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The Security Evaluated Standardized Password Authenticated Key Exchange (SESPAKE) Protocol

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Abstract

This document specifies the Security Evaluated Standardized Password Authenticated Key Exchange (SESPAKE) protocol. The SESPAKE protocol provides password authenticated key exchange for usage in the systems for protection of sensitive information. The security proofs of the protocol were made for the case of an active adversary in the channel, including MitM attacks and attacks based on the impersonation of one of the subjects.

Status of This Memo

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1. Introduction

The current document contains the description of the password authenticated key exchange protocol SESPAKE (security evaluated standardized password authenticated key exchange) for usage in the systems for protection of sensitive information. The protocol is intended to use for establishment of keys that are then used for organization of secure channel for protection of sensitive information. The security proofs of the protocol were made for the case of an active adversary in the channel, including MitM attacks and attacks based on the impersonation of one of the subjects.

2. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Notations

This document uses the following parameters of elliptic curves in accordance with [RFC6090]:

E
: an elliptic curve defined over a finite prime field GF(p), where $p > 3$;

p
: the characteristic of the underlying prime field;

a, b
: the coefficients of the equation of the elliptic curve in the canonical form;

m
: the elliptic curve group order;

q
: the elliptic curve subgroup order;

P
: a generator of the subgroup of order q;

X, Y

the coordinates of the elliptic curve point in the canonical form;

O

zero point (point of infinity) of the elliptic curve.

This memo uses the following functions:

HASH

the underlying hash function;

HMAC

the function for calculating a message authentication code, based on a HASH function in accordance with [RFC2104];

F(PW, salt, n)

the value of the function PBKDF2(PW,salt,n,len), where PBKDF2(PW,salt,n,len) is calculated according to [RFC2898] The parameter len is considered equal to minimal integer that is a multiple of 8 and satisfies the following condition:
len >= floor(log_2(q)).

This document uses the following terms and definitions for the sets and operations on the elements of these sets

B_n

the set of byte strings of size n, n >= 0, for n = 0 the B_n set consists of a single empty string of size 0; if b is an element of B_n, then b = (b_1,...,b_n), where b_1,...,b_n are elements of {0,…,255};

||

concatenation of byte strings A and C, i.e., if A in B_n1, C in B_n2, A = (a_1,a_2,...,a_n1) and C = (c_1,c_2,...,c_n2), then A||C = (a_1,a_2,…,a_n1,c_1,c_2,…,c_n2) is an element of B_(n1+n2);

int(A)

for the byte string A= (a_1,...,a_n) in B_n an integer int(A) = 256^(n-1)a_n +...+ 256^(0)a_1;

bytes_n(X)

the byte string A in B_n such that int(A) = X, where X is integer, 0 <= X < 256^n;

BYTES(Q)

for Q in E, the byte string bytes_n(X) || bytes_n(Y), where X, Y are standard Weierstrass coordinates of point Q and n = ceil(log_{256}(p)).

4. Protocol Description

The main point of the SESPAKE protocol is that parties sharing a weak key (a password) generate a strong common key. The active adversary who has an access to a channel is not able to obtain any information that can be used to find a key in offline mode, i.e. without interaction with legitimate participants.

The protocol is used by the subjects A (client) and B (server) that share some secret parameter that was established in an out-of-band mechanism: a client is a participant who stores a password as a secret parameter and a server is a participant who stores a password-based computed point of the elliptic curve.

The SESPAKE protocol consists of two steps: the key agreement step and the key confirmation step. During the first step (the key agreement step) the parties exchange keys using Diffie-Hellman with public components masked by an element that depends on the password - one of the predefined elliptic curve points multiplied by the password-based coefficient. This approach provides an implicit key authentication, which means that after this step one party is assured that no other party aside from a specifically identified second party may gain access to the generated secret key. During the second step (the key confirmation step) the parties exchange strings that strongly depend on the generated key. After this step the parties are assured that a legitimate party and no one else actually has possession of the secret key.

To protect against online guessing attacks the failed connections counters were introduced in the SESPAKE protocol. There is also a special way of a small order point processing and a mechanism that provides a reflection attack protection by using different operations for different sides.

4.1. Protocol Parameters

Various elliptic curves can be used in the protocol. For each elliptic curve supported by clients the following values MUST be defined:

- the protocol parameters identifier ID_ALG (which can also define a HASH function, PRF used in PBKDF2 function, etc.), that is a byte string of an arbitrary length;
- the point P, that is a generator point of the subgroup of order q of the curve;
- the set of distinct curve points {Q_1,Q_2,...,Q_N} of order q, where the total number of points N is defined for protocol instance.

The method of generation of the points {P,Q_1,Q_2,...,Q_N} is described in Section 5.

The protocol parameters that are used by subject A are the following:

1. The secret password value PW, which is a byte string that is uniformly randomly chosen from a subset of cardinality 10^10 or greater of the set B_k, where k ? 6 is password length.
2. The list of curve identifiers supported by A.
3. Sets of points {Q_1,Q_2,...,Q_N}, corresponding to curves supported by A.
4. The C_1^A counter, that tracks the total number of unsuccessful authentication trials in a row, and a value of CLim_1 that stores the maximum possible number of such events.
5. The C_2^A counter, that tracks the total number of unsuccessful authentication events during the period of usage of the specific PW, and a value of CLim_2 that stores the maximum possible number of such events.
6. The C_3^A counter, that tracks the total number of authentication events (successful and unsuccessful) during the period of usage of the specific PW, and a value of CLim_3 that stores the maximum possible number of such events.
7. The unique identifier ID_A of the subject A (OPTIONAL), which is a byte string of an arbitrary length.

The protocol parameters that are used by subject B are the following:

1. The values ind and salt, where ind is in {1,...,N}, salt is in {1,...,2^128-1}.
2. The point Q_PW, satisfying the following equation:

   Q_PW = int (F (PW, salt, 2000))*Q_ind.

   It is possible that the point Q_PW is not stored and is calculated using PW in the beginning of the protocol. In that case B has to store PW and points Q_1,Q_2,...,Q_N.

3. The ID_ALG identifier.
4. The C_1^B counter, that tracks the total number of unsuccessful authentication trials in a row, and a value of CLim_1 that stores the maximum possible number of such events.
5. The C_2^B counter, that tracks the total number of unsuccessful authentication events during the period of usage of the specific PW, and a value of CLim_2 that stores the maximum possible number of such events.
6. The C_3^B counter, that tracks the total number of authentication events (successful and unsuccessful) during the period of usage of the specific PW, and a value of CLim_3 that stores the maximum possible number of such events.
7. The unique identifier ID_B of the subject B (OPTIONAL), which is a byte string of an arbitrary length.

4.2. Initial Values of the Protocol Counters

After the setup of a new password value PW the values of the counters MUST be assigned as follows:

- C_1^A = C_1^B = CLim_1, where CLim_1 is in {3,…,5};
- C_2^A = C_2^B = CLim_2, where CLim_2 is in {7,…,20};
- C_3^A = C_3^B = CLim_3, where CLim_3 is in {10^3,10^3+1,…,10^5}.

4.3. Protocol Steps

The basic SESPAKE steps are shown in the scheme below:

<table>
<tr><th>A [A_ID, PW]</th><th></th><th>B [B_ID, Q_PW , ind, salt]</th></tr>
<tr><td>if C_1^A or C_2^A or C_3^A = 0 ==> QUIT</td><td></td><td></td></tr>
<tr><td>decrement C_1^A, C_2^A, C_3^A by 1</td><td>A_ID ---></td><td>if C_1^B or C_2^B or C_3^B = 0 ==> QUIT</td></tr>
<tr><td>z_A = 0</td><td><--- ID_ALG, B_ID (OPTIONAL), ind, salt</td><td>decrement C_1^B, C_2^B, C_3^B by 1</td></tr>
<tr><td>Q_PW^A = int(F(PW, salt, 2000)) * Q_ind</td><td></td><td></td></tr>
<tr><td>choose alpha randomly from {1,...,q-1}</td><td></td><td></td></tr>
<tr><td>u_1 = alpha*P - Q_PW^A</td><td>u_1 ---></td><td>if u_1 not in E ==> QUIT</td></tr>
<tr><td></td><td></td><td>z_B = 0</td></tr>
<tr><td></td><td></td><td>Q_B = u_1 + Q_PW</td></tr>
<tr><td></td><td></td><td>choose betta randomly from {1,...,q-1}</td></tr>
<tr><td></td><td></td><td>if m/q*Q_B = O ==> Q_B = betta*P, z_B = 1</td></tr>
<tr><td></td><td></td><td>K_B = HASH(BYTES((m/q*betta*(mod q))*Q_B))</td></tr>
<tr><td>if u_2 not in E ==> QUIT</td><td><--- u_2</td><td>u_2 = betta*P + Q_PW</td></tr>
<tr><td>Q_A = u_2 - Q_PW^A</td><td></td><td></td></tr>
<tr><td>if m/q*Q_A = O ==> Q_A = alpha*P, z_A = 1</td><td></td><td></td></tr>
<tr><td>K_A = HASH(BYTES((m/q*alpha(mod q))*Q_A))</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>U_1 = BYTES(u_1), U_2 = BYTES(u_2)</td><td></td><td></td></tr>
<tr><td>MAC_A = HMAC(K_A, 0x01 || ID_A || ind || salt || U_1 || U_2 || ID_ALG (OPTIONAL) || DATA_A)</td><td>DATA_A, MAC_A ---></td><td>U_1 = BYTES(u_1), U_2 = BYTES(u_2)</td></tr>
<tr><td></td><td></td><td>if MAC_A != HMAC(K_B, 0x01 || ID_A || ind || salt || U_1 || U_2 || ID_ALG (OPTIONAL) || DATA_A) ==> QUIT</td></tr>
<tr><td></td><td></td><td>if z_B = 1 ==> QUIT</td></tr>
<tr><td></td><td></td><td>C_1^B = CLim_1, increment C_2^B by 1</td></tr>
<tr><td>if MAC_B != HMAC(K_A, 0x02 || ID_B || ind || salt || U_1 || U_2 || ID_ALG (OPTIONAL) || DATA_A || DATA_B) ==> QUIT</td><td><--- DATA_B, MAC_B</td><td>MAC_B = HMAC(K_B, 0x02 || ID_B || ind || salt || U_1 || U_2 || ID_ALG (OPTIONAL) || DATA_A || DATA_B)</td></tr>
<tr><td>if z_A = 1 ==> QUIT</td><td></td><td></td></tr>
</table>

A [A_ID, PW]		**B [B_ID, Q_PW , ind, salt]**
C_1^A = CLim_1, increment C_2^A by 1		

SESPAKE protocol steps

The full description of the protocol consists of the following steps:

1. If any of the counters C_1^A, C_2^A, C_3^A is equal to 0, A finishes the protocol with an error that informs of exceeding the number of trials that is controlled by the corresponding counter.
2. A decrements each of the counters C_1^A, C_2^A, C_3^A by 1, requests open authentication information from B and sends the ID_A identifier.
3. If any of the counters C_1^B, C_2^B, C_3^B is equal to 0, B finishes the protocol with an error that informs of exceeding the number of trials that is controlled by the corresponding counter.
4. B decrements each of the counters C_1^B, C_2^B, C_3^B by 1.
5. B sends the values of ind, salt and the ID_ALG identifier to A. B also can OPTIONALLY send the ID_B identifier to A. All following calculations are done by B in the elliptic curve group defined by the ID_ALG identifier.
6. A sets the curve defined by the received ID_ALG identifier as the used elliptic curve. All following calculations are done by A in this elliptic curve group.
7. A calculates the point Q_PW^A = int (F (PW, salt, 2000))*Q_ind.
8. A chooses randomly (according to the uniform distribution) the value alpha, alpha is in {1, …,q-1}, and assigns z_A = 0.
9. A sends the value u_1 = alpha*P - Q_PW^A to B.
10. After receiving u_1, B checks that u_1 is in E. If it is not, B finishes with an error, considering the authentication process unsuccessful.
11. B calculates Q_B = u_1 + Q_PW, assigns z_B = 0 and chooses randomly (according to the uniform distribution) the value betta, betta is in {1,…,q-1}.
12. If m/q*Q_B = O, B assigns Q_B = betta*P and z_B = 1.
13. B calculates K_B = HASH (BYTES((m/q*betta*(mod q))*Q_B)).
14. B sends the value u_2 = betta*P + Q_PW to A.
15. After receiving u_2, A checks that u_2 is in E. If it is not, A finishes with an error, considering the authentication process unsuccessful.
16. A calculates Q_A = u_2 - Q_PW^A.
17. If m/q*Q_A = O, then A assigns Q_A = alpha*P and z_A = 1.
18. A calculates K_A = HASH (BYTES((m/q*alpha(mod q))*Q_A)).
19. A calculates U_1 = BYTES(u_1), U_2 = BYTES(u_2).
20. A calculates MAC_A = HMAC (K_A, 0x01 || ID_A || ind || salt || U_1 || U_2 || ID_ALG (OPTIONAL) || DATA_A), where DATA_A is an OPTIONAL string that is authenticated with MAC_A (if it is not used, then DATA_A is considered to be of zero length).
21. A sends DATA_A, MAC_A to B.
22. B calculates U_1 = BYTES(u_1), U_2 = BYTES(u_2).
23. B checks that the values MAC_A and HMAC (K_B, 0x01 || ID_A || ind || salt || U_1 || U_2 || ID_ALG (OPTIONAL) || DATA_A) are equal. If they are not, it finishes with an error, considering the authentication process unsuccessful.
24. If z_B = 1, B finishes, considering the authentication process unsuccessful.
25. B sets the value of C_1^B to CLim_1 and increments C_2^B by 1.
26. B calculates MAC_B = HMAC(K_B, 0x02 || ID_B || ind || salt || U_1 || U_2 || ID_ALG (OPTIONAL) || DATA_A || DATA_B), where DATA_B is an OPTIONAL string that is authenticated with MAC_B (if it is not used, then DATA_B is considered to be of zero length).
27. B sends DATA_B, MAC_B to A.
28. A checks that the values MAC_B and HMAC (K_A, 0x02 || ID_B || ind || salt || U_1 || U_2 ||

ID_ALG (OPTIONAL) || DATA_A || DATA_B) are equal. If they are not, it finishes with an error, considering the authentication process unsuccessful.

