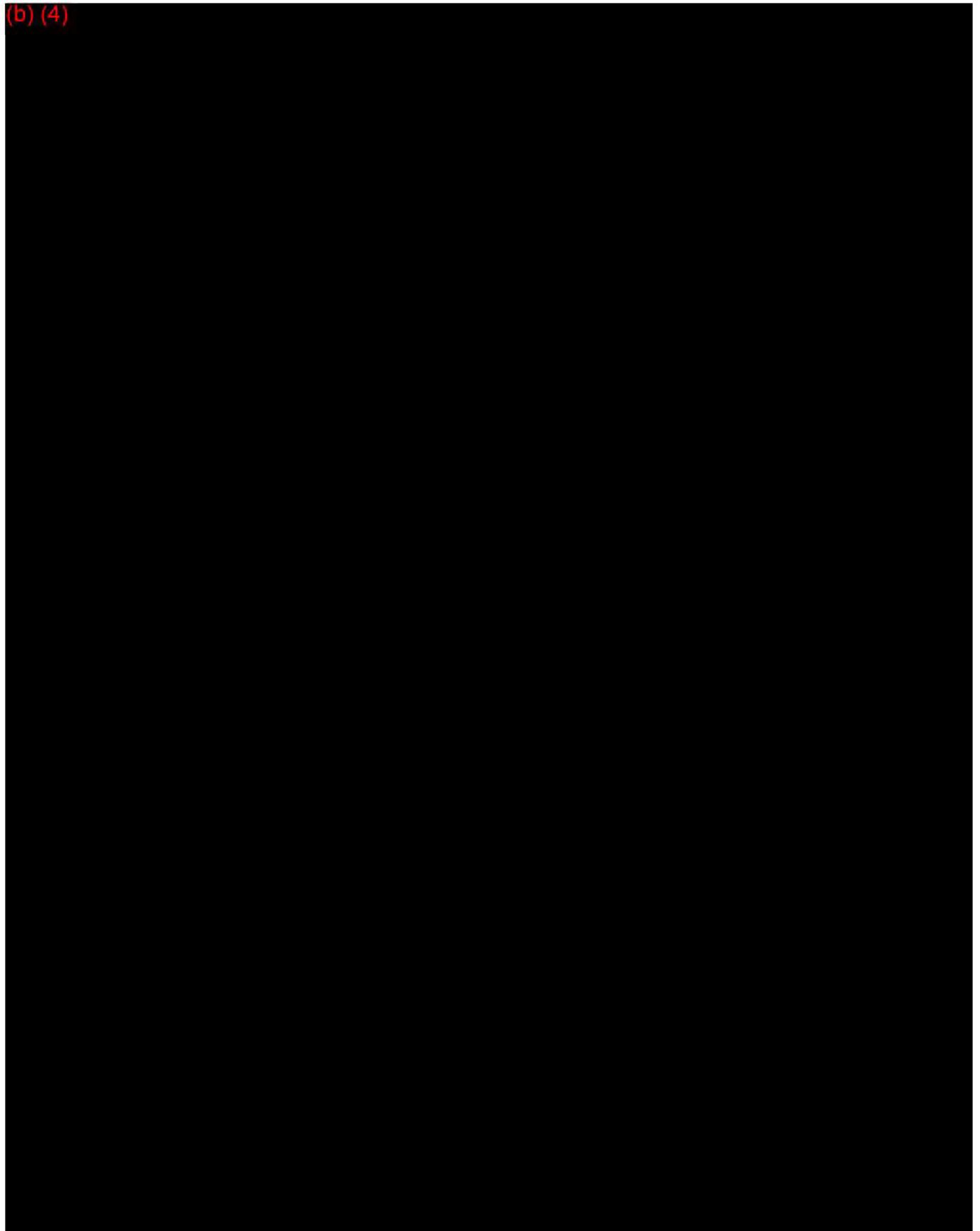
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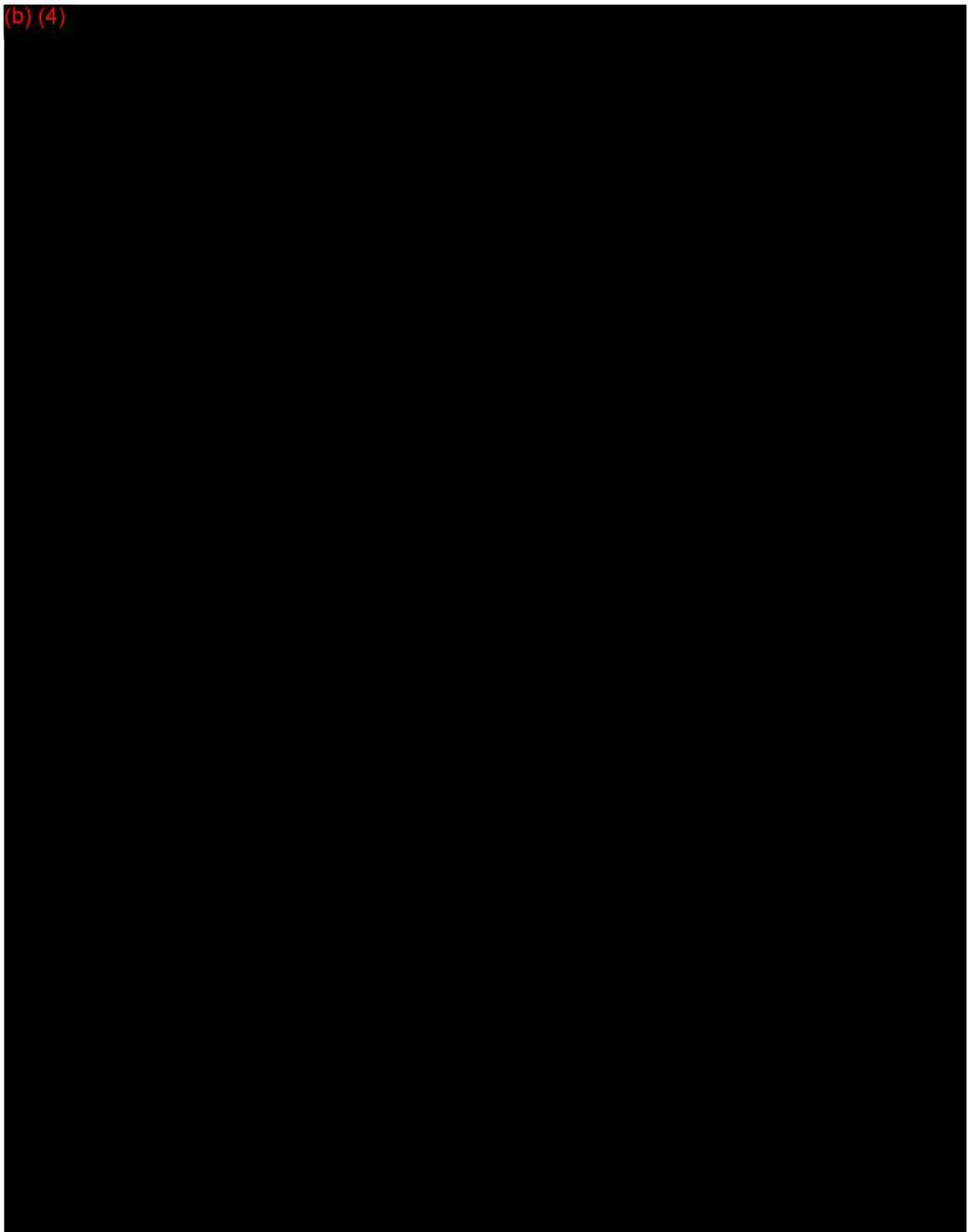
