

# Secure Internet-Facing Application Deployment Guide

High-Assurance Security Implementation  
for Public Production Workloads

*Companion to Comprehensive Cloud-Native  
Architecture Implementation Guide*

Defense-in-Depth Security Controls  
Edge Security • API Protection • DDoS Mitigation  
WAF • Rate Limiting • Zero-Trust Architecture  
Threat Detection • Incident Response

**Technical Reference Guide**

Production-Ready Internet-Facing Deployments

January 19, 2026

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# 1 Executive Summary

This guide provides a comprehensive security implementation framework for deploying internet-facing applications with high assurance requirements. It serves as a companion to the *Comprehensive Cloud-Native Architecture Implementation Guide* and the *Secure Internal Application Hosting Guide*, focusing specifically on the additional security controls, threat mitigations, and operational practices required for public-facing production workloads.

## 1.1 Document Purpose

This implementation guide serves as:

1. **Security Hardening Roadmap:** Progressive maturity from protected pilot to production-ready internet deployment
2. **Defense-in-Depth Framework:** Layered security controls from edge to application to data
3. **Threat Mitigation Playbook:** Specific countermeasures for internet-facing attack vectors
4. **Compliance Accelerator:** Controls aligned with SOC 2, PCI-DSS, HIPAA, and GDPR requirements
5. **Operational Security Guide:** Monitoring, incident response, and continuous validation procedures

## 1.2 Key Insight: Public Internet Changes Everything

### Critical Security Requirement

#### Critical Security Principle:

Internet-facing applications face fundamentally different threat models than internal deployments:

- **Constant Attack Surface:** Automated scanning, credential stuffing, exploit attempts 24/7
- **Anonymized Attackers:** No authentication required for reconnaissance and initial attacks
- **DDoS Vulnerability:** Application and infrastructure overwhelm attacks
- **Zero Trust Required:** Every request must be validated; assume breach at every layer
- **Regulatory Scrutiny:** Compliance frameworks mandate specific controls for public systems

**Internet-facing deployments require defense-in-depth at edge, application, and data layers simultaneously.**

### 1.3 Relationship to Companion Guides

This guide builds upon:

- **Cloud-Native Architecture Guide:** Assumes Kubernetes, service mesh, and cloud platform knowledge
- **Internal Application Hosting Guide:** Inherits all zero-trust controls and adds internet-specific protections

**Critical Distinction:** This guide focuses on *additional* security controls required when applications face the public internet. All internal security controls remain mandatory; internet-facing requires layered defenses beyond those baselines.

### 1.4 Scope and Target Audience

**In Scope:**

- Internet-facing web applications and APIs
- Public-facing microservices architectures
- SaaS and customer-facing platforms
- High-assurance production deployments
- Compliance-regulated internet services
- Multi-tenant internet applications

**Out of Scope:**

- Internal-only applications (see Internal Application Hosting Guide)
- Development or staging environments without production data
- Mobile app backends (covered partially; requires additional mobile-specific controls)
- IoT device management (requires specialized IoT security controls)

**Target Audience:**

- Security engineers implementing internet-facing defenses
- Platform engineers deploying public production workloads
- DevSecOps teams integrating security into CI/CD pipelines
- Compliance officers validating regulatory requirements
- SRE teams responsible for internet service availability and resilience

### 1.5 Security Maturity Phases

This guide defines three security maturity phases for internet-facing deployments:

**Critical Note:** Each phase builds cumulatively. Phase 3 includes all Phase 1 and Phase 2 controls plus additional hardening. Never skip phases for internet-facing deployments.

Phase	Timeframe	Readiness Level
Phase 1	Weeks 1-4	<b>Protected Pilot</b> IP whitelisting, basic WAF, limited user base Controlled internet exposure for testing
Phase 2	Weeks 5-8	<b>Controlled Public Access</b> Full WAF, DDoS protection, rate limiting Beta/limited production with monitoring
Phase 3	Weeks 9-12	<b>Production Internet Deployment</b> Complete defense-in-depth, threat detection Full compliance, incident response capabilities

Table 1: Internet-Facing Security Maturity Phases

## 2 Official Documentation Resources

The following official documentation provides authoritative references for implementing internet-facing security controls. These resources should be used alongside this guide for detailed implementation guidance.

### 2.1 Edge and Ingress Security

#### 2.1.1 Kubernetes Ingress Controllers

NGINX Ingress Controller:

- Main Documentation: <https://kubernetes.github.io/ingress-nginx/>
- User Guide: <https://kubernetes.github.io/ingress-nginx/user-guide/>
- Rate Limiting: <https://kubernetes.github.io/ingress-nginx/user-guide/nginx-configuration/annotations/#rate-limiting>
- ModSecurity WAF: <https://kubernetes.github.io/ingress-nginx/user-guide/third-party-addons/modsecurity/>
- TLS Configuration: <https://kubernetes.github.io/ingress-nginx/user-guide/tls/>
- Security Best Practices: <https://kubernetes.github.io/ingress-nginx/deploy/#security-considerations>

Traefik:

- Main Documentation: <https://doc.traefik.io/traefik/>
- Middlewares: <https://doc.traefik.io/traefik/middlewares/overview/>
- Rate Limiting: <https://doc.traefik.io/traefik/middlewares/http/ratelimit/>
- IP Whitelisting: <https://doc.traefik.io/traefik/middlewares/http/ipwhitelist/>
- HTTPS Configuration: <https://doc.traefik.io/traefik/https/overview/>

**Contour:**

- Main Documentation: <https://projectcontour.io/docs/>
- TLS Configuration: <https://projectcontour.io/docs/main/config/tls-termination/>
- Rate Limiting: <https://projectcontour.io/docs/main/config/rate-limiting/>

**2.1.2 Web Application Firewalls****ModSecurity:**

- Main Documentation: <https://github.com/SpiderLabs/ModSecurity>
- OWASP Core Rule Set: <https://owasp.org/www-project-modsecurity-core-rule-set/>
- CRS Documentation: <https://coreruleset.org/docs/>
- Rule Customization: <https://coreruleset.org/docs/configuring/>

**Coraza WAF:**

- Main Documentation: <https://coraza.io/docs/>
- Kubernetes Integration: <https://github.com/corazawaf/coraza-proxy-wasm>

**2.1.3 Cloud Provider Edge Services****AWS:**

- CloudFront: <https://docs.aws.amazon.com/cloudfront/>
- AWS WAF: <https://docs.aws.amazon.com/waf/>
- WAF Rules: <https://docs.aws.amazon.com/waf/latest/developerguide/waf-rules.html>
- Shield (DDoS): <https://docs.aws.amazon.com/shield/>
- Shield Advanced: <https://docs.aws.amazon.com/waf/latest/developerguide/shield-chapter.html>
- Application Load Balancer: <https://docs.aws.amazon.com/elasticloadbalancing/latest/application/>

**Google Cloud:**

- Cloud CDN: <https://cloud.google.com/cdn/docs>
- Cloud Armor: <https://cloud.google.com/armor/docs>
- Cloud Load Balancing: <https://cloud.google.com/load-balancing/docs>
- Security Policies: <https://cloud.google.com/armor/docs/security-policy-overview>

**Azure:**

- Front Door: <https://docs.microsoft.com/azure/frontdoor/>
- Application Gateway: <https://docs.microsoft.com/azure/application-gateway/>
- WAF Overview: <https://docs.microsoft.com/azure/web-application-firewall/>
- DDoS Protection: <https://docs.microsoft.com/azure/ddos-protection/>

## 2.2 TLS and Certificate Management

### cert-manager:

- Main Documentation: <https://cert-manager.io/docs/>
- Installation: <https://cert-manager.io/docs/installation/>
- ACME (Let's Encrypt): <https://cert-manager.io/docs/configuration/acme/>
- Certificate Resources: <https://cert-manager.io/docs/usage/certificate/>
- Securing Ingress: <https://cert-manager.io/docs/usage/ingress/>

### Let's Encrypt:

- Main Documentation: <https://letsencrypt.org/docs/>
- Rate Limits: <https://letsencrypt.org/docs/rate-limits/>
- Best Practices: <https://letsencrypt.org/docs/best-practice/>

## 2.3 API Security

### API Gateway Solutions:

- Kong Gateway: <https://docs.konghq.com/gateway/>
- Kong Rate Limiting: <https://docs.konghq.com/hub/kong-inc/rate-limiting/>
- Kong Security Plugins: <https://docs.konghq.com/hub/?category=security>
- Tyk API Gateway: <https://tyk.io/docs/>
- KrakenD: <https://www.krakend.io/docs/>