29. If z_A = 1, A finishes, considering the authentication process unsuccessful.
30. A sets the value of C_1^A to CLim_1 and increments C_2^A by 1.

After the successful finish of the procedure the subjects A and B are mutually authenticated and each subject has an explicitly authenticated value of K = K_A = K_B.

N o t e s :

1. In the case when the interaction process can be initiated by any subject (client or server) the ID_A and ID_B options MUST be used and the receiver MUST check that the identifier he had received is not equal to his own, otherwise, it finishes the protocol. If an OPTIONAL parameter ID_A (or ID_B) is not used in the protocol, it SHOULD be considered equal to a fixed byte string (zero-length string is allowed) defined by a specific implementation.
2. The ind, ID_A, ID_B and salt parameters can be agreed in advance. If some parameter is agreed in advance, it is possible not to send it during a corresponding step. Nevertheless, all parameters MUST be used as corresponding inputs to HMAC function during stages 20, 23, 26 and 28.
3. The ID_ALG parameter can be fixed or agreed in advance.
4. The ID_ALG parameter is RECOMMENDED to be used in HMAC during stages 20, 23, 26 and 28.
5. Continuation of protocol interaction in case of any of the counters C_1^A, C_1^B being equal to zero MAY be done without changing password. In this case these counters can be used for protection against denial-of-service attacks. For example, continuation of interaction can be allowed after a certain delay.
6. Continuation of protocol interaction in case of any of the counters C_2^A, C_3^A, C_2^B, C_3^B being equal to zero MUST be done only after changing password.
7. It is RECOMMENDED that during the stages 9 and 14 the points u_1 and u_2 are sent in a non-compressed format (BYTES(u_1) and BYTES(u_2)). However, the point compression MAY be used.
8. The use of several Q points can reinforce the independence of the data streams in case of working with several applications, when, for example, two high-level protocols can use two different points. However, the use of more than one point is OPTIONAL.

5. Construction of Points Q_1,...,Q_N

This section provides an example of possible algorithm for generation of each point Q_i in the set {Q_1,...,Q_N} that corresponds to the given elliptic curve E.

The algorithm is based on choosing points with coordinates with a known preimages of a cryptographic hash function H, which is the GOST R 34.11-2012 hash function (see [RFC6986]) with 256-bit output, if 2^254 < q < 2^256, and the GOST R 34.11-2012 hash function (see [RFC6986]) with 512-bit output , if 2^508 < q < 2^512.

The algorithm consists of the following steps:

1. Set i = 1, SEED = 0, s = 4 or more.
2. Calculate X = int(HASH(BYTES(P)||bytes_s(SEED))) mod p.
3. Check that the value of X^3 + aX + b is a quadratic residue in the field F_p. If it is not, set SEED = SEED + 1 and return to Step 2.
4. Choose the value of Y = min{r1, r2}, where r1, r2 from {0,1,...,p-1} such that r1 != r2 and r1^2 = r2^2 = R mod p for R = X^3 + aX + b.
5. Check that for point Q = (X,Y) the following relations hold: Q != O and q*Q = O. If they do, go to Step 6, if not, set SEED = SEED + 1 and return to Step 2.

6. Set Q_i = Q. If i < N, then set i = i+1 and go to Step 2, else FINISH.

With the defined algorithm for any elliptic curve E point sets {Q_1,...,Q_N} are constructed. Constructed points in one set MUST have distinct X-coordinates.

N o t e : The knowledge of a hash function preimage prevents knowledge of the multiplicity of any point related to generator point P. It is of primary importance, because such a knowledge could be used to implement an attack against protocol with exhaustive search of password.

6. Acknowledgments

We thank Lolita Sonina, Georgiy Borodin, Sergey Agafin and Ekaterina Smyshlyaeva for their careful readings and useful comments.

7. Security Considerations

Any cryptographic algorithms, particularly HASH function and HMAC function, that are used in the SESPAKE protocol MUST be carefully designed and MUST be able to withstand all known types of cryptanalytic attack.

It is RECOMMENDED that the HASH function satisfies the following condition:
hashlen <= log_2(q) + 4, where hashlen is the lengths of the HASH function output.

The output length of hash functions that are used in the SESPAKE protocol is RECOMMENDED to be greater or equal to 256 bits.

The points Q_1, Q_2,...,Q_N and P MUST be chosen in such a way that they are provable pseudorandom. As a practical matter, this means that the algorithm for generation of each point Q_i in the set {Q_1,...,Q_N} (see Section 5) ensures that multiplicity of any point under any other point is unknown.

For a certain ID_ALG using N = 1 is RECOMMENDED.

N o t e: The exact adversary models, which have been considered during the security evaluation, can be found in the paper [SESPAKE-SECURITY], containing the security proofs.

8. References

8.1. Normative References

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[RFC6986] Dolmatov, V. and A. Degtyarev, "GOST R 34.11-2012: Hash Function", RFC 6986, DOI 10.17487/RFC6986, August 2013.

[RFC7091] Dolmatov, V. and A. Degtyarev, "GOST R 34.10-2012: Digital Signature Algorithm", RFC 7091, DOI 10.17487/RFC7091, December 2013.

[RFC7836] Smyshlyaev, S., Alekseev, E., Oshkin, I., Popov, V., Leontiev, S., Podobaev, V. and D. Belyavsky, "Guidelines on the Cryptographic Algorithms to Accompany the Usage of Standards GOST R 34.10-2012 and GOST R 34.11-2012", RFC 7836, DOI 10.17487/RFC7836, March 2016.

8.2. Informative References

[SESPAKE-SECURITY] Smyshlyaev, S., Oshkin, I., Alekseev, E. and L. Ahmetzyanova, "On the Security of One Password Authenticated Key Exchange Protocol", 2015.

Appendix A. Test Examples for GOST-based Protocol Implementation

The following test examples are made for the protocol implementation that is based on the Russian national standards GOST R 34.10-2012 [GOST3410-2012] and GOST R 34.11-2012 [GOST3411-2012]. The English versions of these standards can be found in [RFC7091] and [RFC6986].

A.1. Examples of Points

There is one point Q_1 for each of the elliptic curves below. This points were constructed using the method described in Section 5, in case when N = 1, where the GOST R 34.11-2012 hash function (see [RFC6986]) with 256-bit output is used if 2^254 < q < 2^256, the GOST R 34.11-2012 hash function (see [RFC6986]) with 512-bit output is used if 2^508 < q < 2^512.

Each of the points complies with the GOST R 34.10-2012 [GOST3410-2012] standard and is represented by a pair of (X, Y) coordinates in the canonical form and by a pair of (U, V) coordinates in the twisted Edwards form in accordance with the document [RFC7836] for the curves that have the equivalent representation in this form. There is a SEED value for each point, by which it was generated.

```
A.1.1. Curve id-GostR3410-2001-CryptoPro-A-ParamSet
Point Q_1
X = 0xa69d51caf1a309fa9e9b66187759b0174c274e080356f23cfcbfe84d396ad7bb
Y = 0x5d26f29ecc2e9ac0404dcf7986fa55fe94986362170f54b9616426a659786dac
SEED = 0x0001

A.1.2. Curve id-GostR3410-2001-CryptoPro-B-ParamSet
Point Q_1
X = 0x3d715a874a4b17cb3b517893a9794a2b36c89d2ffc693f01ee4cc27e7f49e399
Y = 0x1c5a641fcf7ce7e87cdf8cea38f3db3096eace2fad158384b53953365f4fe7fe
SEED = 0x0000

A.1.3. Curve id-GostR3410-2001-CryptoPro-C-ParamSet
Point Q_1
X = 0x1e36383e43bb6cfa2917167d71b7b5dd3d6d462b43d7c64282ae67dfbec2559d
Y = 0x137478a9f721c73932ea06b45cf72e37eb78a63f29a542e563c614650c8b6399
SEED = 0x0006

A.1.4. Curve id-tc26-gost-3410-2012-512-paramSetA
Point Q_1
X = 0x2a17f8833a32795327478871b5c5e88aefb91126c64b4b8327289bea62559425
    d18198f133f400874328b220c74497cd240586cb249e158532cb8090776cd61c
Y = 0x728f0c4a73b48da41ce928358fad26b47a6e094e9362bae82559f83cddc4ec3a
    4676bd3707edeaf4cd85e99695c64c241edc622be87dc0cf87f51f4367f723c5
```

```
SEED = 0x0001

A.1.5. Curve id-tc26-gost-3410-2012-512-paramSetB
Point Q_1
X = 0x7e1fae8285e035bec244bef2d0e5ebf436633cf50e55231dea9c9cf21d4c8c33
    df85d4305de92971f0a4b4c07e00d87bdbc720eb66e49079285aaf12e0171149
Y = 0x2cc89998b875d4463805ba0d858a196592db20ab161558ff2f4ef7a85725d209
    53967ae621afdeae89bb77c83a2528ef6fce02f68bda4679d7f2704947dbc408
SEED = 0x0000

A.1.6. Curve id-tc26-gost-3410-2012-256-paramSetA
Point Q_1
X = 0xb51adf93a40ab15792164fad3352f95b66369eb2a4ef5efae32829320363350e
Y = 0x74a358cc08593612f5955d249c96afb7e8b0bb6d8bd2bbe491046650d822be18
U = 0xebe97afffe0d0f88b8b0114b8de430ac2b34564e4420af24728e7305bc48aeaa
V = 0x828f2dcf8f06612b4fea4da72ca509c0f76dd37df424ea22bfa6f4f65748c1e4
SEED = 0x0001

A.1.7. Curve id-tc26-gost-3410-2012-512-paramSetC
Point Q_1
X = 0x489c91784e02e98f19a803abca319917f37689e5a18965251ce2ff4e8d8b298f
    5ba7470f9e0e713487f96f4a8397b3d09a270c9d367eb5e0e6561adeeb51581d
Y = 0x684ea885aca64eaf1b3fee36c0852a3be3bd8011b0ef18e203ff87028d6eb5db
    2c144a0dcc71276542bfd72ca2a43fa4f4939da66d9a60793c704a8c94e16f18
U = 0x3a3496f97e96b3849a4fa7db60fd93858bde89958e4beebd05a6b3214216b37c
    9d9a560076e7ea59714828b18fbfef996ffc98bf3dc9f2d3cb0ed36a0d6ace88
V = 0x52d884c8bf0ad6c5f7b3973e32a668daa1f1ed092eff138dae6203b2ccdec561
    47464d35fec4b727b2480eb143074712c76550c7a54ff3ea26f70059480dcb50
SEED = 0x0013
```

A.2. Test Examples of SESPAKE

This protocol implementation uses the GOST R 34.11-2012 hash function (see [RFC6986]) with 256-bit output as the H function and the HMAC_GOSTR3411_2012_512 function defined in [RFC7836] as a PRF function for the F function. The parameter len is considered equal to 256, if 2^254 < q < 2^256, and equal to 512, if 2^508 < q < 2^512.