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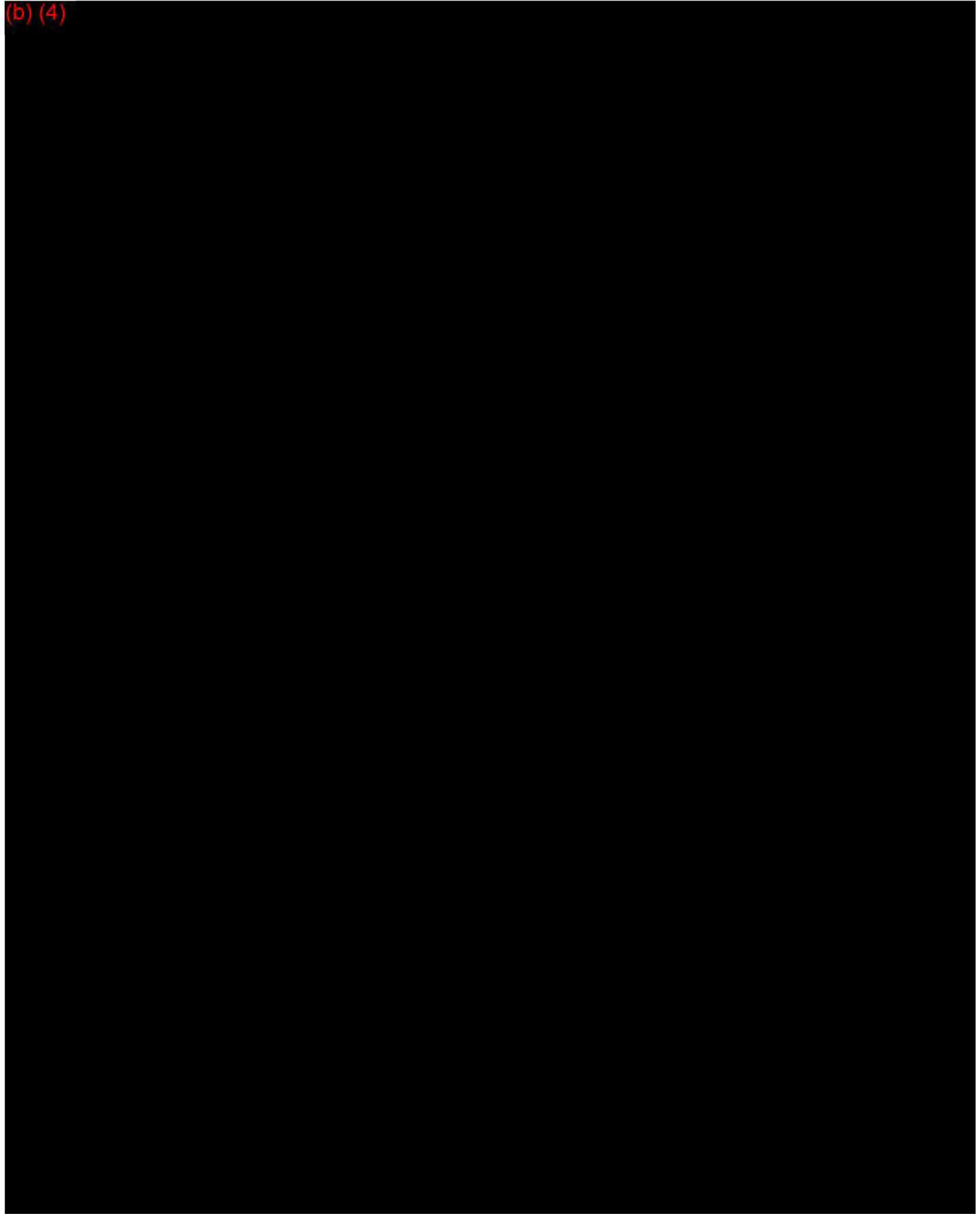