### OAuth 2.0 and OIDC:

- OAuth 2.0 Specification: <https://oauth.net/2/>
- OpenID Connect: <https://openid.net/connect/>
- OAuth 2.0 Security Best Practices: <https://datatracker.ietf.org/doc/html/draft-ietf-oauth-security-topics>
- Keycloak Documentation: <https://www.keycloak.org/documentation>
- Dex (OIDC Provider): <https://dexidp.io/docs/>

## 2.4 DDoS Protection and Rate Limiting

### Rate Limiting Tools:

- Envoy Rate Limiting: [https://www.envoyproxy.io/docs/envoy/latest/configuration/http/http\\_filters/rate\\_limit\\_filter](https://www.envoyproxy.io/docs/envoy/latest/configuration/http/http_filters/rate_limit_filter)
- Redis Rate Limiter: <https://redis.io/docs/manual/patterns/rate-limiter/>
- Nginx Rate Limiting: <https://www.nginx.com/blog/rate-limiting-nginx/>

## 2.5 Service Mesh Security

### Istio:

- Security Concepts: <https://istio.io/latest/docs/concepts/security/>
- Authorization Policies: <https://istio.io/latest/docs/tasks/security/authorization/>
- Request Authentication: <https://istio.io/latest/docs/tasks/security/authentication/authn-policy/>
- Mutual TLS: <https://istio.io/latest/docs/tasks/security/authentication/mtls-migration/>
- Ingress Gateway: <https://istio.io/latest/docs/tasks/traffic-management/ingress/>
- Security Best Practices: <https://istio.io/latest/docs/ops/best-practices/security/>

### Linkerd:

- Automatic mTLS: <https://linkerd.io/2/features/automatic-mtls/>
- Server Policies: <https://linkerd.io/2/features/server-policy/>
- Authorization Policy: <https://linkerd.io/2/reference/authorization-policy/>

## 2.6 Secrets Management

### HashiCorp Vault:

- Main Documentation: <https://www.vaultproject.io/docs>
- Kubernetes Auth: <https://www.vaultproject.io/docs/auth/kubernetes>
- Dynamic Secrets: <https://www.vaultproject.io/docs/secrets>
- Transit Secrets Engine: <https://www.vaultproject.io/docs/secrets/transit>
- PKI Secrets Engine: <https://www.vaultproject.io/docs/secrets/pki>

### External Secrets Operator:

- Main Documentation: <https://external-secrets.io/>
- Cloud Provider Backends: <https://external-secrets.io/latest/provider/aws-secrets-manager/>

## 2.7 Security Scanning and Vulnerability Management

### Container Scanning:

- Trivy: <https://aquasecurity.github.io/trivy/>
- Grype: <https://github.com/anchore/grype>
- Clair: <https://quay.github.io/clair/>
- Snyk Container: <https://snyk.io/product/container-vulnerability-management/>

### Image Signing and Verification:

- Sigstore Cosign: <https://docs.sigstore.dev/cosign/overview/>
- Notary Project: <https://notaryproject.dev/>
- Kyverno Image Verification: <https://kyverno.io/docs/writing-policies/verify-images/>

### Runtime Security:

- Falco: <https://falco.org/docs/>
- Falco Rules: <https://github.com/falcosecurity/rules>
- Tetragon (eBPF): <https://tetragon.io/docs/>

## 2.8 Monitoring, Logging, and Observability

### Prometheus and Alerting:

- Prometheus Documentation: <https://prometheus.io/docs/>
- Security Best Practices: <https://prometheus.io/docs/operating/security/>
- Alertmanager: <https://prometheus.io/docs/alerting/latest/alertmanager/>

### Log Aggregation:

- Loki: <https://grafana.com/docs/loki/latest/>
- Fluentd: <https://docs.fluentd.org/>
- Fluent Bit: <https://docs.fluentbit.io/manual/>

### Distributed Tracing:

- Jaeger: <https://www.jaegertracing.io/docs/>
- Tempo: <https://grafana.com/docs/tempo/latest/>

## 2.9 Policy and Compliance

### Policy Enforcement:

- OPA/Gatekeeper: <https://open-policy-agent.github.io/gatekeeper/>
- Kyverno: <https://kyverno.io/docs/>
- Kyverno Policy Library: <https://kyverno.io/policies/>

### Compliance Frameworks:

- CIS Kubernetes Benchmark: <https://www.cisecurity.org/benchmark/kubernetes>
- NSA Kubernetes Hardening Guide: [https://media.defense.gov/2022/Aug/29/2003066362/-1/-1/0/CTR\\_KUBERNETES\\_HARDENING\\_GUIDANCE\\_1.2\\_20220829.PDF](https://media.defense.gov/2022/Aug/29/2003066362/-1/-1/0/CTR_KUBERNETES_HARDENING_GUIDANCE_1.2_20220829.PDF)
- NIST SP 800-190: <https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-190.pdf>

## 2.10 Incident Response

### Security Incident Management:

- NIST Incident Response Guide: <https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.800-61r2.pdf>
- OWASP Incident Response: [https://owasp.org/www-community/Incident\\_Response](https://owasp.org/www-community/Incident_Response)

## 3 Phase 1: Protected Pilot (Weeks 1-4)

### 3.1 Overview

**Security Posture:** Controlled internet exposure with IP whitelisting and basic protections for pilot testing.

#### Acceptable Risk Profile:

- Limited known IP addresses (corporate network, test users)
- Non-production or pilot data only
- Ability to immediately block all external traffic if needed
- Extensive monitoring and alerting on all access

#### Security Warning

##### Phase 1 Limitation:

This phase is NOT suitable for unrestricted public access. IP whitelisting is the primary control. Any expansion beyond known IPs requires advancing to Phase 2.

## 3.2 Core Security Controls

### 3.2.1 Network Perimeter Protection

#### IP Whitelisting:

- Implement strict IP allowlists at ingress controller level
- Document all whitelisted IP ranges and their business justification
- Establish change control process for IP list modifications
- Monitor for connection attempts from non-whitelisted IPs

#### Example: NGINX Ingress IP Whitelist:

```
apiVersion: networking.k8s.io/v1
kind: Ingress
metadata:
  name: protected-app-ingress
  annotations:
    nginx.ingress.kubernetes.io/whitelist-source-range: |
      203.0.113.0/24,
      198.51.100.0/24
spec:
  ingressClassName: nginx
  tls:
  - hosts:
    - pilot.example.com
    secretName: pilot-tls
  rules:
  - host: pilot.example.com
    http:
      paths:
      - path: /
        pathType: Prefix
        backend:
          service:
            name: app-service
            port:
              number: 80
```

Official documentation: <https://kubernetes.github.io/ingress-nginx/user-guide/nginx-configuration/annotations/#whitelist-source-range>

### 3.2.2 TLS/SSL Configuration

#### Certificate Management with cert-manager:

- Deploy cert-manager with ACME (Let's Encrypt) or internal CA
- Automate certificate issuance and renewal
- Enforce TLS 1.2 minimum, prefer TLS 1.3
- Configure strong cipher suites only

**Example: cert-manager Let's Encrypt Configuration:**

```
apiVersion: cert-manager.io/v1
kind: ClusterIssuer
metadata:
  name: letsencrypt-prod
spec:
  acme:
    server: https://acme-v02.api.letsencrypt.org/directory
    email: security@example.com
    privateKeySecretRef:
      name: letsencrypt-prod
    solvers:
      - http01:
          ingress:
            class: nginx
---
apiVersion: cert-manager.io/v1
kind: Certificate
metadata:
  name: pilot-tls
  namespace: pilot-app
spec:
  secretName: pilot-tls
  issuerRef:
    name: letsencrypt-prod
    kind: ClusterIssuer
  dnsNames:
    - pilot.example.com
```

Official documentation: <https://cert-manager.io/docs/configuration/acme/>

**TLS Configuration Best Practices:**

- Minimum TLS 1.2, prefer TLS 1.3
- Disable weak ciphers (RC4, 3DES, MD5)
- Enable HSTS (HTTP Strict Transport Security)
- Configure secure cipher suites

**Example: NGINX Ingress TLS Hardening:**

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: nginx-configuration
  namespace: ingress-nginx
data:
  ssl-protocols: "TLSv1.2 TLSv1.3"
  ssl-ciphers: "ECDHE-ECDSA-AES128-GCM-SHA256:ECDHE-RSA-AES128-GCM-SHA256:
    ECDHE-ECDSA-AES256-GCM-SHA384:ECDHE-RSA-AES256-GCM-SHA384"
  ssl-prefer-server-ciphers: "true"
  hsts: "true"
  hsts-max-age: "31536000"
  hsts-include-subdomains: "true"
```