The test examples for the point of each curve in Appendix A.1 are given below.

```
A.2.1 Curve id-GostR3410-2001-CryptoPro-A-ParamSet
The input protocol parameters in this example take the following values:
N = 1
ind = 1
ID_A:
  00 00 00 00
ID_B:
  00 00 00 00
PW:
  31 32 33 34 35 36 ('123456')
salt:
  29 23 BE 84 E1 6C D6 AE 52 90 49 F1 F1 BB E9 EB
Q_ind:
  X = 0xA69D51CAF1A309FA9E9B66187759B0174C274E080356F23CFCBFE84D396AD7BB
  Y = 0x5D26F29ECC2E9AC0404DCF7986FA55FE94986362170F54B9616426A659786DAC
```

The function F (PW, salt, 2000) takes the following values:
F(PW,salt,2000):
  BD 04 67 3F 71 49 B1 8E 98 15 5B D1 E2 72 4E 71
  D0 09 9A A2 51 74 F7 92 D3 32 6C 6F 18 12 70 67
The coordinates of the point Q_PW are:
  X = 0x59495655D1E7C7424C622485F575CCF121F3122D274101E8AB734CC9C9A9B45E
  Y = 0x48D1C311D33C9B701F3B03618562A4A07A044E3AF31E3999E67B487778B53C62
During the calculation of the message u_1 on the subject A the parameter
alpha, the point alpha*P and the message u_1 take the following values:
alpha=0x1F2538097D5A031FA68BBB43C84D12B3DE47B7061C0D5E24993E0C873CDBA6B3
alpha*P:
  X = 0xBBC77CF42DC1E62D06227935379B4AA4D14FEA4F565DDF4CB4FA4D31579F9676
  Y = 0x8E16604A4AFDF28246684D4996274781F6CB80ABBBA1414C1513EC988509DABF
u_1:
  X = 0x204F564383B2A76081B907F3FCA8795E806BE2C2ED228730B5B9E37074229E8D
  Y = 0xE84F9E442C61DDE37B601A7F37E7CA11C56183FA071DFA9320EDE3E7521F9D41
During processing a message u_1, calculation the K_B key and the message
u_2 on the subject B the parameters betta, src, K_B = HASH(src), betta*P
and u_2 take the following values:
betta=0xDC497D9EF6324912FD367840EE509A2032AEDB1C0A890D133B45F596FCCBD45D
src:
  2E 01 A3 D8 4F DB 7E 94 7B B8 92 9B E9 36 3D F5
  F7 25 D6 40 1A A5 59 D4 1A 67 24 F8 D5 F1 8E 2C
  A0 DB A9 31 05 CD DA F4 BF AE A3 90 6F DD 71 9D
  BE B2 97 B6 A1 7F 4F BD 96 DC C7 23 EA 34 72 A9
K_B:
  1A 62 65 54 92 1D C2 E9 2B 4D D8 D6 7D BE 5A 56
  62 E5 62 99 37 3F 06 79 95 35 AD 26 09 4E CA A3
betta*P:
  X = 0x6097341C1BE388E83E7CA2DF47FAB86E2271FD942E5B7B2EB2409E49F742BC29
  Y = 0xC81AA48BDB4CA6FA0EF18B9788AE25FE30857AA681B3942217F9FED151BAB7D0
u_2:
  X = 0xDC137A2F1D4A35AEBC0ECBF6D3486DEF8480BFDC752A86DD4F207D7D1910E22D
  Y = 0x7532F0CE99DCC772A4D77861DAE57C138F07AE304A727907FB0AAFDB624ED572
During processing a message u_2 and calculation the key on the subject A
the K_A key takes the following value:
K_A:
  1A 62 65 54 92 1D C2 E9 2B 4D D8 D6 7D BE 5A 56
  62 E5 62 99 37 3F 06 79 95 35 AD 26 09 4E CA A3
The message MAC_A=HMAC (K_A, 0x01 || ID_A || ind || salt || u_1 || u_2)
from the subject A takes the following value:
MAC_A:
  23 7A 03 C3 5F 49 17 CE 86 B3 58 94 45 F1 1E 1A
  6F 10 8B 2F DD 0A A9 E8 10 66 4B 25 59 60 B5 79
The message MAC_B=HMAC (K_B, 0x02 || ID_B || ind || salt || u_1 || u_2)
from the subject B takes the following value:
MAC_B:
  9E E0 E8 73 3B 06 98 50 80 4D 97 98 73 1D CD 1C
  FF E8 7A 3B 15 1F 0A E8 3E A9 6A FB 4F FC 31 E4

A.2.2 Curve id-GostR3410-2001-CryptoPro-B-ParamSet
The input protocol parameters in this example take the following values:
N = 1

```
ind = 1
ID_A:
  00 00 00 00
ID_B:
  00 00 00 00
PW:
  31 32 33 34 35 36 ('123456')
salt:
  29 23 BE 84 E1 6C D6 AE 52 90 49 F1 F1 BB E9 EB
Q_ind:
  X = 0x3D715A874A4B17CB3B517893A9794A2B36C89D2FFC693F01EE4CC27E7F49E399
  Y = 0x1C5A641FCF7CE7E87CDF8CEA38F3DB3096EACE2FAD158384B53953365F4FE7FE
The function F (PW, salt, 2000) takes the following values:
F(PW,salt,2000):
  BD 04 67 3F 71 49 B1 8E 98 15 5B D1 E2 72 4E 71
  D0 09 9A A2 51 74 F7 92 D3 32 6C 6F 18 12 70 67
The coordinates of the point Q_PW are:
  X = 0x6DC2AE26BC691FCA5A73D9C452790D15E34BA5404D92955B914C8D2662ABB985
  Y = 0x3B02AAA9DD65AE30C335CED12F3154BBAC059F66B088306747453EDF6E5DB077
During the calculation of the message u_1 on the subject A the parameter
alpha, the point alpha*P and the message u_1 take the following values:
alpha=0x499D72B90299CAB0DA1F8BE19D9122F622A13B32B730C46BD0664044F2144FAD
alpha*P:
  X = 0x61D6F916DB717222D74877F179F7EBEF7CD4D24D8C1F523C048E34A1DF30F8DD
  Y = 0x3EC48863049CFCFE662904082E78503F4973A4E105E2F1B18C69A5E7FB209000
u_1:
  X = 0x21F5437AF33D2A1171A070226B4AE82D3765CD0EEBFF1ECEFE158EBC50C63AB1
  Y = 0x5C9553B5D11AAAECE738AD9A9F8CB4C100AD4FA5E089D3CBCCEA8C0172EB7ECC
During processing a message u_1, calculation the K_B key and the message
u_2 on the subject B the parameters betta, src, K_B = HASH(src), betta*P
and u_2 take the following values:
betta=0x0F69FF614957EF83668EDC2D7ED614BE76F7B253DB23C5CC9C52BF7DF8F4669D
src:
  50 14 0A 5D ED 33 43 EF C8 25 7B 79 E6 46 D9 F0
  DF 43 82 8C 04 91 9B D4 60 C9 7A D1 4B A3 A8 6B
  00 C4 06 B5 74 4D 8E B1 49 DC 8E 7F C8 40 64 D8
  53 20 25 3E 57 A9 B6 B1 3D 0D 38 FE A8 EE 5E 0A
K_B:
  A6 26 DE 01 B1 68 0F F7 51 30 09 12 2B CE E1 89
  68 83 39 4F 96 03 01 72 45 5C 9A E0 60 CC E4 4A
betta*P:
  X = 0x33BC6F7E9C0BA10CFB2B72546C327171295508EA97F8C8BA9F890F2478AB4D6C
  Y = 0x75D57B396C396F492F057E9222CCC686437A2AAD464E452EF426FC8EEED1A4A6
u_2:
  X = 0x089DDEE718EE8A224A7F37E22CFFD731C25FCBF58860364EE322412CDCEF99AC
  Y = 0x0ECE03D4E395A6354C571871BEF425A532D5D463B0F8FD427F91A43E20CDA55C
During processing a message u_2 and calculation the key on the subject A
the K_A key takes the following value:
K_A:
  A6 26 DE 01 B1 68 0F F7 51 30 09 12 2B CE E1 89
  68 83 39 4F 96 03 01 72 45 5C 9A E0 60 CC E4 4A
The message MAC_A=HMAC (K_A, 0x01 || ID_A || ind || salt || u_1 || u_2)
from the subject A takes the following value:
```

MAC_A:
  B9 1F 43 90 2A FA 90 D3 E5 C6 91 CB DC 43 8A 1E
  BF 54 7F 4C 2C B4 14 43 CC 38 79 7B E2 47 A7 D0
The message MAC_B=HMAC (K_B, 0x02 || ID_B || ind || salt || u_1 || u_2)
from the subject B takes the following value:
MAC_B:
  79 D5 54 83 FD 99 B1 2B CC A5 ED C6 BB E1 D7 B9
  15 CE 04 51 B0 89 1E 77 5D 4A 61 CB 16 E3 3F CC