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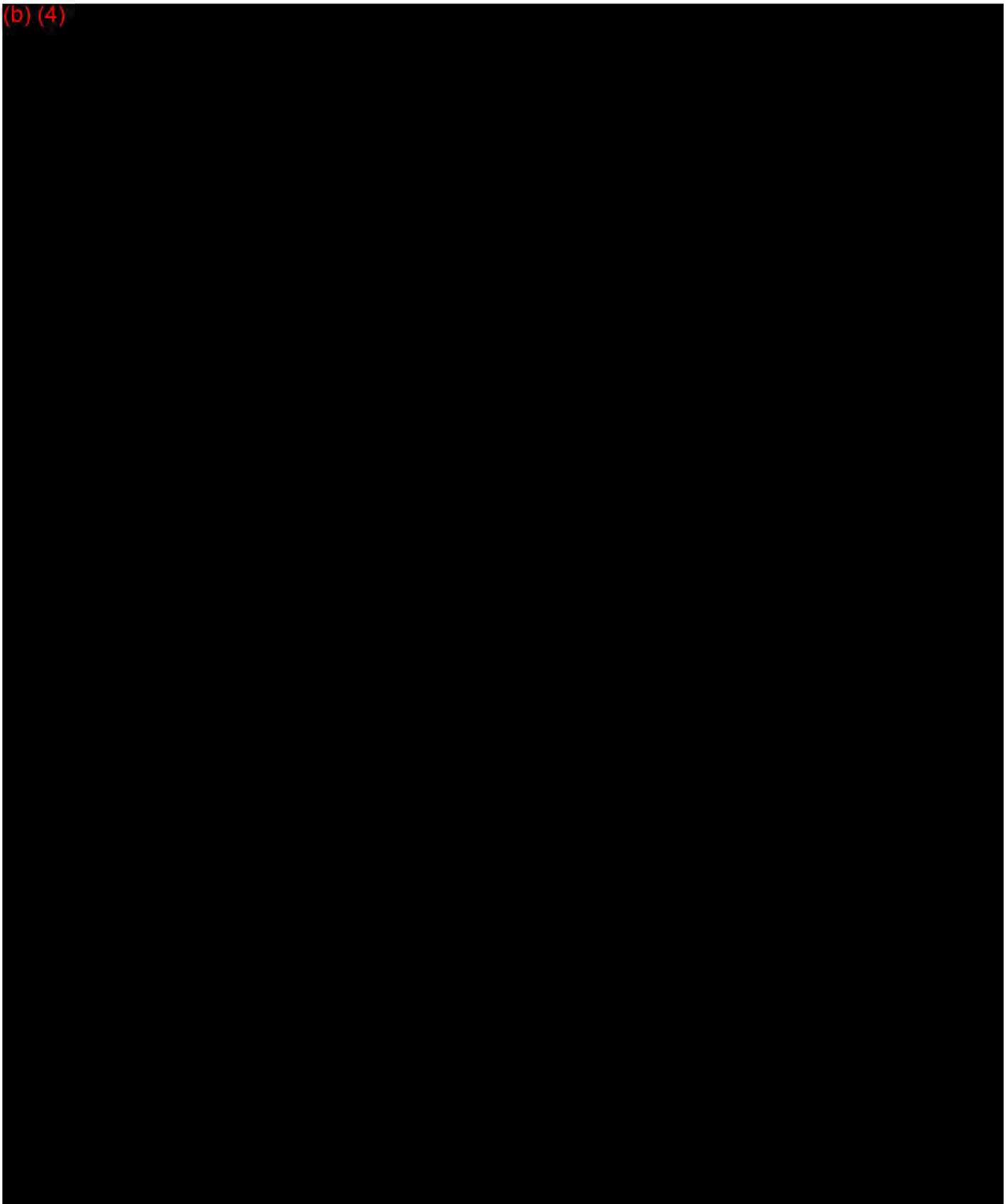
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