```
hsts-preload: "true"
```

Official documentation: <https://kubernetes.github.io/ingress-nginx/user-guide/tls/>

### 3.2.3 Basic Web Application Firewall

#### ModSecurity with OWASP Core Rule Set:

- Deploy ModSecurity with NGINX Ingress Controller
- Enable OWASP Core Rule Set (CRS) in detection mode initially
- Monitor for false positives before enforcing blocking mode
- Tune rules based on application behavior

#### Example: ModSecurity Configuration:

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: nginx-configuration
  namespace: ingress-nginx
data:
  enable-modsecurity: "true"
  enable-owasp-modsecurity-crs: "true"
  modsecurity-snippet: |
    SecRuleEngine DetectionOnly
    SecAuditLog /var/log/modsec_audit.log
    SecAuditLogFormat JSON
```

Official documentation: <https://kubernetes.github.io/ingress-nginx/user-guide/third-party-addons/modsecurity/>

### 3.2.4 Kubernetes Security Baseline

#### Pod Security Standards:

- Enforce restricted Pod Security Standard for application namespaces
- Document any exemptions with security review
- Use security contexts to drop capabilities and run as non-root

#### Example: Pod Security Standard Enforcement:

```
apiVersion: v1
kind: Namespace
metadata:
  name: pilot-app
  labels:
    pod-security.kubernetes.io/enforce: restricted
    pod-security.kubernetes.io/audit: restricted
    pod-security.kubernetes.io/warn: restricted
```

Official documentation: <https://kubernetes.io/docs/concepts/security/pod-security-standards/>

#### Network Policies:

- Implement default-deny network policies
- Allow only required ingress from ingress controller
- Allow only required egress (DNS, external APIs)
- Deny all other traffic by default

#### Example: Default Deny Network Policy:

```
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy
metadata:
  name: default-deny-all
  namespace: pilot-app
spec:
  podSelector: {}
  policyTypes:
  - Ingress
  - Egress
---
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy
metadata:
  name: allow-ingress-controller
  namespace: pilot-app
spec:
  podSelector:
    matchLabels:
      app: web-app
  policyTypes:
  - Ingress
  ingress:
  - from:
    - namespaceSelector:
        matchLabels:
          name: ingress-nginx
    ports:
    - protocol: TCP
      port: 8080
```

Official documentation: <https://kubernetes.io/docs/concepts/services-networking/network-policies/>

### 3.2.5 Secrets Management

#### External Secrets Operator with Cloud Provider:

- Never store secrets in Git or Kubernetes Secrets directly
- Use External Secrets Operator with AWS Secrets Manager, GCP Secret Manager, or Azure Key Vault

- Implement secret rotation policies (30-90 days)
- Audit all secret access

**Example: External Secrets Operator Configuration:**

```
apiVersion: external-secrets.io/v1beta1
kind: SecretStore
metadata:
  name: aws-secretsmanager
  namespace: pilot-app
spec:
  provider:
    aws:
      service: SecretsManager
      region: us-east-1
      auth:
        jwt:
          serviceAccountRef:
            name: external-secrets-sa
---
apiVersion: external-secrets.io/v1beta1
kind: ExternalSecret
metadata:
  name: database-credentials
  namespace: pilot-app
spec:
  refreshInterval: 1h
  secretStoreRef:
    name: aws-secretsmanager
    kind: SecretStore
  target:
    name: db-credentials
    creationPolicy: Owner
  data:
  - secretKey: password
    remoteRef:
      key: pilot-app/database
      property: password
```

Official documentation: <https://external-secrets.io/latest/introduction/getting-started/>

### 3.2.6 Authentication and Authorization

**OAuth 2.0 / OIDC Integration:**

- Implement OAuth 2.0 for API authentication
- Use OIDC for web application authentication
- Integrate with corporate identity provider (Okta, Auth0, Keycloak)
- Enforce MFA for all user access

**Example: OAuth2 Proxy with OIDC:**

```
apiVersion: apps/v1
kind: Deployment
metadata:
  name: oauth2-proxy
  namespace: pilot-app
spec:
  replicas: 2
  selector:
    matchLabels:
      app: oauth2-proxy
  template:
    metadata:
      labels:
        app: oauth2-proxy
    spec:
      containers:
        - name: oauth2-proxy
          image: quay.io/oauth2-proxy/oauth2-proxy:v7.5.1
          args:
            - --provider=oidc
            - --oidc-issuer-url=https://auth.example.com
            - --upstream=http://app-service:80
            - --http-address=0.0.0.0:4180
            - --email-domain=example.com
            - --cookie-secure=true
            - --cookie-samesite=lax
          env:
            - name: OAUTH2_PROXY_CLIENT_ID
              valueFrom:
                secretKeyRef:
                  name: oauth2-proxy-secrets
                  key: client-id
            - name: OAUTH2_PROXY_CLIENT_SECRET
              valueFrom:
                secretKeyRef:
                  name: oauth2-proxy-secrets
                  key: client-secret
            - name: OAUTH2_PROXY_COOKIE_SECRET
              valueFrom:
                secretKeyRef:
                  name: oauth2-proxy-secrets
                  key: cookie-secret
```

Official documentation: <https://oauth2-proxy.github.io/oauth2-proxy/>

### 3.2.7 Logging and Monitoring

#### Security Event Logging:

- Enable Kubernetes audit logging for all API requests
- Centralize logs with Loki or cloud provider logging service
- Retain logs for minimum 90 days

- Configure alerts for security events

### Monitoring and Alerting:

- Deploy Prometheus and Grafana
- Configure alerts for:
  - Non-whitelisted IP connection attempts
  - Failed authentication attempts (>5 per minute)
  - WAF rule violations
  - Certificate expiration warnings (30 days)
  - Anomalous traffic patterns
- Establish on-call rotation for security alerts

### Example: Prometheus Alert Rules:

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: prometheus-alerts
  namespace: monitoring
data:
  security-alerts.yaml: |
    groups:
    - name: security
      interval: 30s
      rules:
      - alert: UnauthorizedAccess
        expr: rate(nginx_ingress_controller_requests{status="403"}[5m]) > 10
        for: 2m
        labels:
          severity: critical
        annotations:
          summary: "High rate of 403 responses"
          description: "Potential unauthorized access attempts detected"

      - alert: CertificateExpiringSoon
        expr: (certmanager_certificate_expiration_timestamp_seconds - time()) / 86400 < 30
        for: 1h
        labels:
          severity: warning
        annotations:
          summary: "Certificate expiring in less than 30 days"
```

Official documentation: [https://prometheus.io/docs/prometheus/latest/configuration/alerting\\_rules/](https://prometheus.io/docs/prometheus/latest/configuration/alerting_rules/)

### 3.3 Phase 1 Go/No-Go Checklist

#### Go/No-Go Checkpoint

**Before enabling internet access in Phase 1, verify:**  
**Network Security:**

- ☐ IP whitelist configured and tested
- ☐ TLS certificates issued and auto-renewing
- ☐ TLS 1.2+ enforced, weak ciphers disabled
- ☐ HSTS headers configured

**Application Security:**

- ☐ ModSecurity with OWASP CRS enabled (detection mode)
- ☐ Pod Security Standards enforced (restricted level)
- ☐ Network policies: default-deny implemented
- ☐ OAuth2/OIDC authentication configured

**Secrets and Credentials:**

- ☐ External Secrets Operator configured
- ☐ No secrets in Git repositories
- ☐ Secret rotation policy documented

**Monitoring and Response:**

- ☐ Kubernetes audit logging enabled
- ☐ Centralized logging configured (90-day retention)
- ☐ Security alerts configured and tested
- ☐ On-call rotation established
- ☐ Incident response runbook created

**Documentation:**

- ☐ Whitelisted IPs documented with justification
- ☐ Architecture diagram created
- ☐ Runbook for adding/removing IPs from whitelist
- ☐ Emergency shutdown procedure documented

## 4 Phase 2: Controlled Public Access (Weeks 5-8)

### 4.1 Overview

**Security Posture:** Full WAF protection, DDoS mitigation, and rate limiting for controlled public access (beta/limited production).

**Acceptable Risk Profile:**

- Limited public user base (beta users, limited launch)
- Production-like data with comprehensive monitoring
- Ability to implement emergency rate limiting or blocking
- 24/7 security monitoring and incident response

#### Critical Security Requirement

**Phase 2 Transition:**

Removing IP whitelisting exposes application to internet-wide attacks. All Phase 2 controls must be implemented BEFORE removing IP restrictions. Never partially deploy Phase 2 controls.

### 4.2 Enhanced Security Controls

#### 4.2.1 Cloud-Native DDoS Protection

**Cloud Provider DDoS Services:**

- Enable AWS Shield Standard (automatic for all AWS customers)
- Consider AWS Shield Advanced for Layer 7 protection
- Alternatively: Google Cloud Armor or Azure DDoS Protection
- Configure automatic scaling for DDoS absorption

**AWS Shield Standard Configuration:**

- Automatically enabled for CloudFront and Route 53
- Protects against common Layer 3/4 DDoS attacks
- No additional configuration required
- Monitor via CloudWatch metrics

Official documentation: <https://docs.aws.amazon.com/shield/latest/developerguide/what-is-aws-shield.html>

**Google Cloud Armor:**