A.2.3 Curve id-GostR3410-2001-CryptoPro-C-ParamSet
The input protocol parameters in this example take the following values:
N = 1
ind = 1
ID_A:
  00 00 00 00
ID_B:
  00 00 00 00
PW:
  31 32 33 34 35 36 ('123456')
salt:
  29 23 BE 84 E1 6C D6 AE 52 90 49 F1 F1 BB E9 EB
Q_ind:
  X = 0x1E36383E43BB6CFA2917167D71B7B5DD3D6D462B43D7C64282AE67DFBEC2559D
  Y = 0x137478A9F721C73932EA06B45CF72E37EB78A63F29A542E563C614650C8B6399
The function F (PW, salt, 2000) takes the following values:
F(PW,salt,2000):
  BD 04 67 3F 71 49 B1 8E 98 15 5B D1 E2 72 4E 71
  D0 09 9A A2 51 74 F7 92 D3 32 6C 6F 18 12 70 67
The coordinates of the point Q_PW are:
  X = 0x945821DAF91E158B839939630655A3B21FF3E146D27041E86C05650EB3B46B59
  Y = 0x3A0C2816AC97421FA0E879605F17F0C9C3EB734CFF196937F6284438D70BDC48
During the calculation of the message u_1 on the subject A the parameter
alpha, the point alpha*P and the message u_1 take the following values:
alpha=0x3A54AC3F19AD9D0B1EAC8ACDCEA70E581F1DAC33D13FEAFD81E762378639C1A8
alpha*P:
  X = 0x96B7F09C94D297C257A7DA48364C0076E59E48D221CBA604AE111CA3933B446A
  Y = 0x54E4953D86B77ECCEB578500931E822300F7E091F79592CA202A020D762C34A6
u_1:
  X = 0x81BBD6FCA464D2E2404A66D786CE4A777E739A89AEB68C2DAC99D53273B75387
  Y = 0x6B6DBD922EA7E060998F8B230AB6EF07AD2EC86B2BF66391D82A30612EADD411
During processing a message u_1, calculation the K_B key and the message
u_2 on the subject B the parameters betta, src, K_B = HASH(src), betta*P
and u_2 take the following values:
betta=0x448781782BF7C0E52A1DD9E6758FD3482D90D3CFCCF42232CF357E59A4D49FD4
src:
  16 A1 2D 88 54 7E 1C 90 06 BA A0 08 E8 CB EC C9
  D1 68 91 ED C8 36 CF B7 5F 8E B9 56 FA 76 11 94
  D2 8E 25 DA D3 81 8D 16 3C 49 4B 05 9A 8C 70 A5
  A1 B8 8A 7F 80 A2 EE 35 49 30 18 46 54 2C 47 0B
K_B:
  BE 7E 7E 47 B4 11 16 F2 C7 7E 3B 8F CE 40 30 72
  CA 82 45 0D 65 DE FC 71 A9 56 49 E4 DE EA EC EE
betta*P:

```
  X = 0x4B9C0AB55A938121F282F48A2CC4396EB16E7E0068B495B0C1DD4667786A3EB7
  Y = 0x223460AA8E09383E9DF9844C5A0F2766484738E5B30128A171B69A77D9509B96
u_2:
  X = 0x2ED9B903254003A672E89EBEBC9E31503726AD124BB5FC0A726EE0E6FCCE323E
  Y = 0x4CF5E1042190120391EC8DB62FE25E9E26EC60FB0B78B242199839C295FCD022
During processing a message u_2 and calculation the key on the subject A
the K_A key takes the following value:
K_A:
  BE 7E 7E 47 B4 11 16 F2 C7 7E 3B 8F CE 40 30 72
  CA 82 45 0D 65 DE FC 71 A9 56 49 E4 DE EA EC EE
The message MAC_A=HMAC (K_A, 0x01 || ID_A || ind || salt || u_1 || u_2)
from the subject A takes the following value:
MAC_A:
  D3 B4 1A E2 C9 43 11 36 06 3E 6D 08 A6 1B E9 63
  BD 5E D6 A1 FF F9 37 FA 8B 09 0A 98 E1 62 BF ED
The message MAC_B=HMAC (K_B, 0x02 || ID_B || ind || salt || u_1 || u_2)
from the subject B takes the following value:
MAC_B:
  D6 B3 9A 44 99 BE D3 E0 4F AC F9 55 50 2D 16 B2
  CB 67 4A 20 5F AC 3C D8 3D 54 EC 2F D5 FC E2 58

A.2.4 Curve id-tc26-gost-3410-2012-512-paramSetA
The input protocol parameters in this example take the following values:
N = 1
ind = 1
ID_A:
  00 00 00 00
ID_B:
  00 00 00 00
PW:
  31 32 33 34 35 36 ('123456')
salt:
  29 23 BE 84 E1 6C D6 AE 52 90 49 F1 F1 BB E9 EB
Q_ind:
  X = 0x2A17F8833A32795327478871B5C5E88AEFB91126C64B4B8327289BEA62559425
      D18198F133F400874328B220C74497CD240586CB249E158532CB8090776CD61C
  Y = 0x728F0C4A73B48DA41CE928358FAD26B47A6E094E9362BAE82559F83CDDC4EC3A
      4676BD3707EDEAF4CD85E99695C64C241EDC622BE87DC0CF87F51F4367F723C5
The function F (PW, salt, 2000) takes the following values:
F(PW,salt,2000):
  BD 04 67 3F 71 49 B1 8E 98 15 5B D1 E2 72 4E 71
  D0 09 9A A2 51 74 F7 92 D3 32 6C 6F 18 12 70 67
  1C 62 13 E3 93 0E FD DA 26 45 17 92 C6 20 81 22
  EE 60 D2 00 52 0D 69 5D FD 9F 5F 0F D5 AB A7 02
The coordinates of the point Q_PW are:
  X = 0x0C0AB53D0E0A9C607CAD758F558915A0A7DC5DC87B45E9A58FDDF30EC3385960
      283E030CD322D9E46B070637785FD49D2CD711F46807A24C40AF9A42C8E2D740
  Y = 0xDF93A8012B86D3A3D4F8A4D487DA15FC739EB31B20B3B0E8C8C032AAF8072C63
      37CF7D5B404719E5B4407C41D9A3216A08CA69C271484E9ED72B8AAA52E28B8B
During the calculation of the message u_1 on the subject A the parameter
alpha, the point alpha*P and the message u_1 take the following values:
alpha=0x3CE54325DB52FE798824AEAD11BB16FA766857D04A4AF7D468672F16D90E7396
      046A46F815693E85B1CE5464DA9270181F82333B0715057BBE8D61D400505F0E
```

```
alpha*P:
  X = 0xB93093EB0FCC463239B7DF276E09E592FCFC9B635504EA4531655D76A0A3078E
      2B4E51CFE2FA400CC5DE9FBE369DB204B3E8ED7EDD85EE5CCA654C1AED70E396
  Y = 0x809770B8D910EA30BD2FA89736E91DC31815D2D9B31128077EEDC371E9F69466
      F497DC64DD5B1FADC587F860EE256109138C4A9CD96B628E65A8F590520FC882
u_1:
  X = 0xE7510A9EDD37B869566C81052E2515E1563FDFE79F1D782D6200F33C3CC2764D
      40D0070B73AD5A47BAE9A8F2289C1B07DAC26A1A2FF9D3ECB0A8A94A4F179F13
  Y = 0xBA333B912570777B626A5337BC7F727952460EEBA2775707FE4537372E902DF5
      636080B25399751BF48FB154F3C2319A91857C23F39F89EF54A8F043853F82DE
During processing a message u_1, calculation the K_B key and the message
u_2 on the subject B the parameters betta, src, K_B = HASH(src), betta*P
and u_2 take the following values:
betta=0xB5C286A79AA8E97EC0E19BC1959A1D15F12F8C97870BA9D68CC12811A56A3BB1
      1440610825796A49D468CDC9C2D02D76598A27973D5960C5F50BCE28D8D345F4
src:
  84 59 C2 0C B5 C5 32 41 6D B9 28 EB 50 C0 52 0F
  B2 1B 9C D3 9A 4E 76 06 B2 21 BE 15 CA 1D 02 DA
  08 15 DE C4 49 79 C0 8C 7D 23 07 AF 24 7D DA 1F
  89 EC 81 20 69 F5 D9 CD E3 06 AF F0 BC 3F D2 6E
  D2 01 B9 53 52 A2 56 06 B6 43 E8 88 30 2E FC 8D
  3E 95 1E 3E B4 68 4A DB 5C 05 7B 8F 8C 89 B6 CC
  0D EE D1 00 06 5B 51 8A 1C 71 7F 76 82 FF 61 2B
  BC 79 8E C7 B2 49 0F B7 00 3F 94 33 87 37 1C 1D
K_B:
  53 24 DE F8 48 B6 63 CC 26 42 2F 5E 45 EE C3 4C
  51 D2 43 61 B1 65 60 CA 58 A3 D3 28 45 86 CB 7A
betta*P:
  X = 0x238B38644E440452A99FA6B93D9FD7DA0CB83C32D3C1E3CFE5DF5C3EB0F9DB91
      E588DAEDC849EA2FB867AE855A21B4077353C0794716A6480995113D8C20C7AF
  Y = 0xB2273D5734C1897F8D15A7008B862938C8C74CA7E877423D95243EB7EBD02FD2
      C456CF9FC956F078A59AA86F19DD1075E5167E4ED35208718EA93161C530ED14
u_2:
  X = 0xC33844126216E81B372001E77C1FE9C7547F9223CF7BB865C4472EC18BE0C79A
      678CC5AE4028E3F3620CCE355514F1E589F8A0C433CEAFCBD2EE87884D953411
  Y = 0x8B520D083AAF257E8A54EC90CBADBAF4FEED2C2D868C82FF04FCBB9EF6F38E56
      F6BAF9472D477414DA7E36F538ED223D2E2EE02FAE1A20A98C5A9FCF03B6F30D
During processing a message u_2 and calculation the key on the subject A
the K_A key takes the following value:
K_A:
  53 24 DE F8 48 B6 63 CC 26 42 2F 5E 45 EE C3 4C
  51 D2 43 61 B1 65 60 CA 58 A3 D3 28 45 86 CB 7A
The message MAC_A=HMAC (K_A, 0x01 || ID_A || ind || salt || u_1 || u_2)
from the subject A takes the following value:
MAC_A:
  E8 EF 9E A8 F1 E6 B1 26 68 E5 8C D2 2D D8 EE C6
  4A 16 71 00 39 FA A6 B6 03 99 22 20 FA FE 56 14
The message MAC_B=HMAC (K_B, 0x02 || ID_B || ind || salt || u_1 || u_2)
from the subject B takes the following value:
MAC_B:
  61 14 34 60 83 6B 23 5C EC D0 B4 9B 58 7E A4 5D
  51 3C 3A 38 78 3F 1C 9D 3B 05 97 0A 95 6A 55 BA
```

A.2.5 Curve id-tc26-gost-3410-2012-512-paramSetB

The input protocol parameters in this example take the following values:

N = 1

ind = 1

ID_A:

```
  00 00 00 00
```

ID_B:

```
  00 00 00 00
```

PW:

```
  31 32 33 34 35 36 ('123456')
```

salt:

```
  29 23 BE 84 E1 6C D6 AE 52 90 49 F1 F1 BB E9 EB
```

Q_ind:

```
  X = 0x7E1FAE8285E035BEC244BEF2D0E5EBF436633CF50E55231DEA9C9CF21D4C8C33
        DF85D4305DE92971F0A4B4C07E00D87BDBC720EB66E49079285AAF12E0171149
  Y = 0x2CC89998B875D4463805BA0D858A196592DB20AB161558FF2F4EF7A85725D209
        53967AE621AFDEAE89BB77C83A2528EF6FCE02F68BDA4679D7F2704947DBC408
```

The function F (PW, salt, 2000) takes the following values:

F(PW,salt,2000):

```
  BD 04 67 3F 71 49 B1 8E 98 15 5B D1 E2 72 4E 71
  D0 09 9A A2 51 74 F7 92 D3 32 6C 6F 18 12 70 67
  1C 62 13 E3 93 0E FD DA 26 45 17 92 C6 20 81 22
  EE 60 D2 00 52 0D 69 5D FD 9F 5F 0F D5 AB A7 02
```

The coordinates of the point Q_PW are:

```
  X = 0x7D03E65B8050D1E12CBB601A17B9273B0E728F5021CD47C8A4DD822E4627BA5F
        9C696286A2CDDA9A065509866B4DEDEDC4A118409604AD549F87A60AFA621161
  Y = 0x16037DAD45421EC50B00D50BDC6AC3B85348BC1D3A2F85DB27C3373580FEF87C
        2C743B7ED30F22BE22958044E716F93A61CA3213A361A2797A16A3AE62957377
```

During the calculation of the message u_1 on the subject A the parameter
alpha, the point alpha*P and the message u_1 take the following values:

```
alpha=0x715E893FA639BF341296E0623E6D29DADF26B163C278767A7982A989462A3863
        FE12AEF8BD403D59C4DC4720570D4163DB0805C7C10C4E818F9CB785B04B9997
```

alpha*P:

```
  X = 0x10C479EA1C04D3C2C02B0576A9C42D96226FF033C1191436777F66916030D87D
        02FB93738ED7669D07619FFCE7C1F3C4DB5E5DF49E2186D6FA1E2EB5767602B9
  Y = 0x039F6044191404E707F26D59D979136A831CCE43E1C5F0600D1DDF8F39D0CA3D
        52FBD943BF04DDCED1AA2CE8F5EBD7487ACDEF239C07D015084D796784F35436
```

u_1:

```
  X = 0x45C05CCE8290762F2470B719B4306D62B2911CEB144F7F72EF11D10498C7E921
        FF163FE72044B4E7332AD8CBEC3C12117820F53A60762315BCEB5BC6DA5CF1E0
  Y = 0x5BE483E382D0F5F0748C4F6A5045D99E62755B5ACC9554EC4A5B2093E121A2DD
        5C6066BC9EDE39373BA19899208BB419E38B39BBDEDEB0B09A5CAAEAA984D02E
```

