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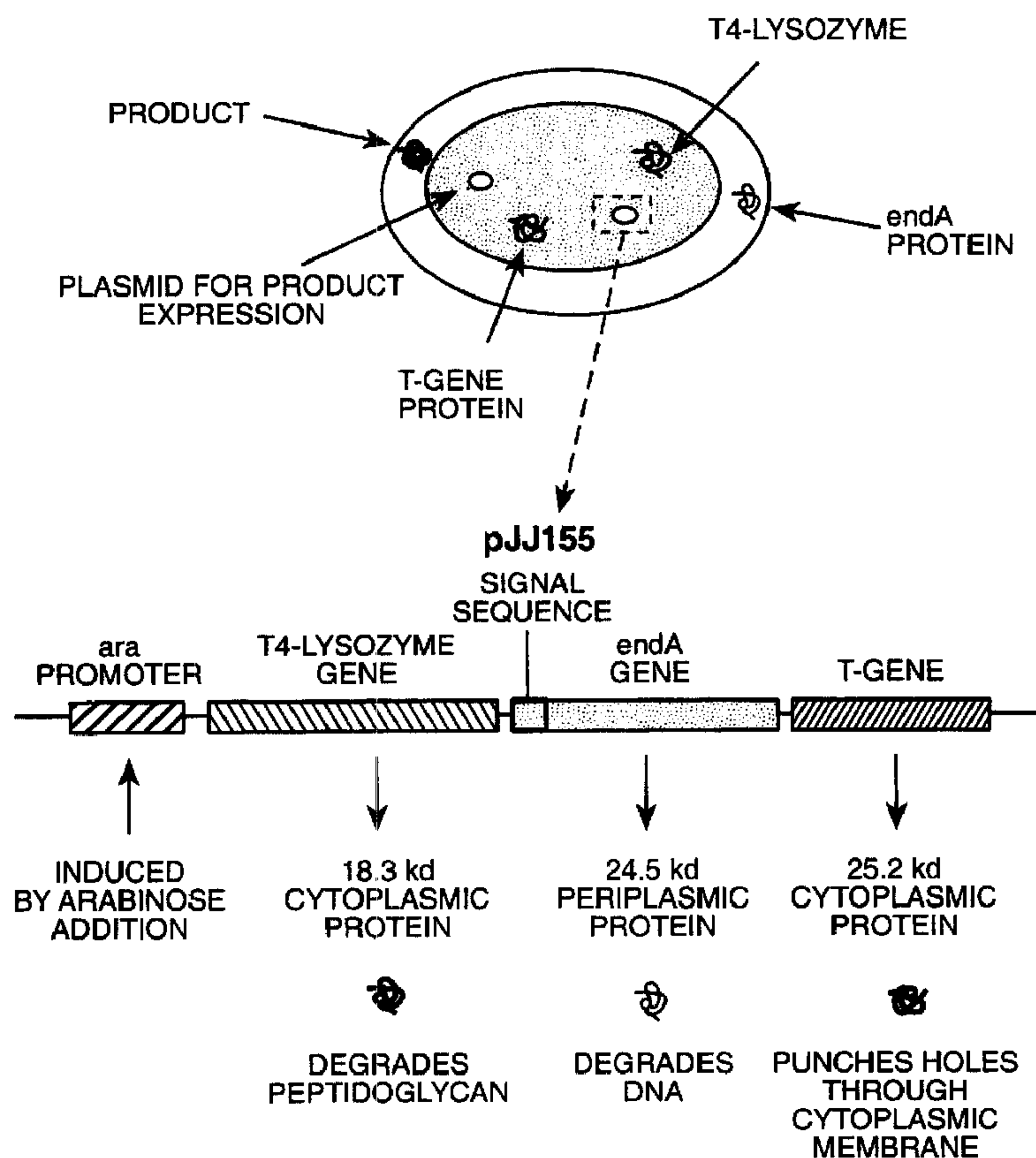
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(54) Titre : PROCÉDE DE RECUPERATION DE POLYPEPTIDES HÉTÉROLOGUES À PARTIR DE CELLULES BACTÉRIENNES