```
# Create security policy
gcloud compute security-policies create internet-app-policy \
  --description "DDoS and WAF protection for internet-facing app"

# Add rate limiting rule
gcloud compute security-policies rules create 1000 \
  --security-policy internet-app-policy \
  --expression "true" \
  --action "rate-based-ban" \
  --rate-limit-threshold-count 100 \
  --rate-limit-threshold-interval-sec 60 \
  --ban-duration-sec 600 \
  --conform-action allow \
  --exceed-action deny-403
```

Official documentation: <https://cloud.google.com/armor/docs/security-policy-overview>

## 4.2.2 Production-Grade WAF Configuration

### ModSecurity Transition to Blocking Mode:

- Review detection mode logs for false positives
- Create exception rules for legitimate traffic patterns
- Enable blocking mode for OWASP CRS rules
- Implement graduated response (log, rate-limit, block)

### Example: ModSecurity Blocking Mode:

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: nginx-configuration
  namespace: ingress-nginx
data:
  enable-modsecurity: "true"
  enable-owasp-modsecurity-crs: "true"
  modsecurity-snippet: |
    SecRuleEngine On
    SecAuditEngine RelevantOnly
    SecAuditLog /var/log/modsec_audit.log
    SecAuditLogFormat JSON

    # Custom rule to allow legitimate traffic
    SecRule REQUEST_URI "@streq /healthz" \
      "id:1000,phase:1,pass,nolog,ctl:ruleEngine=Off"

    # Set paranoia level (1-4, higher = stricter)
    SecAction "id:900000,phase:1,nolog,pass,\
      t:none,setvar:tx.paranoia_level=2"
```

### OWASP CRS Protection Coverage:

- SQL Injection (SQLi) protection
- Cross-Site Scripting (XSS) prevention
- Local/Remote File Inclusion detection
- Command Injection blocking
- Protocol attack prevention
- Malicious automation detection

Official documentation: <https://coreruleset.org/docs/>

### 4.2.3 Comprehensive Rate Limiting

#### Multi-Layer Rate Limiting Strategy:

1. **Edge/CDN Layer:** Coarse-grained rate limiting (1000s req/min)
2. **Ingress Layer:** Per-path rate limiting (100s req/min)
3. **Application Layer:** Per-user/API key rate limiting (10s req/min)

#### Example: NGINX Ingress Rate Limiting:

```
apiVersion: networking.k8s.io/v1
kind: Ingress
metadata:
  name: rate-limited-ingress
  annotations:
    # Global rate limit: 100 requests per second from same IP
    nginx.ingress.kubernetes.io/limit-rps: "100"

    # Burst allowance
    nginx.ingress.kubernetes.io/limit-burst-multiplier: "5"

    # Rate limit by client IP
    nginx.ingress.kubernetes.io/limit-rate-after: "100"
    nginx.ingress.kubernetes.io/limit-rate: "500"

    # Connection limits
    nginx.ingress.kubernetes.io/limit-connections: "10"
spec:
  ingressClassName: nginx
  rules:
  - host: app.example.com
    http:
      paths:
      - path: /api
        pathType: Prefix
        backend:
          service:
            name: api-service
            port:
              number: 80
```

Official documentation: <https://kubernetes.github.io/ingress-nginx/user-guide/nginx-configuration/annotations/#rate-limiting>

#### API-Specific Rate Limiting with Kong:

```
apiVersion: configuration.konghq.com/v1
kind: KongPlugin
metadata:
  name: api-rate-limit
  namespace: production
plugin: rate-limiting
config:
  minute: 100
  hour: 5000
  policy: redis
  redis_host: redis.default.svc.cluster.local
  redis_port: 6379
  fault_tolerant: true
---
apiVersion: networking.k8s.io/v1
kind: Ingress
metadata:
  name: api-ingress
  annotations:
    konghq.com/plugins: api-rate-limit
spec:
  ingressClassName: kong
  rules:
  - host: api.example.com
    http:
      paths:
      - path: /v1
        pathType: Prefix
        backend:
          service:
            name: api-service
            port:
              number: 80
```

Official documentation: <https://docs.konghq.com/hub/kong-inc/rate-limiting/>

## 4.2.4 Advanced Authentication and Authorization

### API Key Management:

- Implement API key rotation (90-day lifecycle)
- Hash API keys in storage (never store plaintext)
- Rate limit per API key
- Monitor for compromised keys (unusual geographic access, rate spikes)

### JWT Token Validation:

- Validate JWT signatures at ingress layer

- Enforce short token expiration (15 minutes access, 7 days refresh)
- Implement token revocation list for compromised tokens
- Use RS256 or ES256 (not HS256 for production)

**Example: Istio JWT Validation:**

```
apiVersion: security.istio.io/v1beta1
kind: RequestAuthentication
metadata:
  name: jwt-validation
  namespace: production
spec:
  selector:
    matchLabels:
      app: api-service
  jwtRules:
    - issuer: "https://auth.example.com"
      jwksUri: "https://auth.example.com/.well-known/jwks.json"
      audiences:
        - "api.example.com"
      forwardOriginalToken: true
---
apiVersion: security.istio.io/v1beta1
kind: AuthorizationPolicy
metadata:
  name: require-jwt
  namespace: production
spec:
  selector:
    matchLabels:
      app: api-service
  action: DENY
  rules:
    - from:
        - source:
            notRequestPrincipals: ["*"]
```

Official documentation: <https://istio.io/latest/docs/tasks/security/authentication/authn-policy/>

#### 4.2.5 Container Image Security

**Image Scanning in CI/CD:**

- Scan all images for vulnerabilities before deployment
- Fail builds with HIGH or CRITICAL vulnerabilities
- Generate SBOM (Software Bill of Materials)
- Block images without valid signatures

**Example: Trivy Scanning in CI/CD:**

```
# Scan image for vulnerabilities
trivy image --severity HIGH,CRITICAL \
  --exit-code 1 \
  myapp:latest

# Generate SBOM
trivy image --format cyclonedx \
  --output sbom.json \
  myapp:latest
```

Official documentation: <https://aquasecurity.github.io/trivy/>

#### Image Signing and Verification:

- Sign all production images with Cosign
- Verify signatures at admission time with Kyverno
- Store signatures in OCI registry
- Reject unsigned images in production namespaces

#### Example: Cosign Image Signing:

```
# Generate keypair (one-time)
cosign generate-key-pair

# Sign image
cosign sign --key cosign.key \
  myregistry.io/myapp:v1.2.3

# Verify signature
cosign verify --key cosign.pub \
  myregistry.io/myapp:v1.2.3
```

#### Example: Kyverno Image Verification Policy:

```
apiVersion: kyverno.io/v1
kind: ClusterPolicy
metadata:
  name: verify-image-signatures
spec:
  validationFailureAction: enforce
  background: false
  rules:
    - name: verify-signature
      match:
        any:
          - resources:
              kinds:
                - Pod
              namespaces:
                - production
      verifyImages:
        - imageReferences:
            - "myregistry.io/*"
```

```

attestors:
- count: 1
  entries:
  - keys:
      publicKeys: |-
        -----BEGIN PUBLIC KEY-----
        ...
        -----END PUBLIC KEY-----

```

Official documentation: <https://kyverno.io/docs/writing-policies/verify-images/>

#### 4.2.6 Service Mesh Security

##### Mutual TLS Between Services:

- Deploy service mesh (Istio or Linkerd)
- Enable automatic mTLS for all inter-service communication
- Enforce STRICT mTLS mode (reject plaintext)
- Monitor certificate rotation