During processing a message u_1, calculation the K_B key and the message
u_2 on the subject B the parameters betta, src, K_B = HASH(src), betta*P
and u_2 take the following values:

```
betta=0x30FA8C2B4146C2DBBE82BED04D7378877E8C06753BD0A0FF71EBF2BEFE8DA8F3
        DC0836468E2CE7C5C961281B6505140F8407413F03C2CB1D201EA1286CE30E6D
```

src:

```
  3F 04 02 E4 0A 9D 59 63 20 5B CD F4 FD 89 77 91
  9B BA F4 80 F8 E4 FB D1 25 5A EC E6 ED 57 26 4B
  D0 A2 87 98 4F 59 D1 02 04 B5 F4 5E 4D 77 F3 CF
  8A 63 B3 1B EB 2D F5 9F 8A F7 3C 20 9C CA 8B 50
  B4 18 D8 01 E4 90 AE 13 3F 04 F4 F3 F4 D8 FE 8E
```

```
  19 64 6A 1B AF 44 D2 36 FC C2 1B 7F 4D 8F C6 A1
  E2 9D 6B 69 AC CE ED 4E 62 AB B2 0D AD 78 AC F4
  FE B0 ED 83 8E D9 1E 92 12 AB A3 89 71 4E 56 0C
K_B:
  D5 90 E0 5E F5 AE CE 8B 7C FB FC 71 BE 45 5F 29
  A5 CC 66 6F 85 CD B1 7E 7C C7 16 C5 9F F1 70 E9
betta*P:
  X = 0x34C0149E7BB91AE377B02573FCC48AF7BFB7B16DEB8F9CE870F384688E3241A3
      A868588CC0EF4364CCA67D17E3260CD82485C202ADC76F895D5DF673B1788E67
  Y = 0x608E944929BD643569ED5189DB871453F13333A1EAF82B2FE1BE8100E775F13D
      D9925BD317B63BFAF05024D4A738852332B64501195C1B2EF789E34F23DDAFC5
u_2:
  X = 0x0535F95463444C4594B5A2E14B35760491C670925060B4BEBC97DE3A3076D1A5
      81F89026E04282B040925D9250201024ACA4B2713569B6C3916A6F3344B840AD
  Y = 0x40E6C2E55AEC31E7BCB6EA0242857FC6DFB5409803EDF4CA20141F72CC3C7988
      706E076765F4F004340E5294A7F8E53BA59CB67502F0044558C854A7D63FE900
During processing a message u_2 and calculation the key on the subject A
the K_A key takes the following value:
K_A:
  D5 90 E0 5E F5 AE CE 8B 7C FB FC 71 BE 45 5F 29
  A5 CC 66 6F 85 CD B1 7E 7C C7 16 C5 9F F1 70 E9
The message MAC_A=HMAC (K_A, 0x01 || ID_A || ind || salt || u_1 || u_2)
from the subject A takes the following value:
MAC_A:
  DE 46 BB 4C 8C E0 8A 6E F3 B8 DF AC CC 1A 39 B0
  8D 8C 27 B6 CB 0F CF 59 23 86 A6 48 F4 E5 BD 8C
The message MAC_B=HMAC (K_B, 0x02 || ID_B || ind || salt || u_1 || u_2)
from the subject B takes the following value:
MAC_B:
  EC B1 1D E2 06 1C 55 F1 D1 14 59 CB 51 CE 31 40
  99 99 99 2F CA A1 22 2F B1 4F CE AB 96 EE 7A AC

A.2.6 Curve id-tc26-gost-3410-2012-256-paramSetA
The input protocol parameters in this example take the following values:
N = 1
ind = 1
ID_A:
  00 00 00 00
ID_B:
  00 00 00 00
PW:
  31 32 33 34 35 36 ('123456')
salt:
  29 23 BE 84 E1 6C D6 AE 52 90 49 F1 F1 BB E9 EB
Q_ind:
  X = 0xB51ADF93A40AB15792164FAD3352F95B66369EB2A4EF5EFAE32829320363350E
  Y = 0x74A358CC08593612F5955D249C96AFB7E8B0BB6D8BD2BBE491046650D822BE18
The function F (PW, salt, 2000) takes the following values:
F(PW,salt,2000):
  BD 04 67 3F 71 49 B1 8E 98 15 5B D1 E2 72 4E 71
  D0 09 9A A2 51 74 F7 92 D3 32 6C 6F 18 12 70 67
The coordinates of the point Q_PW are:
  X = 0xDBF99827078956812FA48C6E695DF589DEF1D18A2D4D35A96D75BF6854237629
```

Y = 0x9FDDD48BFBC57BEE1DA0CFF282884F284D471B388893C48F5ECB02FC18D67589
During the calculation of the message u_1 on the subject A the parameter
alpha, the point alpha*P and the message u_1 take the following values:
alpha=0x147B72F6684FB8FD1B418A899F7DBECAF5FCE60B13685BAA95328654A7F0707F
alpha*P:
  X = 0x33FBAC14EAE538275A769417829C431BD9FA622B6F02427EF55BD60EE6BC2888
  Y = 0x22F2EBCF960A82E6CDB4042D3DDDA511B2FBA925383C2273D952EA2D406EAE46
u_1:
  X = 0xE569AB544E3A13C41077DE97D659A1B7A13F61DDD808B633A5621FE2583A2C43
  Y = 0xA21A743A08F4D715661297ECD6F86553A808925BF34802BF7EC34C548A40B2C0
During processing a message u_1, calculation the K_B key and the message
u_2 on the subject B the parameters betta, src, K_B = HASH(src), betta*P
and u_2 take the following values:
betta=0x30D5CFADAA0E31B405E6734C03EC4C5DF0F02F4BA25C9A3B320EE6453567B4CB
src:
  A3 39 A0 B8 9C EF 1A 6F FD 4C A1 28 04 9E 06 84
  DF 4A 97 75 B6 89 A3 37 84 1B F7 D7 91 20 7F 35
  11 86 28 F7 28 8E AA 0F 7E C8 1D A2 0A 24 FF 1E
  69 93 C6 3D 9D D2 6A 90 B7 4D D1 A2 66 28 06 63
K_B:
  7D F7 1A C3 27 ED 51 7D 0D E4 03 E8 17 C6 20 4B
  C1 91 65 B9 D1 00 2B 9F 10 88 A6 CD A6 EA CF 27
betta*P:
  X = 0x2B2D89FAB735433970564F2F28CFA1B57D640CB902BC6334A538F44155022CB2
  Y = 0x10EF6A82EEF1E70F942AA81D6B4CE5DEC0DDB9447512962874870E6F2849A96F
u_2:
  X = 0x190D2F283F7E861065DB53227D7FBDF429CEBF93791262CB29569BDF63C86CA4
  Y = 0xB3F1715721E9221897CCDE046C9B843A8386DBF7818A112F15A02BC820AC8F6D
During processing a message u_2 and calculation the key on the subject A
the K_A key takes the following value:
K_A:
  7D F7 1A C3 27 ED 51 7D 0D E4 03 E8 17 C6 20 4B
  C1 91 65 B9 D1 00 2B 9F 10 88 A6 CD A6 EA CF 27
The message MAC_A=HMAC (K_A, 0x01 || ID_A || ind || salt || u_1 || u_2)
from the subject A takes the following value:
MAC_A:
  F9 29 B6 1A 3C 83 39 85 B8 29 F2 68 55 7F A8 11
  00 9F 82 0A B1 A7 30 B5 AA 33 4C 3E 6B A3 17 7F
The message MAC_B=HMAC (K_B, 0x02 || ID_B || ind || salt || u_1 || u_2)
from the subject B takes the following value:
MAC_B:
  A2 92 8A 5C F6 20 BB C4 90 0D E4 03 F7 FC 59 A5
  E9 80 B6 8B E0 46 D0 B5 D9 B4 AE 6A BF A8 0B D6

A.2.7 Curve id-tc26-gost-3410-2012-512-paramSetC
The input protocol parameters in this example take the following values:
N = 1
ind = 1
ID_A:
  00 00 00 00
ID_B:
  00 00 00 00
PW:

```
  31 32 33 34 35 36 ('123456')
salt:
  29 23 BE 84 E1 6C D6 AE 52 90 49 F1 F1 BB E9 EB
Q_ind:
  X = 0x489C91784E02E98F19A803ABCA319917F37689E5A18965251CE2FF4E8D8B298F
        5BA7470F9E0E713487F96F4A8397B3D09A270C9D367EB5E0E6561ADEEB51581D
  Y = 0x684EA885ACA64EAF1B3FEE36C0852A3BE3BD8011B0EF18E203FF87028D6EB5DB
        2C144A0DCC71276542BFD72CA2A43FA4F4939DA66D9A60793C704A8C94E16F18
The function F (PW, salt, 2000) takes the following values:
F(PW,salt,2000):
  BD 04 67 3F 71 49 B1 8E 98 15 5B D1 E2 72 4E 71
  D0 09 9A A2 51 74 F7 92 D3 32 6C 6F 18 12 70 67
  1C 62 13 E3 93 0E FD DA 26 45 17 92 C6 20 81 22
  EE 60 D2 00 52 0D 69 5D FD 9F 5F 0F D5 AB A7 02
The coordinates of the point Q_PW are:
  X = 0x0185AE6271A81BB7F236A955F7CAA26FB63849813C0287D96C83A15AE6B6A864
        67AB13B6D88CE8CD7DC2E5B97FF5F28FAC2C108F2A3CF3DB5515C9E6D7D210E8
  Y = 0xED0220F92EF771A71C64ECC77986DB7C03D37B3E2AB3E83F32CE5E074A762EC0
        8253C9E2102B87532661275C4B1D16D2789CDABC58ACFDF7318DE70AB64F09B8
During the calculation of the message u_1 on the subject A the parameter
alpha, the point alpha*P and the message u_1 take the following values:
alpha=0x332F930421D14CFE260042159F18E49FD5A54167E94108AD80B1DE60B13DE799
        9A34D611E63F3F870E5110247DF8EC7466E648ACF385E52CCB889ABF491EDFF0
alpha*P:
  X = 0x561655966D52952E805574F4281F1ED3A2D498932B00CBA9DECB42837F09835B
        FFBFE2D84D6B6B242FE7B57F92E1A6F2413E12DDD6383E4437E13D72693469AD
  Y = 0xF6B18328B2715BD7F4178615273A36135BC0BF62F7D8BB9F080164AD36470AD0
        3660F51806C64C6691BADEF30F793720F8E3FEAED631D6A54A4C372DCBF80E82
u_1:
  X = 0x40645B4B9A908D74DEF98886A336F98BAE6ADA4C1AC9B7594A33D5E4A16486C5
        533C7F3C5DD84797AB5B4340BFC70CAF1011B69A01A715E5B9B5432D5151CBD7
  Y = 0x267FBB18D0B79559D1875909F2A15F7B49ECD8ED166CF7F4FCD1F44891550483
        5E80D52BE8D34ADA5B5E159CF52979B1BCFE8F5048DC443A0983AA19192B8407
During processing a message u_1, calculation the K_B key and the message
u_2 on the subject B the parameters betta, src, K_B = HASH(src), betta*P
and u_2 take the following values:
betta=0x38481771E7D054F96212686B613881880BD8A6C89DDBC656178F014D2C093432
        A033EE10415F13A160D44C2AD61E6E2E05A7F7EC286BCEA3EA4D4D53F8634FA2
src:
  4F 4D 64 B5 D0 70 08 E9 E6 85 87 4F 88 2C 3E 1E
  60 A6 67 5E ED 42 1F C2 34 16 3F DE B4 4C 69 18
  B7 BC CE AB 88 A0 F3 FB 78 8D A8 DB 10 18 51 FF
  1A 41 68 22 BA 37 C3 53 CE C4 C5 A5 23 95 B7 72
  AC 93 C0 54 E3 F4 05 5C ED 6F F0 BE E4 A6 A2 4E
  D6 8B 86 FE FA 70 DE 4A 2B 16 08 51 42 A4 DF F0
  5D 32 EC 7D DF E3 04 F5 C7 04 FD FA 06 0F 64 E9
  E8 32 14 00 25 F3 92 E5 03 50 77 0E 3F B6 2C AC
K_B:
  A0 83 84 A6 2F 4B E1 AE 48 98 FC A3 6D AA 3F AA
  45 1B 3E C5 B5 9C E3 75 F8 9E 92 9F 4B 13 25 8C
betta*P:
  X = 0xB7C5818687083433BC1AFF61CB5CA79E38232025E0C1F123B8651E62173CE687
        3F3E6FFE7281C2E45F4F524F66B0C263616ED08FD210AC4355CA3292B51D71C3
```

```
  Y = 0x497F14205DBDC89BDDAF50520ED3B1429AD30777310186BE5E68070F016A44E0
        C766DB08E8AC23FBDFDE6D675AA4DF591EB18BA0D348DF7AA40973A2F1DCFA55
u_2:
  X = 0xB772FD97D6FDEC1DA0771BC059B3E5ADF9858311031EAE5AEC6A6EC8104B4105
        C45A6C65689A8EE636C687DB62CC0AFC9A48CA66E381286CC73F374C1DD8F445
  Y = 0xC64F69425FFEB2995130E85A08EDC3A686EC28EE6E8469F7F09BD3BCBDD843AC
        573578DA6BA1CB3F5F069F205233853F06255C4B28586C9A1643537497B1018C
During processing a message u_2 and calculation the key on the subject A
the K_A key takes the following value:
K_A:
  A0 83 84 A6 2F 4B E1 AE 48 98 FC A3 6D AA 3F AA
  45 1B 3E C5 B5 9C E3 75 F8 9E 92 9F 4B 13 25 8C
The message MAC_A=HMAC (K_A, 0x01 || ID_A || ind || salt || u_1 || u_2)
from the subject A takes the following value:
MAC_A:
  12 63 F2 89 0E 90 EE 42 6B 9B A0 8A B9 EA 7F 1F
  FF 26 E1 60 5C C6 5D E2 96 96 91 15 E5 31 76 87
The message MAC_B=HMAC (K_B, 0x02 || ID_B || ind || salt || u_1 || u_2)
from the subject B takes the following value:
MAC_B:
  6D FD 06 04 5D 6D 97 A0 E4 19 B0 0E 00 35 B9 D2
  E3 AB 09 8B 7C A4 AD 52 54 60 FA B6 21 85 AA 57
```