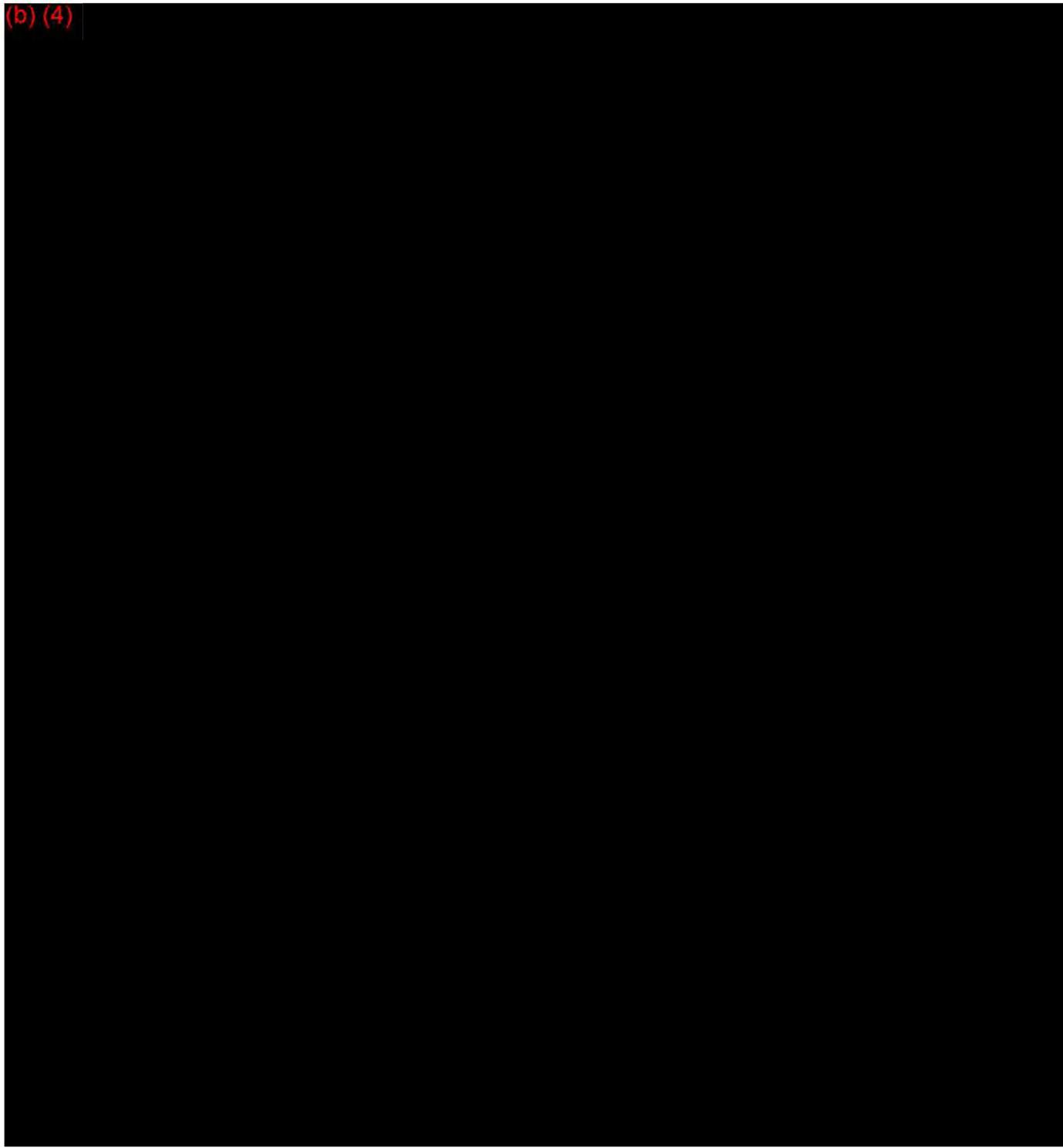
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