(54) Title: PROCESS FOR RECOVERING HETEROLOGOUS POLYPEPTIDES FROM BACTERIAL CELLS



(57) Abrégé/Abstract:

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(57) Abrégé(suite)/Abstract(continued):

encoding a protein that displays DNA-digesting activity, wherein these nucleic acids are linked to a first promoter, and nucleic acid encoding the heterologous polypeptide, which nucleic acid is linked to a second promoter, under certain conditions to produce a broth lysate; and recovering accumulated heterologous polypeptide from the broth lysate. Another process entails culturing bacterial cells that comprise nucleic acid encoding phage lysozyme, gene t, and nucleic acid encoding a protein that displays DNA-digesting activity under the control of a signal sequence for secretion of said DNA-digesting protein, wherein said nucleic acids are linked to one or more promoters, and nucleic acid encoding the heterologous polypeptide, which nucleic acid encoding the heterologous polypeptide is linked to another promoter that is inducible, under certain conditions to produce a broth lysate; and recovering accumulated heterologous polypeptide from the broth lysate.

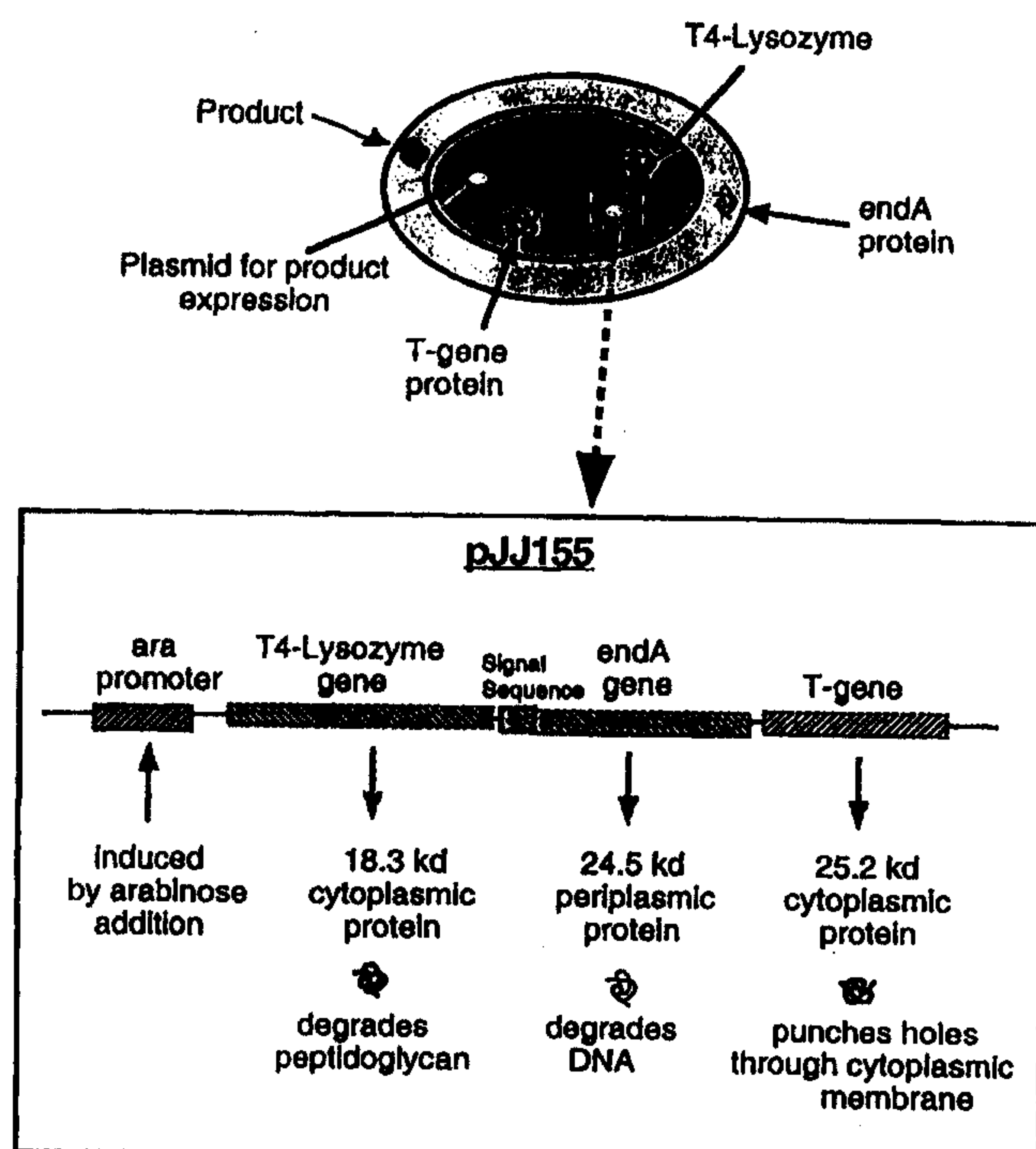
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(54) Title: PROCESS FOR RECOVERING HETEROLOGOUS POLYPEPTIDES FROM BACTERIAL CELLS**(57) Abstract**