Appendix B. Point Verification Script

The points from the Appendix A.1 were generated with the following point verification script that is written in Python:

```

curvesParams = [
{
"OID":"id-GostR3410-2001-CryptoPro-A-ParamSet",
"p":0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFD97,
"a":0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFD94,
"b":166,
"m":0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF6C611070995AD10045841B09B761B893,
"q":0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF6C611070995AD10045841B09B761B893,
"x":1,
"y":0x8D91E471E0989CDA27DF505A453F2B7635294F2DDF23E3B122ACC99C9E9F1E14,
"n":32
},
{
"OID":"id-GostR3410-2001-CryptoPro-B-ParamSet",
"p":0x8000000000000000000000000000000000000000000000000000000000000C99,
"a":0x8000000000000000000000000000000000000000000000000000000000000C96,
"b":0x3E1AF419A269A5F866A7D3C25C3DF80AE979259373FF2B182F49D4CE7E1BBC8B,
"m":0x800000000000000000000000000000015F700CFFF1A624E5E497161BCC8A198F,
"q":0x800000000000000000000000000000015F700CFFF1A624E5E497161BCC8A198F,
"x":1,
"y":0x3FA8124359F96680B83D1C3EB2C070E5C545C9858D03ECFB744BF8D717717EFC,
"n":32
},
{
```

```
"OID":"id-GostR3410-2001-CryptoPro-C-ParamSet",
"p":0x9B9F605F5A858107AB1EC85E6B41C8AACF846E86789051D37998F7B9022D759B,
"a":0x9B9F605F5A858107AB1EC85E6B41C8AACF846E86789051D37998F7B9022D7598,
"b":32858,
"m":0x9B9F605F5A858107AB1EC85E6B41C8AA582CA3511EDDFB74F02F3A6598980BB9,
"q":0x9B9F605F5A858107AB1EC85E6B41C8AA582CA3511EDDFB74F02F3A6598980BB9,
"x":0,
"y":0x41ECE55743711A8C3CBF3783CD08C0EE4D4DC440D4641A8F366E550DFDB3BB67,
"n":32
},
{
"OID":"id-tc26-gost-3410-2012-512-paramSetA",
"p":(0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<296)+\
   (0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<80)+\
   0xFFFFFFFFFFFFFFFFFDC7L,
"a":(0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<296)+\
   (0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<80)+\
   0xFFFFFFFFFFFFFFFFFDC4L,
"b":(0xE8C2505DEDFC86DDC1BD0B2B6667F1DA34B82574761CB0E879BD08L<<296)+\
   (0x1CFD0B6265EE3CB090F30D27614CB4574010DA90DD862EF9D4EBEEL<<80)+\
   0x4761503190785A71C760L,
"m":(0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<296)+\
   (0xFFFFFFFFFF27E69532F48D89116FF22B8D4E0560609B4B38ABFAD2L<<80)+\
   0xB85DCACDB1411F10B275L,
"q":(0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<296)+\
   (0xFFFFFFFFFF27E69532F48D89116FF22B8D4E0560609B4B38ABFAD2L<<80)+\
   0xB85DCACDB1411F10B275L,
"x":3,
"y":(0x7503CFE87A836AE3A61B8816E25450E6CE5E1C93ACF1ABC1778064L<<296)+\
   (0xFDCBEFA921DF1626BE4FD036E93D75E6A50E3A41E98028FE5FC235L<<80)+\
   0xF5B889A589CB5215F2A4L,
"n":64
},
{
"OID":"id-tc26-gost-3410-2012-512-paramSetB",
"p":(0x800000000000000000000000000000000000000000000000000000L<<296)+\
   (0x000000000000000000000000000000000000000000000000000000L<<80)+\
   0x0000000000000000006FL,
"a":(0x800000000000000000000000000000000000000000000000000000L<<296)+\
   (0x000000000000000000000000000000000000000000000000000000L<<80)+\
   0x0000000000000000006CL,
"b":(0x687D1B459DC841457E3E06CF6F5E2517B97C7D614AF138BCBF85DCL<<296)+\
   (0x806C4B289F3E965D2DB1416D217F8B276FAD1AB69C50F78BEE1FA3L<<80)+\
   0x106EFB8CCBC7C5140116L,
"m":(0x800000000000000000000000000000000000000000000000000000L<<296)+\
   (0x000000000149A1EC142565A545ACFDB77BD9D40CFA8B996712101BL<<80)+\
   0xEA0EC6346C54374F25BDL,
"q":(0x800000000000000000000000000000000000000000000000000000L<<296)+\
   (0x000000000149A1EC142565A545ACFDB77BD9D40CFA8B996712101BL<<80)+\
   0xEA0EC6346C54374F25BDL,
"x":2,
"y":(0x1A8F7EDA389B094C2C071E3647A8940F3C123B697578C213BE6DD9L<<296)+\
   (0xE6C8EC7335DCB228FD1EDF4A39152CBCAAF8C0398828041055F94CL<<80)+\
```

```
    0xEEEC7E21340780FE41BDL,
"n":64
},
{
"OID":"id-tc26-gost-3410-2012-256-paramSetA",
"p":0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFD97,
"a":0xC2173F1513981673AF4892C23035A27CE25E2013BF95AA33B22C656F277E7335,
"b":0x295F9BAE7428ED9CCC20E7C359A9D41A22FCCD9108E17BF7BA9337A6F8AE9513,
"m":0x1000000000000000000000000000000003F63377F21ED98D70456BD55B0D8319C,
"q":0x400000000000000000000000000000000FD8CDDFC87B6635C115AF556C360C67,
"x":0x91E38443A5E82C0D880923425712B2BB658B9196932E02C78B2582FE742DAA28,
"y":0x32879423AB1A0375895786C4BB46E9565FDE0B5344766740AF268ADB32322E5C,
"n":32
},
{
'OID':"id-tc26-gost-3410-2012-512-paramSetC",
"p":(0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<296)+\
    (0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<80)+\
    0xFFFFFFFFFFFFFFFFFDC7L,
"a":(0xDC9203E514A721875485A529D2C722FB187BC8980EB866644DE41CL<<296)+\
    (0x68E143064546E861C0E2C9EDD92ADE71F46FCF50FF2AD97F951FDAL<<80)+\
    0x9F2A2EB6546F39689BD3L,
"b":(0xB4C4EE28CEBC6C2C8AC12952CF37F16AC7EFB6A9F69F4B57FFDA2EL<<296)+\
    (0x4F0DE5ADE038CBC2FFF719D2C18DE0284B8BFEF3B52B8CC7A5F5BFL<<80)+\
    0x0A3C8D2319A5312557E1L,
"m":(0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<296)+\
    (0xFFFFFFFFFF26336E91941AAC0130CEA7FD451D40B323B6A79E9DA6L<<80)+\
    0x849A5188F3BD1FC08FB4L,
"q":(0x3FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFL<<296)+\
    (0xFFFFFFFFFFC98CDBA46506AB004C33A9FF5147502CC8EDA9E7A769L<<80)+\
    0xA12694623CEF47F023EDL,
"x":(0xE2E31EDFC23DE7BDEBE241CE593EF5DE2295B7A9CBAEF021D385F7L<<296)+\
    (0x074CEA043AA27272A7AE602BF2A7B9033DB9ED3610C6FB85487EAEL<<80)+\
    0x97AAC5BC7928C1950148L,
"y":(0xF5CE40D95B5EB899ABBCCFF5911CB8577939804D6527378B8C108CL<<296)+\
    (0x3D2090FF9BE18E2D33E3021ED2EF32D85822423B6304F726AA854BL<<80)+\
    0xAE07D0396E9A9ADDC40FL,
"n":64
}
]

def str2list( s ):
  res = []
  for c in s:
    res += [ ord( c ) ]
  return res

def list2str( l ):
  r = ""
  for k in l:
    r += chr( k )
  return r
```

```
def hprint( data ):
  r = ""
  for i in range( len( data ) ):
    r += "%02X " % data[ i ]
    if i % 16 == 15:
      r += "\n"
  print( r )

class Stribog:

  __A = [
    0x8e20faa72ba0b470, 0x47107ddd9b505a38, 0xad08b0e0c3282d1c,
    0xd8045870ef14980e, 0x6c022c38f90a4c07, 0x3601161cf205268d,
    0x1b8e0b0e798c13c8, 0x83478b07b2468764, 0xa011d380818e8f40,
    0x5086e740ce47c920, 0x2843fd2067adea10, 0x14aff010bdd87508,
    0x0ad97808d06cb404, 0x05e23c0468365a02, 0x8c711e02341b2d01,
    0x46b60f011a83988e, 0x90dab52a387ae76f, 0x486dd4151c3dfdb9,
    0x24b86a840e90f0d2, 0x125c354207487869, 0x092e94218d243cba,
    0x8a174a9ec8121e5d, 0x4585254f64090fa0, 0xaccc9ca9328a8950,
    0x9d4df05d5f661451, 0xc0a878a0a1330aa6, 0x60543c50de970553,
    0x302a1e286fc58ca7, 0x18150f14b9ec46dd, 0x0c84890ad27623e0,
    0x0642ca05693b9f70, 0x0321658cba93c138, 0x86275df09ce8aaa8,
    0x439da0784e745554, 0xafc0503c273aa42a, 0xd960281e9d1d5215,
    0xe230140fc0802984, 0x71180a8960409a42, 0xb60c05ca30204d21,
    0x5b068c651810a89e, 0x456c34887a3805b9, 0xac361a443d1c8cd2,
    0x561b0d22900e4669, 0x2b838811480723ba, 0x9bcf4486248d9f5d,
    0xc3e9224312c8c1a0, 0xeffa11af0964ee50, 0xf97d86d98a327728,
    0xe4fa2054a80b329c, 0x727d102a548b194e, 0x39b008152acb8227,
    0x9258048415eb419d, 0x492c024284fbaec0, 0xaa16012142f35760,
    0x550b8e9e21f7a530, 0xa48b474f9ef5dc18, 0x70a6a56e2440598e,
    0x3853dc371220a247, 0x1ca76e95091051ad, 0x0edd37c48a08a6d8,
    0x07e095624504536c, 0x8d70c431ac02a736, 0xc83862965601dd1b,
    0x641c314b2b8ee083
  ]

  __Sbox = [
    0xFC, 0xEE, 0xDD, 0x11, 0xCF, 0x6E, 0x31, 0x16, 0xFB, 0xC4, 0xFA,
    0xDA, 0x23, 0xC5, 0x04, 0x4D, 0xE9, 0x77, 0xF0, 0xDB, 0x93, 0x2E,
    0x99, 0xBA, 0x17, 0x36, 0xF1, 0xBB, 0x14, 0xCD, 0x5F, 0xC1, 0xF9,
    0x18, 0x65, 0x5A, 0xE2, 0x5C, 0xEF, 0x21, 0x81, 0x1C, 0x3C, 0x42,
    0x8B, 0x01, 0x8E, 0x4F, 0x05, 0x84, 0x02, 0xAE, 0xE3, 0x6A, 0x8F,
    0xA0, 0x06, 0x0B, 0xED, 0x98, 0x7F, 0xD4, 0xD3, 0x1F, 0xEB, 0x34,
    0x2C, 0x51, 0xEA, 0xC8, 0x48, 0xAB, 0xF2, 0x2A, 0x68, 0xA2, 0xFD,
    0x3A, 0xCE, 0xCC, 0xB5, 0x70, 0x0E, 0x56, 0x08, 0x0C, 0x76, 0x12,
    0xBF, 0x72, 0x13, 0x47, 0x9C, 0xB7, 0x5D, 0x87, 0x15, 0xA1, 0x96,
    0x29, 0x10, 0x7B, 0x9A, 0xC7, 0xF3, 0x91, 0x78, 0x6F, 0x9D, 0x9E,
    0xB2, 0xB1, 0x32, 0x75, 0x19, 0x3D, 0xFF, 0x35, 0x8A, 0x7E, 0x6D,
    0x54, 0xC6, 0x80, 0xC3, 0xBD, 0x0D, 0x57, 0xDF, 0xF5, 0x24, 0xA9,