##### Example: Istio Strict mTLS:

```

apiVersion: security.istio.io/v1beta1
kind: PeerAuthentication
metadata:
  name: default
  namespace: production
spec:
  mtls:
    mode: STRICT
---
apiVersion: networking.istio.io/v1beta1
kind: DestinationRule
metadata:
  name: mtls-for-all
  namespace: production
spec:
  host: "*.production.svc.cluster.local"
  trafficPolicy:
    tls:
      mode: ISTIO_MUTUAL

```

Official documentation: <https://istio.io/latest/docs/tasks/security/authentication/mtls-migration/>

##### Fine-Grained Authorization Policies:

- Implement least-privilege service-to-service authorization
- Deny all traffic by default, explicitly allow required paths
- Use namespaces and service accounts for authorization

##### Example: Istio Authorization Policy:

```
apiVersion: security.istio.io/v1beta1
kind: AuthorizationPolicy
metadata:
  name: frontend-to-backend
  namespace: production
spec:
  selector:
    matchLabels:
      app: backend-api
  action: ALLOW
  rules:
  - from:
    - source:
        principals: ["cluster.local/ns/production/sa/frontend"]
      to:
      - operation:
          methods: ["GET", "POST"]
          paths: ["/api/v1/*"]
  ---
apiVersion: security.istio.io/v1beta1
kind: AuthorizationPolicy
metadata:
  name: deny-all-default
  namespace: production
spec:
  {} # Empty spec = deny all
```

Official documentation: <https://istio.io/latest/docs/tasks/security/authorization/>

### 4.3 Phase 2 Go/No-Go Checklist

#### Go/No-Go Checkpoint

**Before removing IP whitelist and enabling public access:****DDoS and Rate Limiting:**

- ☐ Cloud DDoS protection enabled (Shield/Armor/DDoS Protection)
- ☐ CDN/edge caching configured
- ☐ Ingress rate limiting implemented and tested
- ☐ Application-layer rate limiting configured
- ☐ Auto-scaling policies configured

**WAF and Attack Prevention:**

- ☐ ModSecurity in blocking mode with tuned rules
- ☐ OWASP CRS false positives resolved
- ☐ Custom WAF rules for application-specific attacks
- ☐ WAF alerts configured and tested

**Authentication and Authorization:**

- ☐ OAuth2/OIDC fully implemented and tested
- ☐ API key management system deployed
- ☐ JWT validation at ingress layer
- ☐ MFA enforced for administrative access
- ☐ Service mesh mTLS enabled (STRICT mode)

**Image and Container Security:**

- ☐ Image scanning in CI/CD pipeline
- ☐ Image signing implemented
- ☐ Signature verification enforced
- ☐ No HIGH/CRITICAL vulnerabilities in production images

**Monitoring and Response:**

- ☐ Security monitoring dashboard deployed
- ☐ DDoS attack alerts configured
- ☐ WAF violation alerts configured
- ☐ Failed authentication alerts configured
- ☐ 24/7 on-call coverage established
- ☐ Incident response playbooks created

## 5 Phase 3: Production Internet Deployment (Weeks 9-12)

### 5.1 Overview

**Security Posture:** Complete defense-in-depth with advanced threat detection, compliance controls, and mature incident response for unrestricted public production deployment.

**Acceptable Risk Profile:**

- Full production deployment with unrestricted public access
- Compliance requirements (SOC 2, PCI-DSS, HIPAA, GDPR)
- High-assurance security with continuous monitoring
- Mature incident response and disaster recovery capabilities

### 5.2 Advanced Security Controls

#### 5.2.1 Runtime Security and Threat Detection

**Falco for Runtime Anomaly Detection:**

- Deploy Falco to detect runtime anomalies
- Configure rules for:
  - Unauthorized file access
  - Unexpected network connections
  - Container escape attempts
  - Privilege escalation
  - Crypto-mining activity
- Integrate with SIEM or incident response platform

**Example: Falco Custom Rules:**

```
# Detect reverse shells
- rule: Reverse Shell
  desc: Detect reverse shell connection attempts
  condition: >
    spawned_process and
    (proc.name in (netcat, nc, ncat) or
     (proc.name = bash and proc.args contains "-i"))
  output: >
    Reverse shell detected (user=%user.name command=%proc.cmdline
    container=%container.id image=%container.image.repository)
  priority: CRITICAL
  tags: [network, shell]

# Detect unauthorized file access
- rule: Read Sensitive File
  desc: Detect reads to sensitive files
  condition: >
    open_read and
```

```

    fd.name in (/etc/shadow, /etc/sudoers, ~/.ssh/id_rsa)
    and not proc.name in (sshd, sudo)
output: >
    Sensitive file accessed (user=%user.name file=%fd.name
    command=%proc.cmdline container=%container.id)
priority: WARNING
tags: [filesystem, security]

```

Official documentation: <https://falco.org/docs/rules/>  
**Tetragon for eBPF-based Security Observability:**

- Deploy Tetragon for deep kernel-level observability
- Monitor system calls, network activity, file access
- Create security policies based on observed behavior
- Generate real-time security events

Official documentation: <https://tetragon.io/docs/>

## 5.2.2 Advanced Secrets Management

**HashiCorp Vault for Dynamic Secrets:**

- Deploy Vault in HA mode with auto-unsealing
- Use dynamic database credentials (short-lived)
- Implement PKI as a Service for certificate management
- Enable secret versioning and rollback
- Configure audit logging for all secret access

**Example: Vault Dynamic Database Secrets:**

```

# Configure database secrets engine
vault write database/config/production-db \
    plugin_name=postgresql-database-plugin \
    allowed_roles="application-role" \
    connection_url="postgresql://{{username}}:{{password}}@postgres:5432/
    app" \
    username="vault" \
    password="vault-password"

# Create role with dynamic credentials
vault write database/roles/application-role \
    db_name=production-db \
    creation_statements="CREATE ROLE \"{{name}}\" WITH LOGIN PASSWORD '{{
    password}}' VALID UNTIL '{{expiration}}'; \
    GRANT SELECT, INSERT, UPDATE, DELETE ON ALL TABLES IN SCHEMA
    public TO \"{{name}}\";" \
    default_ttl="1h" \
    max_ttl="24h"

```

```
# Application retrieves dynamic credentials
vault read database/creds/application-role
# Returns:
# lease_id: database/creds/application-role/abc123
# username: v-token-applicati-abc123def456
# password: A1a-randompassword123
```

Official documentation: <https://www.vaultproject.io/docs/secrets/databases>

#### Vault Kubernetes Integration:

```
apiVersion: v1
kind: ServiceAccount
metadata:
  name: app-service-account
  namespace: production
---
apiVersion: apps/v1
kind: Deployment
metadata:
  name: secure-app
  namespace: production
spec:
  template:
    metadata:
      annotations:
        vault.hashicorp.com/agent-inject: "true"
        vault.hashicorp.com/role: "application-role"
        vault.hashicorp.com/agent-inject-secret-db: "database/creds/
          application-role"
        vault.hashicorp.com/agent-inject-template-db: |
          {{- with secret "database/creds/application-role" -}}
          export DB_USER="{{ .Data.username }}"
          export DB_PASS="{{ .Data.password }}"
          {{- end }}
    spec:
      serviceAccountName: app-service-account
      containers:
        - name: app
          image: myapp:v1.2.3
          command: ["/bin/sh", "-c"]
          args: ["source /vault/secrets/db && ./app"]
```

Official documentation: <https://www.vaultproject.io/docs/platform/k8s>

### 5.2.3 Comprehensive Security Monitoring

#### Security Information and Event Management (SIEM):

- Aggregate logs from all security controls (WAF, Falco, Kubernetes audit, application)
- Correlate events across multiple sources
- Create detection rules for attack patterns
- Implement automated response workflows

## Key Security Metrics to Monitor:

### 1. Authentication Metrics:

- Failed login attempts per IP/user
- Successful logins from new geographic locations
- API key usage patterns
- Token refresh rates

### 2. Traffic Anomalies:

- Request rate deviations from baseline
- Unusual user agent patterns
- Geographic access anomalies
- HTTP method distribution changes

### 3. WAF and Attack Detection:

- WAF rule violations by type
- Blocked request sources (IP, ASN)
- SQL injection/XSS attempt patterns
- File upload anomalies

### 4. Runtime Security:

- Falco alerts by severity
- Container escape attempts
- Privilege escalation events
- Unexpected network connections

### 5. Infrastructure:

- Certificate expiration status
- Security policy violations
- Image vulnerability trends
- Secret access patterns