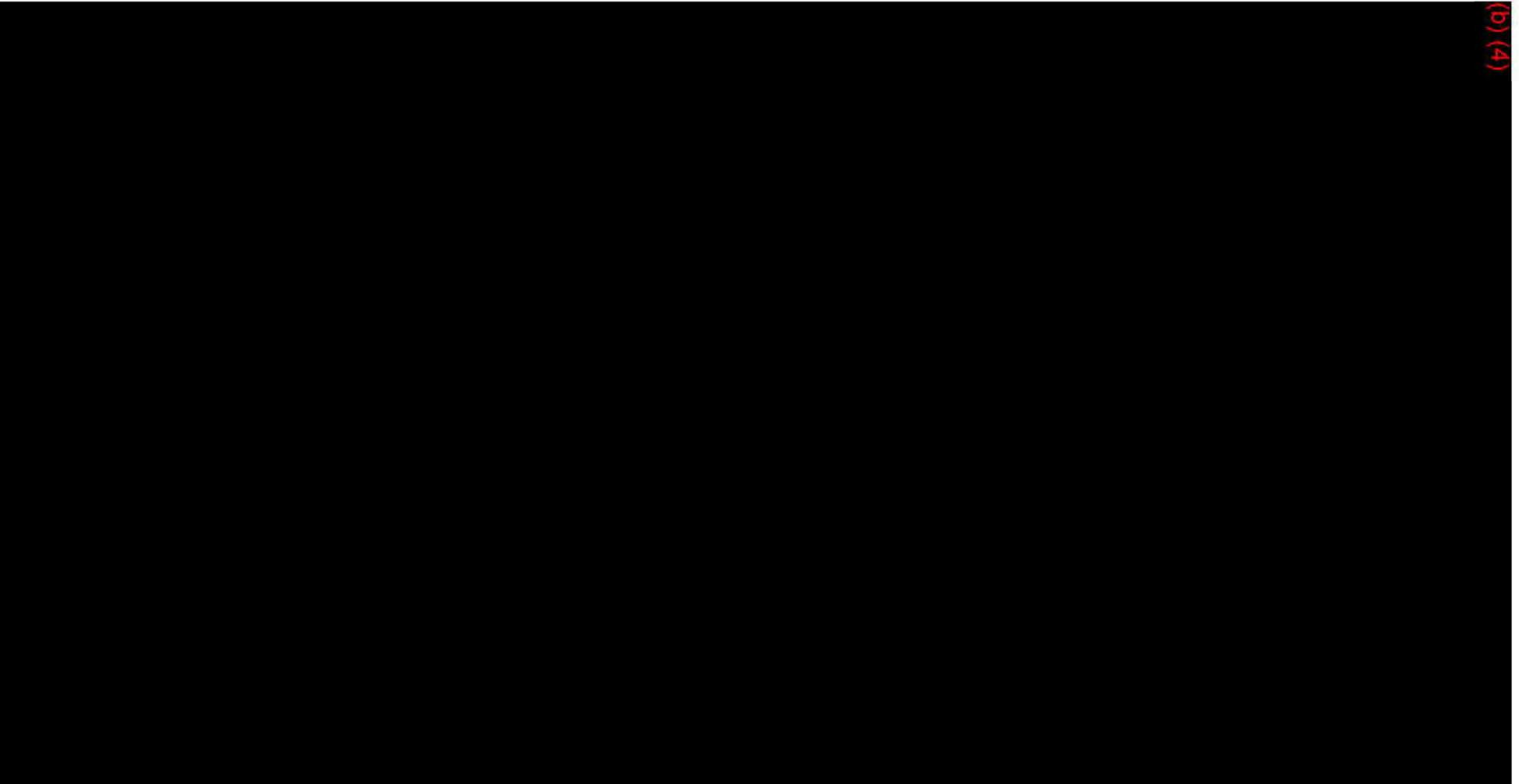


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**BOEING PROPRIETARY**  