    0x3E, 0xA8, 0x43, 0xC9, 0xD7, 0x79, 0xD6, 0xF6, 0x7C, 0x22, 0xB9,
    0x03, 0xE0, 0x0F, 0xEC, 0xDE, 0x7A, 0x94, 0xB0, 0xBC, 0xDC, 0xE8,
    0x28, 0x50, 0x4E, 0x33, 0x0A, 0x4A, 0xA7, 0x97, 0x60, 0x73, 0x1E,
    0x00, 0x62, 0x44, 0x1A, 0xB8, 0x38, 0x82, 0x64, 0x9F, 0x26, 0x41,
    0xAD, 0x45, 0x46, 0x92, 0x27, 0x5E, 0x55, 0x2F, 0x8C, 0xA3, 0xA5,
```

```
  0x7D, 0x69, 0xD5, 0x95, 0x3B, 0x07, 0x58, 0xB3, 0x40, 0x86, 0xAC,
  0x1D, 0xF7, 0x30, 0x37, 0x6B, 0xE4, 0x88, 0xD9, 0xE7, 0x89, 0xE1,
  0x1B, 0x83, 0x49, 0x4C, 0x3F, 0xF8, 0xFE, 0x8D, 0x53, 0xAA, 0x90,
  0xCA, 0xD8, 0x85, 0x61, 0x20, 0x71, 0x67, 0xA4, 0x2D, 0x2B, 0x09,
  0x5B, 0xCB, 0x9B, 0x25, 0xD0, 0xBE, 0xE5, 0x6C, 0x52, 0x59, 0xA6,
  0x74, 0xD2, 0xE6, 0xF4, 0xB4, 0xC0, 0xD1, 0x66, 0xAF, 0xC2, 0x39,
  0x4B, 0x63, 0xB6
]

__Tau = [
  0,  8, 16, 24, 32, 40, 48, 56,
  1,  9, 17, 25, 33, 41, 49, 57,
  2, 10, 18, 26, 34, 42, 50, 58,
  3, 11, 19, 27, 35, 43, 51, 59,
  4, 12, 20, 28, 36, 44, 52, 60,
  5, 13, 21, 29, 37, 45, 53, 61,
  6, 14, 22, 30, 38, 46, 54, 62,
  7, 15, 23, 31, 39, 47, 55, 63
]

__C = [
  [
    0xb1, 0x08, 0x5b, 0xda, 0x1e, 0xca, 0xda, 0xe9,
    0xeb, 0xcb, 0x2f, 0x81, 0xc0, 0x65, 0x7c, 0x1f,
    0x2f, 0x6a, 0x76, 0x43, 0x2e, 0x45, 0xd0, 0x16,
    0x71, 0x4e, 0xb8, 0x8d, 0x75, 0x85, 0xc4, 0xfc,
    0x4b, 0x7c, 0xe0, 0x91, 0x92, 0x67, 0x69, 0x01,
    0xa2, 0x42, 0x2a, 0x08, 0xa4, 0x60, 0xd3, 0x15,
    0x05, 0x76, 0x74, 0x36, 0xcc, 0x74, 0x4d, 0x23,
    0xdd, 0x80, 0x65, 0x59, 0xf2, 0xa6, 0x45, 0x07
  ],
  [
    0x6f, 0xa3, 0xb5, 0x8a, 0xa9, 0x9d, 0x2f, 0x1a,
    0x4f, 0xe3, 0x9d, 0x46, 0x0f, 0x70, 0xb5, 0xd7,
    0xf3, 0xfe, 0xea, 0x72, 0x0a, 0x23, 0x2b, 0x98,
    0x61, 0xd5, 0x5e, 0x0f, 0x16, 0xb5, 0x01, 0x31,
    0x9a, 0xb5, 0x17, 0x6b, 0x12, 0xd6, 0x99, 0x58,
    0x5c, 0xb5, 0x61, 0xc2, 0xdb, 0x0a, 0xa7, 0xca,
    0x55, 0xdd, 0xa2, 0x1b, 0xd7, 0xcb, 0xcd, 0x56,
    0xe6, 0x79, 0x04, 0x70, 0x21, 0xb1, 0x9b, 0xb7
  ],
  [
    0xf5, 0x74, 0xdc, 0xac, 0x2b, 0xce, 0x2f, 0xc7,
    0x0a, 0x39, 0xfc, 0x28, 0x6a, 0x3d, 0x84, 0x35,
    0x06, 0xf1, 0x5e, 0x5f, 0x52, 0x9c, 0x1f, 0x8b,
    0xf2, 0xea, 0x75, 0x14, 0xb1, 0x29, 0x7b, 0x7b,
    0xd3, 0xe2, 0x0f, 0xe4, 0x90, 0x35, 0x9e, 0xb1,
    0xc1, 0xc9, 0x3a, 0x37, 0x60, 0x62, 0xdb, 0x09,
    0xc2, 0xb6, 0xf4, 0x43, 0x86, 0x7a, 0xdb, 0x31,
    0x99, 0x1e, 0x96, 0xf5, 0x0a, 0xba, 0x0a, 0xb2
  ],
  [
    0xef, 0x1f, 0xdf, 0xb3, 0xe8, 0x15, 0x66, 0xd2,
```

```
    0xf9, 0x48, 0xe1, 0xa0, 0x5d, 0x71, 0xe4, 0xdd,
    0x48, 0x8e, 0x85, 0x7e, 0x33, 0x5c, 0x3c, 0x7d,
    0x9d, 0x72, 0x1c, 0xad, 0x68, 0x5e, 0x35, 0x3f,
    0xa9, 0xd7, 0x2c, 0x82, 0xed, 0x03, 0xd6, 0x75,
    0xd8, 0xb7, 0x13, 0x33, 0x93, 0x52, 0x03, 0xbe,
    0x34, 0x53, 0xea, 0xa1, 0x93, 0xe8, 0x37, 0xf1,
    0x22, 0x0c, 0xbe, 0xbc, 0x84, 0xe3, 0xd1, 0x2e
  ],
  [
    0x4b, 0xea, 0x6b, 0xac, 0xad, 0x47, 0x47, 0x99,
    0x9a, 0x3f, 0x41, 0x0c, 0x6c, 0xa9, 0x23, 0x63,
    0x7f, 0x15, 0x1c, 0x1f, 0x16, 0x86, 0x10, 0x4a,
    0x35, 0x9e, 0x35, 0xd7, 0x80, 0x0f, 0xff, 0xbd,
    0xbf, 0xcd, 0x17, 0x47, 0x25, 0x3a, 0xf5, 0xa3,
    0xdf, 0xff, 0x00, 0xb7, 0x23, 0x27, 0x1a, 0x16,
    0x7a, 0x56, 0xa2, 0x7e, 0xa9, 0xea, 0x63, 0xf5,
    0x60, 0x17, 0x58, 0xfd, 0x7c, 0x6c, 0xfe, 0x57
  ],
  [
    0xae, 0x4f, 0xae, 0xae, 0x1d, 0x3a, 0xd3, 0xd9,
    0x6f, 0xa4, 0xc3, 0x3b, 0x7a, 0x30, 0x39, 0xc0,
    0x2d, 0x66, 0xc4, 0xf9, 0x51, 0x42, 0xa4, 0x6c,
    0x18, 0x7f, 0x9a, 0xb4, 0x9a, 0xf0, 0x8e, 0xc6,
    0xcf, 0xfa, 0xa6, 0xb7, 0x1c, 0x9a, 0xb7, 0xb4,
    0x0a, 0xf2, 0x1f, 0x66, 0xc2, 0xbe, 0xc6, 0xb6,
    0xbf, 0x71, 0xc5, 0x72, 0x36, 0x90, 0x4f, 0x35,
    0xfa, 0x68, 0x40, 0x7a, 0x46, 0x64, 0x7d, 0x6e
  ],
  [
    0xf4, 0xc7, 0x0e, 0x16, 0xee, 0xaa, 0xc5, 0xec,
    0x51, 0xac, 0x86, 0xfe, 0xbf, 0x24, 0x09, 0x54,
    0x39, 0x9e, 0xc6, 0xc7, 0xe6, 0xbf, 0x87, 0xc9,
    0xd3, 0x47, 0x3e, 0x33, 0x19, 0x7a, 0x93, 0xc9,
    0x09, 0x92, 0xab, 0xc5, 0x2d, 0x82, 0x2c, 0x37,
    0x06, 0x47, 0x69, 0x83, 0x28, 0x4a, 0x05, 0x04,
    0x35, 0x17, 0x45, 0x4c, 0xa2, 0x3c, 0x4a, 0xf3,
    0x88, 0x86, 0x56, 0x4d, 0x3a, 0x14, 0xd4, 0x93
  ],
  [
    0x9b, 0x1f, 0x5b, 0x42, 0x4d, 0x93, 0xc9, 0xa7,
    0x03, 0xe7, 0xaa, 0x02, 0x0c, 0x6e, 0x41, 0x41,
    0x4e, 0xb7, 0xf8, 0x71, 0x9c, 0x36, 0xde, 0x1e,
    0x89, 0xb4, 0x44, 0x3b, 0x4d, 0xdb, 0xc4, 0x9a,
    0xf4, 0x89, 0x2b, 0xcb, 0x92, 0x9b, 0x06, 0x90,
    0x69, 0xd1, 0x8d, 0x2b, 0xd1, 0xa5, 0xc4, 0x2f,
    0x36, 0xac, 0xc2, 0x35, 0x59, 0x51, 0xa8, 0xd9,
    0xa4, 0x7f, 0x0d, 0xd4, 0xbf, 0x02, 0xe7, 0x1e
  ],
  [
    0x37, 0x8f, 0x5a, 0x54, 0x16, 0x31, 0x22, 0x9b,
    0x94, 0x4c, 0x9a, 0xd8, 0xec, 0x16, 0x5f, 0xde,
    0x3a, 0x7d, 0x3a, 0x1b, 0x25, 0x89, 0x42, 0x24,
    0x3c, 0xd9, 0x55, 0xb7, 0xe0, 0x0d, 0x09, 0x84,
```

```
    0x80, 0x0a, 0x44, 0x0b, 0xdb, 0xb2, 0xce, 0xb1,
    0x7b, 0x2b, 0x8a, 0x9a, 0xa6, 0x07, 0x9c, 0x54,
    0x0e, 0x38, 0xdc, 0x92, 0xcb, 0x1f, 0x2a, 0x60,
    0x72, 0x61, 0x44, 0x51, 0x83, 0x23, 0x5a, 0xdb
  ],
  [
    0xab, 0xbe, 0xde, 0xa6, 0x80, 0x05, 0x6f, 0x52,
    0x38, 0x2a, 0xe5, 0x48, 0xb2, 0xe4, 0xf3, 0xf3,
    0x89, 0x41, 0xe7, 0x1c, 0xff, 0x8a, 0x78, 0xdb,
    0x1f, 0xff, 0xe1, 0x8a, 0x1b, 0x33, 0x61, 0x03,
    0x9f, 0xe7, 0x67, 0x02, 0xaf, 0x69, 0x33, 0x4b,
    0x7a, 0x1e, 0x6c, 0x30, 0x3b, 0x76, 0x52, 0xf4,
    0x36, 0x98, 0xfa, 0xd1, 0x15, 0x3b, 0xb6, 0xc3,
    0x74, 0xb4, 0xc7, 0xfb, 0x98, 0x45, 0x9c, 0xed
  ],
  [
    0x7b, 0xcd, 0x9e, 0xd0, 0xef, 0xc8, 0x89, 0xfb,
    0x30, 0x02, 0xc6, 0xcd, 0x63, 0x5a, 0xfe, 0x94,
    0xd8, 0xfa, 0x6b, 0xbb, 0xeb, 0xab, 0x07, 0x61,
    0x20, 0x01, 0x80, 0x21, 0x14, 0x84, 0x66, 0x79,
    0x8a, 0x1d, 0x71, 0xef, 0xea, 0x48, 0xb9, 0xca,
    0xef, 0xba, 0xcd, 0x1d, 0x7d, 0x47, 0x6e, 0x98,
    0xde, 0xa2, 0x59, 0x4a, 0xc0, 0x6f, 0xd8, 0x5d,
    0x6b, 0xca, 0xa4, 0xcd, 0x81, 0xf3, 0x2d, 0x1b
  ],
  [
    0x37, 0x8e, 0xe7, 0x67, 0xf1, 0x16, 0x31, 0xba,
    0xd2, 0x13, 0x80, 0xb0, 0x04, 0x49, 0xb1, 0x7a,
    0xcd, 0xa4, 0x3c, 0x32, 0xbc, 0xdf, 0x1d, 0x77,
    0xf8, 0x20, 0x12, 0xd4, 0x30, 0x21, 0x9f, 0x9b,
    0x5d, 0x80, 0xef, 0x9d, 0x18, 0x91, 0xcc, 0x86,
    0xe7, 0x1d, 0xa4, 0xaa, 0x88, 0xe1, 0x28, 0x52,
    0xfa, 0xf4, 0x17, 0xd5, 0xd9, 0xb2, 0x1b, 0x99,
    0x48, 0xbc, 0x92, 0x4a, 0xf1, 0x1b, 0xd7, 0x20
  ]
]

def __AddModulo(self, A, B):
  result = [0] * 64
  t = 0
  for i in reversed(range(0, 64)):
    t = A[i] + B[i] + (t >> 8)
    result[i] = t & 0xFF
  return result

def __AddXor(self, A, B):
  result = [0] * 64
  for i in range(0, 64):
    result[i] = A[i] ^ B[i]
  return result

def __S(self, state):
  result = [0] * 64
```

```
    for i in range(0, 64):
      result[i] = self.__Sbox[state[i]]
    return result

  def __P(self, state):
    result = [0] * 64
    for i in range(0, 64):
      result[i] = state[self.__Tau[i]]
    return result

  def __L(self, state):
    result = [0] * 64
    for i in range(0, 8):
      t = 0
      for k in range(0, 8):
        for j in range(0, 8):
          if ((state[i * 8 + k] & (1 << (7 - j))) != 0):
            t ^= self.__A[k * 8 + j]
      for k in range(0, 8):
        result[i * 8 + k] = (t & (0xFF << (7 - k) * 8)) >> (7 - k) * 8

    return result

  def __KeySchedule(self, K, i):
    K = self.__AddXor(K, self.__C[i])
    K = self.__S(K)
    K = self.__P(K)
    K = self.__L(K)
    return K

  # E(K, m)
  def __E(self, K, m):
    state = self.__AddXor(K, m)
    for i in range(0, 12):
      state = self.__S(state)
      state = self.__P(state)
      state = self.__L(state)
      K = self.__KeySchedule(K, i)
      state = self.__AddXor(state, K)
    return state

  def __G_n(self, N, h, m):
    K = self.__AddXor(h, N)
    K = self.__S(K)
    K = self.__P(K)
    K = self.__L(K)
    t = self.__E(K, m)
    t = self.__AddXor(t, h)
    return self.__AddXor(t, m)

  def __Padding(self, last, N, h, Sigma):
    if (len(last) < 64):
      padding = [0] * (64 - len(last))
```

```
            padding[-1] = 1
            padded_message = padding + last
        h = self.__G_n(N, h, padded_message)
        N_len = [0] * 64
        N_len[63] = (len(last) * 8) & 0xff
        N_len[62] = (len(last) * 8) >> 8
        N = self.__AddModulo(N, N_len)