## Example: Comprehensive Security Dashboard (Grafana):

```
{
  "dashboard": {
    "title": "Security Monitoring Dashboard",
    "panels": [
      {
        "title": "Failed Authentication Attempts",
        "targets": [
          {
            "expr": "rate(authentication_failures_total[5m])"
          }
        ]
      }
    ]
  }
}
```

```

    ]
  },
  {
    "title": "WAF Blocks by Rule",
    "targets": [
      {
        "expr": "sum by (rule_id) (waf_blocks_total)"
      }
    ]
  },
  {
    "title": "Falco Critical Alerts",
    "targets": [
      {
        "expr": "falco_alerts{priority=\"Critical\"}"
      }
    ]
  }
]
}
}
}

```

### 5.2.4 Security Policy Enforcement

#### OPA/Gatekeeper for Admission Control:

- Enforce security policies at cluster admission
- Validate container images are signed
- Require security contexts on all pods
- Block privileged containers
- Enforce resource limits
- Validate network policy definitions

#### Example: Gatekeeper Constraint Templates:

```

apiVersion: templates.gatekeeper.sh/v1
kind: ConstraintTemplate
metadata:
  name: k8srequiredsecuritycontrols
spec:
  crd:
    spec:
      names:
        kind: K8sRequiredSecurityControls
  targets:
    - target: admission.k8s.gatekeeper.sh
      rego: |
        package k8srequiredsecuritycontrols

        violation[{"msg": msg}] {

```

```

        container := input.review.object.spec.containers[_]
        not container.securityContext.runAsNonRoot
        msg := sprintf("Container %v must run as non-root", [container.
            name])
    }

    violation[{"msg": msg}] {
        container := input.review.object.spec.containers[_]
        not container.securityContext.readOnlyRootFilesystem
        msg := sprintf("Container %v must have read-only root filesystem",
            [container.name])
    }

    violation[{"msg": msg}] {
        container := input.review.object.spec.containers[_]
        container.securityContext.allowPrivilegeEscalation
        msg := sprintf("Container %v must not allow privilege escalation",
            [container.name])
    }
}
---
apiVersion: constraints.gatekeeper.sh/v1beta1
kind: K8sRequiredSecurityControls
metadata:
  name: security-controls-required
spec:
  enforcementAction: deny
  match:
    kinds:
      - apiGroups: [""]
        kinds: ["Pod"]
    namespaces:
      - production

```

Official documentation: <https://open-policy-agent.github.io/gatekeeper/website/docs/>

### Kyverno Policy Examples:

```

apiVersion: kyverno.io/v1
kind: ClusterPolicy
metadata:
  name: production-security-standards
spec:
  validationFailureAction: enforce
  background: true
  rules:
    - name: require-image-signature
      match:
        any:
          - resources:
              kinds:
                - Pod
              namespaces:
                - production
      verifyImages:

```

```

- imageReferences:
  - "*"
  attestors:
  - count: 1
    entries:
    - keys:
        publicKey: |-
          -----BEGIN PUBLIC KEY-----
          ...
          -----END PUBLIC KEY-----

- name: require-resource-limits
  match:
    any:
    - resources:
        kinds:
        - Pod
        namespaces:
        - production
  validate:
    message: "All containers must have CPU and memory limits"
    pattern:
    spec:
      containers:
      - resources:
          limits:
            memory: "?*"
            cpu: "?*"

- name: block-latest-tag
  match:
    any:
    - resources:
        kinds:
        - Pod
        namespaces:
        - production
  validate:
    message: "Using 'latest' tag is not allowed in production"
    pattern:
    spec:
      containers:
      - image: "!*:latest"

```

Official documentation: <https://kyverno.io/policies/>

### 5.2.5 Compliance and Audit Controls

#### SOC 2 Type II Controls:

- Implement continuous audit logging (all API access, data access, admin actions)
- Enable log immutability (write-once storage)
- Maintain audit trail retention (minimum 1 year)

- Implement change management process with approval workflows
- Document and test disaster recovery procedures quarterly
- Conduct penetration testing annually

**PCI-DSS Compliance (if applicable):**

- Network segmentation for cardholder data environment (CDE)
- Encrypt cardholder data at rest and in transit
- Implement strong access control measures (MFA, least privilege)
- Regularly monitor and test networks
- Maintain vulnerability management program
- Implement and maintain firewall configurations

**GDPR Compliance (if applicable):**

- Implement data encryption at rest and in transit
- Enable data portability mechanisms
- Support right to erasure (data deletion)
- Maintain data processing records
- Implement breach notification procedures (72-hour requirement)
- Conduct Data Protection Impact Assessments (DPIAs)

**Example: Audit Log Policy:**

```
apiVersion: audit.k8s.io/v1
kind: Policy
rules:
# Log all requests at metadata level
- level: Metadata
  omitStages:
  - RequestReceived

# Log request and response bodies for secret access
- level: RequestResponse
  resources:
  - group: ""
    resources: ["secrets"]

# Log request and response for authentication
- level: RequestResponse
  verbs: ["create", "update", "patch", "delete"]
  resources:
  - group: ""
    resources: ["serviceaccounts", "tokenreviews"]
```

```
# Log all API access in production namespaces
- level: Request
  namespaces: ["production", "production-data"]
  verbs: ["create", "update", "patch", "delete"]

# Don't log certain high-volume, low-value resources
- level: None
  resources:
  - group: ""
    resources: ["events"]
```

Official documentation: <https://kubernetes.io/docs/tasks/debug/debug-cluster/audit/>

## 5.2.6 Incident Response Capabilities

### Automated Incident Response:

- Automated blocking of malicious IPs (based on WAF violations, Falco alerts)
- Automatic scaling during DDoS attacks
- Auto-rotation of compromised secrets
- Automated pod quarantine for suspicious behavior

### Example: Automated IP Blocking:

```
#!/bin/bash
# Prometheus Alertmanager webhook receiver
# Automatically blocks IPs with excessive WAF violations

while read -r alert; do
  ip=$(echo "$alert" | jq -r '.labels.client_ip')
  violation_count=$(echo "$alert" | jq -r '.annotations.violation_count')
)

  if [ "$violation_count" -gt 100 ]; then
    # Add IP to blocklist
    kubectl annotate ingress production-ingress \
      nginx.ingress.kubernetes.io/blacklist-source-range+="$ip/32"

    # Log to SIEM
    logger -t incident-response "Blocked IP $ip due to $violation_count WAF violations"

    # Create incident ticket
    create_incident_ticket "IP $ip auto-blocked" "$ip" "$violation_count"
  fi
done
```

### Incident Response Playbooks:

#### 1. DDoS Attack Response:

- Activate emergency auto-scaling

- Enable aggressive rate limiting
- Contact cloud provider for additional DDoS mitigation
- Notify stakeholders and establish incident bridge

## **2. Data Breach Response:**

- Isolate affected systems (network policies)
- Preserve evidence (pod logs, network captures)
- Rotate all credentials
- Activate breach notification procedures
- Conduct post-incident review

## **3. Compromised Credentials:**

- Immediately revoke compromised credentials
- Audit access logs for unauthorized activity
- Rotate all related secrets
- Force re-authentication for affected users
- Review and strengthen authentication controls

## **4. Zero-Day Vulnerability:**

- Assess impact and exposure
- Implement temporary mitigations (WAF rules, network isolation)
- Fast-track patching process
- Monitor for exploitation attempts
- Communicate with stakeholders

## **Incident Documentation Requirements:**

- Timeline of events
- Root cause analysis
- Impact assessment
- Remediation actions taken
- Lessons learned and improvements
- Compliance notifications (if required)

### 5.3 Disaster Recovery and Business Continuity

#### Backup Strategy:

- Automated daily backups with Velero
- Off-site backup storage (different region/provider)
- Backup encryption at rest
- Regular restore testing (quarterly)
- Document RTO (Recovery Time Objective) and RPO (Recovery Point Objective)

#### Example: Velero Backup Configuration:

```
apiVersion: velero.io/v1
kind: BackupStorageLocation
metadata:
  name: default
  namespace: velero
spec:
  provider: aws
  objectStorage:
    bucket: production-backups-encrypted
    prefix: kubernetes
  config:
    region: us-west-2
    s3ForcePathStyle: "true"
    serverSideEncryption: AES256
---
apiVersion: velero.io/v1
kind: Schedule
metadata:
  name: production-daily-backup
  namespace: velero
spec:
  schedule: "0 2 * * *" # Daily at 2 AM
  template:
    includedNamespaces:
      - production
      - production-data
    ttl: 720h # 30 days retention
    snapshotVolumes: true
    volumeSnapshotLocations:
      - default
```

Official documentation: <https://velero.io/docs/>

#### Multi-Region Deployment:

- Deploy to multiple geographic regions
- Implement global load balancing with health checks
- Synchronize data across regions (with appropriate consistency model)
- Test regional failover procedures