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(b) (4)

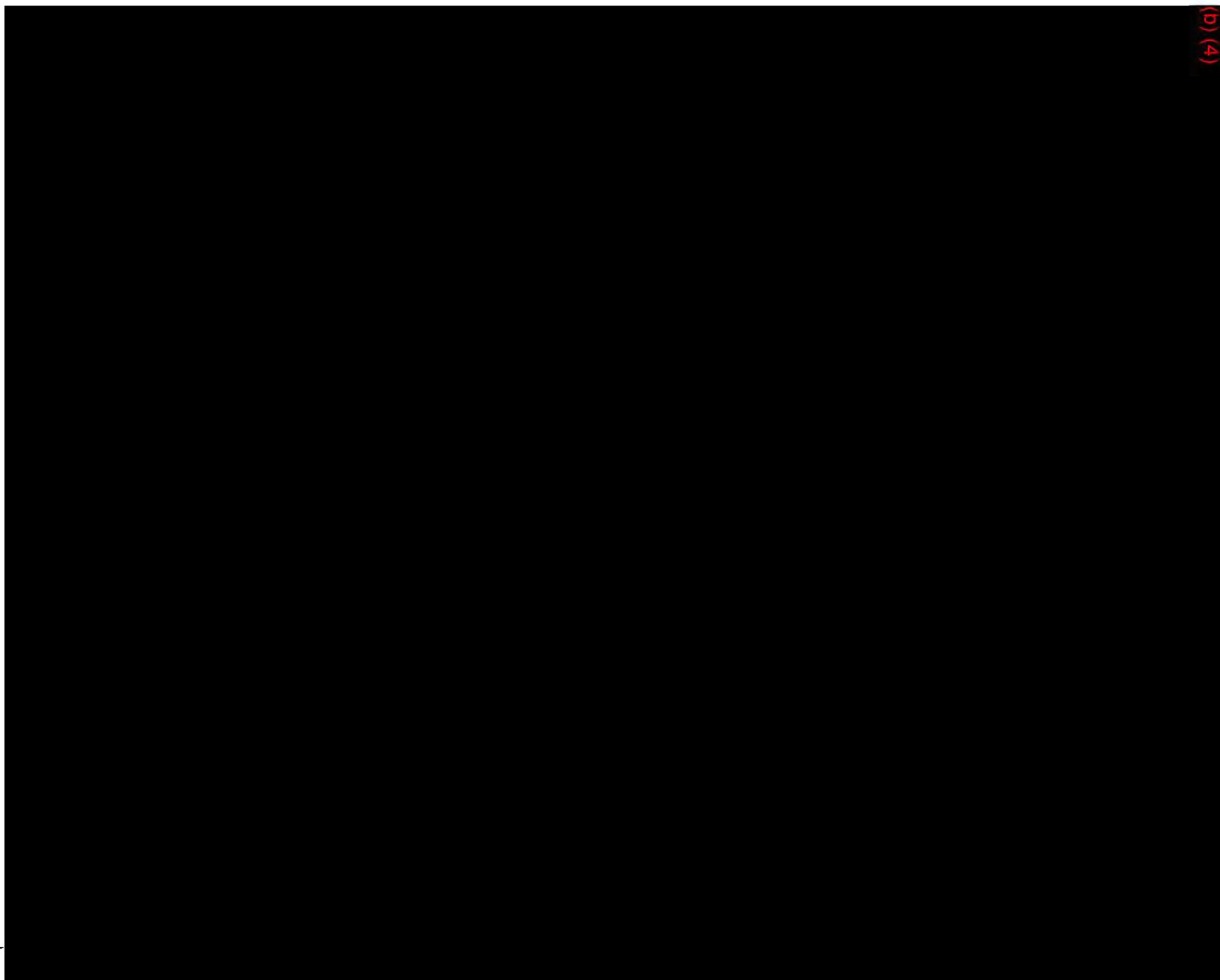