        Sigma = self.__AddModulo(Sigma, padded_message)
        return (h, N, Sigma)

    def digest( self, message, out=512 ):
        return list2str( self.GetHash( str2list( message ), out ) )

    def GetHash(self, message, out=512, no_pad=False):
        N = [0] * 64
        Sigma = [0] * 64
        if out == 512:
            h = [0] * 64
        elif out == 256:
            h = [0x01] * 64
        else:
            print("Wrong hash out length!")


        N_512 = [0] * 64
        N_512[62] = 0x02    # 512 = 0x200

        length_bits = len(message) * 8
        length = len(message)

        i = 0
        asd = message[::-1]
        while (length_bits >= 512):
            tmp = (message[i * 64: (i + 1) * 64])[::-1]
            h = self.__G_n(N, h, tmp)
            N = self.__AddModulo(N, N_512)
            Sigma = self.__AddModulo(Sigma, tmp)
            length_bits -= 512
            i += 1


        last = (message[i * 64: length])[::-1]

        if (len(last) == 0 and no_pad):
            pass
        else:
            h, N, Sigma = self.__Padding(last, N, h, Sigma)

        N_0 = [0] * 64
        h = self.__G_n(N_0, h, N)
        h = self.__G_n(N_0, h, Sigma)

        if out == 512:
```

```
    return h[::-1]
  elif out == 256:
    return (h[0:32])[::-1]

 def hash(self, str_message, out=512, no_pad=False):
  return list2str(self.GetHash(str2list(str_message), out, no_pad))

def H256(msg):
 S = Stribog()
 return S.hash(msg, out=256)

def H512(msg):
 S = Stribog()
 return S.hash(msg)

def num2le( s, n ):
 res = ""
 for i in range(n):
  res += chr(s & 0xFF)
  s >>= 8
 return res

def le2num( s ):
 res = 0
 for i in range(len(s) - 1, -1, -1):
  res = (res << 8) + ord(s[i])
 return res

def XGCD(a,b):
 """XGCD(a,b) returns a list of form [g,x,y], where g is GCD(a,b) and
 x,y satisfy the equation g = ax + by."""
 a1=1; b1=0; a2=0; b2=1; aneg=1; bneg=1; swap = False
 if(a < 0):
  a = -a; aneg=-1
 if(b < 0):
  b = -b; bneg=-1
 if(b > a):
  swap = True
  [a,b] = [b,a]
 while (1):
  quot = -(a / b)
  a = a % b
  a1 = a1 + quot*a2; b1 = b1 + quot*b2
  if(a == 0):
   if(swap):
    return [b, b2*bneg, a2*aneg]
   else:
    return [b, a2*aneg, b2*bneg]
  quot = -(b / a)
  b = b % a
  a2 = a2 + quot*a1; b2 = b2 + quot*b1
  if(b == 0):
   if(swap):
```

```
      return [a, b1*bneg, a1*aneg]
    else:
      return [a, a1*aneg, b1*bneg]

def getMultByMask( elems, mask ):
  n = len( elems )
  r = 1
  for i in range( n ):
    if mask & 1:
      r *= elems[ n - 1 - i ]
    mask = mask >> 1
  return r


def subF(P, other, p):
  return (P - other) % p


def divF(P, other, p):
  return mulF(P, invF(other, p), p)


def addF(P, other, p):
  return (P + other) % p


def mulF(P, other, p):
  return (P * other) % p


def invF(R, p):
  assert (R != 0)
  return XGCD(R, p)[1] % p

def negF(R, p):
  return (-R) % p

def powF(R, m, p):
  assert R != None
  assert type(m) in (int, long)

  if m == 0:
    assert R != 0
    return 1
  elif m < 0:
    t = invF(R, p)
    return powF(t, (-m), p)
  else:
    i = m.bit_length() - 1
    r = 1
    while i > 0:
      if (m >> i) & 1:
        r = (r * R) % p
```

```
    r = (r * r) % p
    i -= 1
  if m & 1:
    r = (r * R) % p
  return r

def add(Px, Py, Qx, Qy, p, a, b):
  if Qx == Qy == None:
    return [Px, Py]

  if Px == Py == None:
    return [Qx, Qy]

  if (Px == Qx) and (Py == negF(Qy, p)):
    return [None, None]

  if (Px == Qx) and (Py == Qy):
    assert Py != 0
    return duplicate(Px, Py, p, a)
  else:
    l = divF( subF( Qy, Py, p ), subF( Qx, Px, p ), p )
    resX = subF( subF( powF( l, 2, p ), Px, p ), Qx, p )
    resY = subF( mulF( l, subF( Px, resX, p ), p ), Py, p )
    return [resX, resY]

def duplicate(Px, Py, p, a):
  if (Px == None) and (Py == None):
    return [None, None]

  if Py == 0:
    return [None, None]

  l = divF(addF(mulF(powF(Px, 2, p), 3, p), a, p), mulF(Py, 2, p), p)
  resX = subF(powF(l, 2, p), mulF(Px, 2, p), p)
  resY = subF(mulF(l, subF(Px, resX, p), p), Py, p)
  return [resX, resY]

def mul(Px, Py, s, p, a, b):
  assert type(s) in (int, long)
  assert Px != None and Py != None

  X = Px
  Y = Py

  i = s.bit_length() - 1
  resX = None
  resY = None
  while i > 0:
    if (s >> i) & 1:
      resX, resY = add(resX, resY, X, Y, p, a, b)
    resX, resY = duplicate(resX, resY, p, a)
    i -= 1
  if s & 1:
```

```
    resX, resY = add(resX, resY, X, Y, p, a, b)
  return [resX, resY]

def Ord(Px, Py, m, q, p, a, b):
  assert Px != None and Py != None
  assert (m != None) and (q != None)
  assert mul(Px, Py, m, p, a, b) == [None, None]

  X = Px
  Y = Py
  r = m
  for mask in range(1 << len(q)):
    t = getMultByMask(q, mask)
    Rx, Ry = mul(X, Y, t, p, a, b)
    if (Rx == None) and (Ry == None):
      r = min(r, t)
  return r

def isQuadraticResidue( R, p ):
  if R == 0:
    assert False
  temp = powF(R, ((p - 1) / 2), p)
  if temp == (p - 1):
    return False
  else:
    assert temp == 1
    return True

def getRandomQuadraticNonresidue(p):
  from random import randint
  r = (randint(2, p - 1)) % p
  while isQuadraticResidue(r, p):
    r = (randint(2, p - 1)) % p
  return r

def ModSqrt( R, p ):
  assert R != None
  assert isQuadraticResidue(R, p)

  if p % 4 == 3:
    res = powF(R, (p + 1) / 4, p)
    if powF(res, 2, p) != R:
      res = None
    return [res, negF(res, p)]
  else:
    ainvF = invF(R, p)

    s = p - 1
    alpha = 0
    while (s % 2) == 0:
      alpha += 1
      s = s / 2
```

```
    b = powF(getRandomQuadraticNonresidue(p), s, p)
    r = powF(R, (s + 1) / 2, p)

    bj = 1
    for k in range(0, alpha - 1):  # alpha >= 2 because p % 4 = 1
      d = 2 ** (alpha - k - 2)
      x = powF(mulF(powF(mulF(bj, r, p), 2, p), ainvF, p), d, p)
      if x != 1:
        bj = mulF(bj, powF(b, (2 ** k), p), p)
    res = mulF(bj, r, p)
    return [res, negF(res, p)]

def generateQs( p, pByteSize, a, b, m, q, orderDivisors, Px, Py, N ):
  assert pByteSize in ( 256 / 8, 512 / 8 )
  PxBytes = num2le( Px, pByteSize )
  PyBytes = num2le( Py, pByteSize )
  Qs = []
  S = []
  Hash_src = []
  Hash_res = []
  co_factor = m / q

  seed = 0
  while len( Qs ) != N:
    hashSrc = PxBytes + PyBytes + num2le( seed, 4 )
    if pByteSize == ( 256 / 8 ):
      QxBytes = H256( hashSrc )
    else:
      QxBytes = H512( hashSrc )

    Qx = le2num( QxBytes ) % p

    R = addF( addF( powF(Qx, 3, p ), mulF(Qx, a, p), p), b, p )
    if ( R == 0 ) or ( not isQuadraticResidue( R, p ) ):
      seed += 1
      continue

    Qy_sqrt = ModSqrt( R, p )
    Qy = min(Qy_sqrt)
    if co_factor * Ord(Qx, Qy, m, orderDivisors, p, a, b) != m:
      seed += 1
      continue

    Qs += [(Qx, Qy)]
    S += [seed]
    Hash_src += [hashSrc]
    Hash_res += [QxBytes]
    seed += 1

  return Qs, S, Hash_src, Hash_res

if __name__ == "__main__":
  for i, curve in enumerate(curvesParams):
```

```
print "A.1." + str(i+1) + ". Curve " + curve["OID"]
if "3410-2012-256-paramSetA" in curve["OID"] or \
       "3410-2012-512-paramSetC" in curve["OID"]:
  Q, S, Hash_src, Hash_res = generateQs(curve["p"],\
                         curve["n"],\
                         curve["a"],\
                         curve["b"],\
                         curve["m"],\
                         curve["q"],\
                         [ 2, 2, curve["q"]],\
                         curve["x"],\
                         curve["y"],\
                         1)
else:
  Q, S, Hash_src, Hash_res = generateQs(curve["p"],\
                         curve["n"],\
                         curve["a"],\
                         curve["b"],\
                         curve["m"],\
                         curve["q"],\
                         [curve["q"]],\
                         curve["x"],\
                         curve["y"],\
                         1)

j = 1
for q, s, hash_src, hash_res in zip(Q, S, Hash_src, Hash_res):
  print "Point Q_" + str(j)
  j += 1

  print "X=", hex(q[0])[:-1]
  print "Y=", hex(q[1])[:-1]

  print "SEED=","{0:#0{1}x}".format(s,6)
  print
```

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