## 5.4 Phase 3 Go/No-Go Checklist

### Go/No-Go Checkpoint

#### Before full production deployment with unrestricted access:

##### Advanced Threat Detection:

- ☐ Falco deployed with custom rules
- ☐ Runtime security alerts integrated with incident response
- ☐ SIEM correlation rules configured
- ☐ Automated threat response workflows tested

##### Secrets and Credential Management:

- ☐ Vault deployed in HA mode
- ☐ Dynamic secrets implemented for databases
- ☐ Secret rotation automated (30-90 day lifecycle)
- ☐ Vault audit logging enabled

##### Policy and Compliance:

- ☐ OPA/Gatekeeper policies enforced
- ☐ Image signature verification required
- ☐ Security contexts enforced on all pods
- ☐ CIS Kubernetes Benchmark compliance validated
- ☐ Compliance audit logging enabled (SOC 2/PCI/HIPAA/GDPR)

##### Monitoring and Observability:

- ☐ Security dashboard deployed
- ☐ All critical security metrics monitored
- ☐ Alert fatigue minimized (tuned thresholds)
- ☐ Distributed tracing implemented
- ☐ Log retention meets compliance requirements (1+ years)

##### Incident Response:

- ☐ Incident response playbooks documented
- ☐ Automated response workflows tested
- ☐ 24/7 security operations coverage
- ☐ Incident communication plan established
- ☐ Post-incident review process defined
- ☐ Breach notification procedures documented

## 6 Defense-in-Depth Architecture

This section provides the conceptual framework for layered security controls across the entire application stack.

### 6.1 Security Layer Model

Layer	Controls	Technologies
<b>Edge/Perimeter</b>	DDoS protection, WAF, rate limiting, geo-blocking	CloudFront, Shield, Cloud Armor, ModSecurity
<b>Ingress</b>	TLS termination, authentication, path-based routing	NGINX, Traefik, Istio Ingress Gateway
<b>Service Mesh</b>	mTLS, service-to-service authz, observability	Istio, Linkerd
<b>Application</b>	Input validation, output encoding, session management	Application code, API gateway
<b>Platform</b>	RBAC, network policies, pod security, admission control	Kubernetes, OPA/Gatekeeper
<b>Runtime</b>	Anomaly detection, syscall monitoring, container isolation	Falco, Tetragon, seccomp
<b>Data</b>	Encryption at rest, encryption in transit, access logging	Vault, database TLS, audit logs
<b>Infrastructure</b>	Network segmentation, host hardening, patch management	VPC, security groups, CIS benchmarks

Table 2: Defense-in-Depth Security Layers

### 6.2 Zero-Trust Principles

**Core Tenets:**

1. **Verify Explicitly:** Always authenticate and authorize based on all available data points
2. **Least Privilege Access:** Limit user and service access with just-in-time and just-enough-access
3. **Assume Breach:** Minimize blast radius and segment access; verify end-to-end encryption

**Implementation in Kubernetes:**

- No implicit trust based on network location
- Every service-to-service call authenticated (mTLS)
- Every service-to-service call authorized (Istio AuthorizationPolicy)

- Minimal pod permissions (restrictive security contexts)
- Network segmentation (NetworkPolicies with default deny)
- Continuous verification (Falco runtime monitoring)

## 6.3 Attack Surface Reduction

### Minimize Exposure:

- Expose only required ports and services
- Disable unnecessary Kubernetes APIs
- Use distroless or minimal base images
- Remove debugging tools from production images
- Implement read-only root filesystems
- Drop all unnecessary Linux capabilities

### Example: Minimal Security Context:

```
apiVersion: v1
kind: Pod
metadata:
  name: secure-app
spec:
  securityContext:
    runAsNonRoot: true
    runAsUser: 10000
    fsGroup: 10000
    seccompProfile:
      type: RuntimeDefault
  containers:
  - name: app
    image: myapp:v1.2.3
    securityContext:
      allowPrivilegeEscalation: false
      readOnlyRootFilesystem: true
      capabilities:
        drop:
        - ALL
    volumeMounts:
    - name: tmp
      mountPath: /tmp
  volumes:
  - name: tmp
    emptyDir: {}
```

## 7 API Security Best Practices

### 7.1 API Authentication Methods

#### Comparison of Authentication Approaches:

Method	Use Case	Pros	Cons
API Keys	Server-to-server, public APIs	Simple, fast	Not suitable for user auth, difficult rotation
OAuth 2.0	Third-party integrations	Standard, delegated access	Complex, requires token management
JWT	Microservices, SPAs	Stateless, self-contained	Token size, revocation challenges
Mutual TLS	Service mesh, high security	Strong authentication	Certificate management complexity

Table 3: API Authentication Methods

## 7.2 API Rate Limiting Strategies

### Rate Limit Tiers:

1. **Anonymous/Unauthenticated:** 10 requests/minute (strict)
2. **Authenticated User:** 100 requests/minute
3. **Premium/Paid Tier:** 1000 requests/minute
4. **Trusted Partners:** 10000 requests/minute

### Rate Limiting Algorithms:

- **Token Bucket:** Allows bursts, smooths traffic over time
- **Leaky Bucket:** Enforces constant rate, no bursts
- **Fixed Window:** Simple but allows double traffic at window boundaries
- **Sliding Window:** More accurate but more complex

**Recommended:** Token bucket for most use cases, sliding window for strict enforcement.

## 7.3 API Security Headers

### Essential Security Headers:

```
# NGINX Ingress security headers
apiVersion: v1
kind: ConfigMap
metadata:
  name: nginx-configuration
  namespace: ingress-nginx
data:
  # Prevent clickjacking
  add-headers: "X-Frame-Options: DENY"

  # Prevent MIME sniffing
  add-headers: "X-Content-Type-Options: nosniff"
```

```
# Enable XSS protection
add-headers: "X-XSS-Protection: 1; mode=block"

# Content Security Policy
add-headers: "Content-Security-Policy: default-src 'self'"

# Referrer Policy
add-headers: "Referrer-Policy: strict-origin-when-cross-origin"

# HSTS
hsts: "true"
hsts-max-age: "31536000"
hsts-include-subdomains: "true"
```

## 7.4 Input Validation and Sanitization

### Validation Principles:

- Validate on server side (never trust client)
- Whitelist allowed characters/patterns (reject by default)
- Enforce maximum lengths
- Validate data types and formats
- Reject unexpected input immediately

### Common Injection Prevention:

- **SQL Injection:** Use parameterized queries, never string concatenation
- **XSS:** Encode output, use Content Security Policy
- **Command Injection:** Avoid shell execution, validate inputs strictly
- **Path Traversal:** Validate file paths, use chroot/jails

## 8 Security Testing and Validation

### 8.1 Automated Security Testing in CI/CD

#### Pipeline Security Gates:

1. **SAST (Static Application Security Testing):** Source code analysis for vulnerabilities
2. **Dependency Scanning:** Check for known vulnerabilities in dependencies
3. **Container Scanning:** Scan images for CVEs, malware, misconfigurations
4. **Infrastructure as Code Scanning:** Validate Terraform/Kubernetes manifests
5. **Secret Scanning:** Detect accidentally committed secrets

**Example: GitHub Actions Security Pipeline:**

```
name: Security Scanning
on: [push, pull_request]

jobs:
  security-scan:
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v3

      # SAST with Semgrep
      - name: Semgrep Security Scan
        uses: returntocorp/semgrep-action@v1
        with:
          config: p/security-audit

      # Dependency scanning
      - name: Dependency Check
        run: |
          npm audit --audit-level=high
          pip-audit

      # Container image scanning
      - name: Build and scan image
        run: |
          docker build -t myapp:${{ github.sha }} .
          trivy image --severity HIGH,CRITICAL \
            --exit-code 1 myapp:${{ github.sha }}

      # IaC scanning
      - name: Terraform security scan
        run: |
          tfsec ./terraform/
          checkov -d ./terraform/ --framework terraform

      # Secret scanning
      - name: Secret scanning
        uses: trufflesecurity/trufflehog@main
        with:
          path: ./
          base: ${{{ github.event.repository.default_branch }}}
          head: HEAD
```

## 8.2 Penetration Testing

### Annual Penetration Test Scope:

- External network penetration testing
- Web application security assessment (OWASP Top 10)
- API security testing
- Authentication and authorization bypass attempts

- Business logic testing
- Social engineering (phishing simulations)