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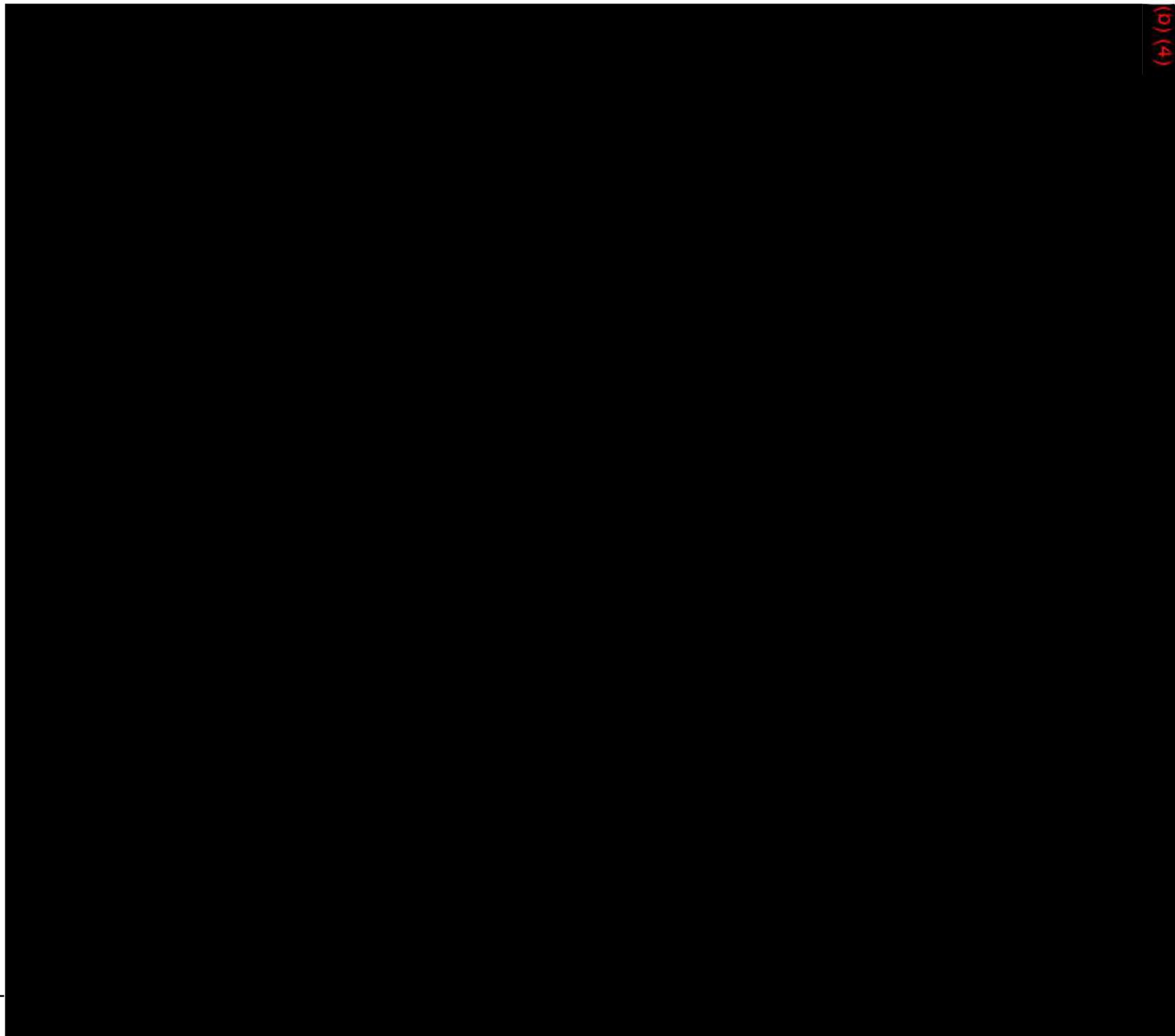


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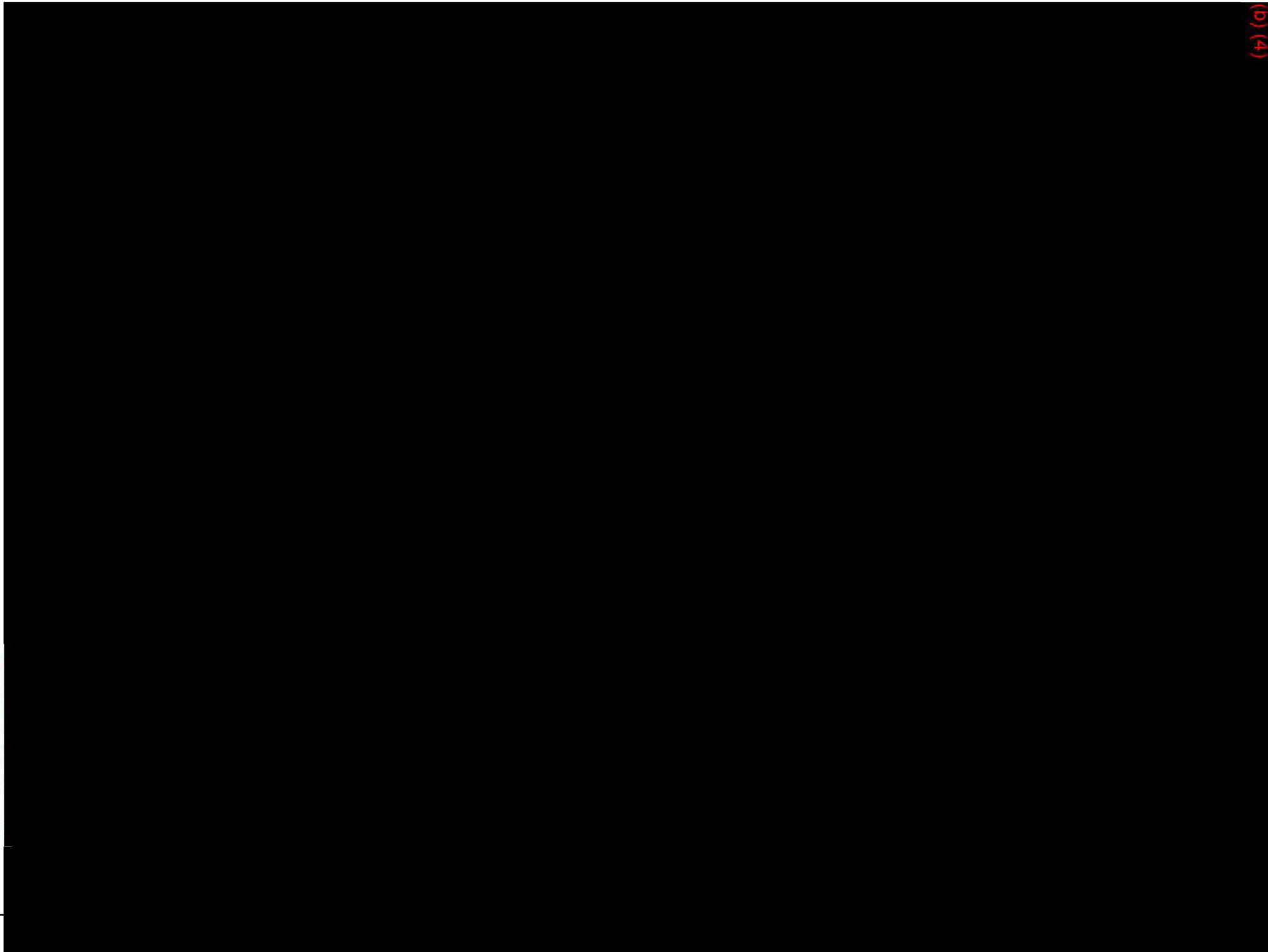
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