**Bug Bounty Program:**

- Establish responsible disclosure policy
- Define scope (in-scope vs out-of-scope targets)
- Set bounty rewards based on severity
- Provide clear communication channels
- Respond to submissions within 48 hours

**8.3 Security Chaos Engineering**

**Attack Simulation Scenarios:**

- Simulate credential compromise and test auto-rotation
- Inject malicious traffic and validate WAF blocking
- Test DDoS response with synthetic traffic spike
- Simulate certificate expiration and validate auto-renewal
- Test incident response procedures with tabletop exercises

**9 Compliance and Regulatory Requirements**

**9.1 Compliance Framework Mapping**

Framework	Key Requirements	Implementation
SOC 2 Type II	• Access controls	• RBAC + MFA
	• Change management	• GitOps with approval workflows
	• Risk assessment	• Annual risk assessments
	• Vendor management	• Vendor security reviews
	• Incident response	• Documented IR play-books

Framework	Key Requirements	Implementation
<b>PCI-DSS</b>		
	<ul style="list-style-type: none"> <li>• Network segmentation</li> <li>• Encryption in transit/at rest</li> <li>• Access controls (MFA)</li> <li>• Logging and monitoring</li> <li>• Vulnerability management</li> </ul>	<ul style="list-style-type: none"> <li>• Dedicated CDE namespace</li> <li>• TLS 1.2+ and AES-256</li> <li>• OAuth2 + MFA enforced</li> <li>• 1-year audit log retention</li> <li>• Monthly vulnerability scans</li> </ul>
<b>HIPAA</b>		
	<ul style="list-style-type: none"> <li>• PHI encryption</li> <li>• Access controls</li> <li>• Audit controls</li> <li>• Transmission security</li> <li>• Integrity controls</li> </ul>	<ul style="list-style-type: none"> <li>• Encryption at rest/transit</li> <li>• Least-privilege RBAC</li> <li>• Comprehensive audit logging</li> <li>• mTLS for all services</li> <li>• Digital signatures (Cosign)</li> </ul>
<b>GDPR</b>		
	<ul style="list-style-type: none"> <li>• Data protection by design</li> <li>• Right to erasure</li> <li>• Data portability</li> <li>• Breach notification (72hr)</li> <li>• DPIAs for high-risk processing</li> </ul>	<ul style="list-style-type: none"> <li>• Encryption, pseudonymization</li> <li>• Data deletion APIs</li> <li>• Export functionality</li> <li>• Automated alerting system</li> <li>• DPIA templates and process</li> </ul>

Framework	Key Requirements	Implementation
ISO 27001	<ul style="list-style-type: none"> <li>• ISMS framework</li> <li>• Risk assessment</li> <li>• Asset management</li> <li>• Incident management</li> <li>• Business continuity</li> </ul>	<ul style="list-style-type: none"> <li>• Documented ISMS policies</li> <li>• Annual risk assessments</li> <li>• Asset inventory (CMDB)</li> <li>• IR procedures and drills</li> <li>• DR testing (quarterly)</li> </ul>

Table 4: Compliance Framework Implementation

## 9.2 Audit Trail Requirements

### Minimum Audit Logging:

- User authentication events (success and failure)
- Authorization decisions (access granted/denied)
- Resource creation, modification, deletion
- Administrative actions
- Security policy changes
- Secret access
- Data access (especially PII/PHI)

### Log Retention:

- SOC 2: Minimum 1 year
- PCI-DSS: Minimum 1 year, online for 3 months
- HIPAA: Minimum 6 years
- GDPR: Varies by data type and legal basis

## 10 Continuous Security Improvement

### 10.1 Security Metrics and KPIs

#### Track and Report Monthly:

1. Vulnerability Metrics:

- Mean Time to Detect (MTTD) vulnerabilities
- Mean Time to Remediate (MTTR) vulnerabilities
- Number of HIGH/CRITICAL vulnerabilities in production
- Percentage of images with known vulnerabilities

## 2. **Attack Metrics:**

- WAF block rate (blocked requests / total requests)
- DDoS attack frequency and duration
- Failed authentication attempts
- API rate limit violations

## 3. **Compliance Metrics:**

- Audit findings (open vs closed)
- Policy violations detected
- Time to compliance for new services
- Percentage of resources meeting security standards

## 4. **Incident Response Metrics:**

- Mean Time to Detect (MTTD) incidents
- Mean Time to Respond (MTTR) incidents
- Number of security incidents by severity
- Percentage of incidents with complete post-mortems

## 10.2 Security Review Cadence

### **Quarterly Activities:**

- Review and update security policies
- Conduct tabletop incident response exercises
- Review access control lists (user and service accounts)
- Test disaster recovery procedures
- Update threat model

### **Annual Activities:**

- Third-party penetration testing
- Security awareness training for all staff
- Comprehensive security architecture review
- Compliance audit preparation and execution
- Risk assessment update

## 10.3 Threat Intelligence Integration

### Integrate Threat Feeds:

- Subscribe to CVE databases (NVD, vendor advisories)
- Monitor CISA Known Exploited Vulnerabilities catalog
- Track Kubernetes security advisories
- Join cloud provider security bulletins
- Participate in industry-specific ISACs (Information Sharing and Analysis Centers)

### Actionable Threat Intelligence:

- Automatically update WAF rules based on threat intelligence
- Prioritize patching based on active exploitation
- Update IP blocklists with known malicious sources
- Adjust monitoring rules for emerging attack patterns

## 11 Conclusion

### 11.1 Critical Success Factors

Successful internet-facing application security requires:

1. **Defense-in-Depth:** Multiple layers of security controls, no single point of failure
2. **Zero-Trust Architecture:** Continuous verification at every layer
3. **Automation:** Security controls integrated into CI/CD, not bolt-on
4. **Continuous Monitoring:** Real-time visibility and alerting
5. **Incident Response Readiness:** Documented procedures, tested regularly
6. **Security Culture:** Security is everyone's responsibility, not just security team

## 11.2 Common Pitfalls to Avoid

### Security Warning

#### Avoid These Common Mistakes:

- Skipping security phases to accelerate deployment
- Deploying internet-facing before Phase 2 controls complete
- Relying solely on perimeter security (no defense-in-depth)
- Neglecting log monitoring and alerting
- Using default credentials or weak passwords
- Failing to patch vulnerabilities promptly
- Ignoring security alerts due to alert fatigue
- Not testing incident response procedures

## 11.3 Roadmap Beyond Phase 3

### Continuous Improvement:

- Implement machine learning for anomaly detection
- Adopt eBPF-based security tools (Tetragon, Cilium)
- Expand to multi-region active-active deployment
- Implement automated threat hunting
- Achieve additional compliance certifications
- Establish bug bounty program
- Develop security chaos engineering practice

## 11.4 Final Checklist

### Go/No-Go Checkpoint

#### **Production Readiness Final Verification: Security Controls (All Phases):**

- ☐ All Phase 1, 2, and 3 controls implemented
- ☐ Defense-in-depth at all layers verified
- ☐ Zero-trust principles enforced

#### **Testing and Validation:**

- ☐ Penetration testing completed with findings remediated
- ☐ Load testing at 3x expected capacity
- ☐ Disaster recovery procedures tested successfully
- ☐ Incident response drills conducted

#### **Operational Readiness:**

- ☐ 24/7 security monitoring operational
- ☐ On-call rotation established
- ☐ Runbooks documented and accessible
- ☐ Escalation procedures defined

#### **Compliance:**

- ☐ All required compliance controls implemented
- ☐ Audit logging meets retention requirements
- ☐ Compliance documentation complete
- ☐ Privacy policies updated

#### **Documentation:**

- ☐ Architecture diagrams current
- ☐ Security policies documented
- ☐ Incident response playbooks complete
- ☐ Disaster recovery procedures documented

## 11.5 Resources and Community

### **Kubernetes Security Resources:**

- Kubernetes Security SIG: <https://github.com/kubernetes/community/tree/master/sig-security>
- CNCF Security Technical Advisory Group: <https://github.com/cncf/tag-security>
- Kubernetes Security Checklist: <https://kubernetes.io/docs/concepts/security/security-checklist/>

#### **Security Training and Certifications:**

- Certified Kubernetes Security Specialist (CKS)
- Certified Information Systems Security Professional (CISSP)
- GIAC Cloud Security Automation (GCSA)
- Cloud Security Alliance (CSA) Certifications

#### **Security Communities:**

- OWASP Foundation: <https://owasp.org/>
- Cloud Native Security Con: <https://events.linuxfoundation.org/cloudnativesecuritycon-north-america/>
- r/kubernetes (Reddit)
- Kubernetes Slack #sig-security channel