Processes are described for recovering heterologous polypeptide from bacterial cells, including the periplasm and cytoplasm. One process involves culturing the bacterial cells, which cells comprise nucleic acid encoding phage lysozyme and nucleic acid encoding a protein that displays DNA-digesting activity, wherein these nucleic acids are linked to a first promoter, and nucleic acid encoding the heterologous polypeptide, which nucleic acid is linked to a second promoter, under certain conditions to produce a broth lysate; and recovering accumulated heterologous polypeptide from the broth lysate. Another process entails culturing bacterial cells that comprise nucleic acid encoding phage lysozyme, gene *t*, and nucleic acid encoding a protein that displays DNA-digesting activity under the control of a signal sequence for secretion of said DNA-digesting protein, wherein said nucleic acids are linked to one or more promoters, and nucleic acid encoding the heterologous polypeptide, which nucleic acid encoding the heterologous polypeptide is linked to another promoter that is inducible, under certain conditions to produce a broth lysate; and recovering accumulated heterologous polypeptide from the broth lysate.

Two Plasmid System for Co-expression of
T4-Lysozyme+endA+t-gene with
Heterologous Polypeptide Product

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PROCESS FOR RECOVERING HETEROLOGOUS POLYPEPTIDES FROM BACTERIAL CELLS

Field of the Invention

This invention relates to a process for producing and recovering
5 heterologous polypeptides from bacterial cells. More particularly, this invention relates to a process wherein recovery of soluble or aggregated recombinant heterologous polypeptides from bacterial cytoplasm and periplasm is facilitated or increased.

Description of Related Disclosures

10 *Escherichia coli* has been widely used for the production of heterologous proteins in the laboratory and industry. *E. coli* does not generally excrete proteins to the extracellular medium apart from colicins and hemolysin (Pugsley and Schwartz, Microbiology, 32: 3-38 (1985)). Heterologous proteins expressed
15 by *E. coli* may accumulate as soluble product or insoluble aggregates. See Figure 1 herein. They may be found intracellularly in the cytoplasm or be secreted into the periplasm if preceded by a signal sequence. How one proceeds initially in the recovery of the products greatly depends upon how and where the product accumulates. Generally, to isolate the proteins, the cells may be subjected to treatments for periplasmic extraction or be disintegrated to
20 release trapped products that are otherwise inaccessible.

The conventional isolation of heterologous polypeptide from gram-negative bacteria poses problems owing to the tough, rigid cell walls that surround these cells. The bacterial cell wall maintains the shape of the cell and protects the cytoplasm from osmotic pressures that may cause cell lysis; it
25 performs these functions as a result of a highly cross-linked peptidoglycan (also known as murein) backbone that gives the wall its characteristic rigidity. A recent model described the space between the cytoplasmic and outer membranes as a continuous phase filled with an inner periplasmic polysaccharide gel that extends into an outer highly cross-linked peptidoglycan gel (Hobot et
30 *al.*, J. Bact., 160: 143 (1984)). This peptidoglycan sacculus constitutes a barrier to the recovery of any heterologous polypeptide not excreted by the bacterium into the medium.

To release recombinant proteins from the *E. coli* periplasm, treatments involving chemicals such as chloroform (Ames et *al.*, J. Bacteriol., 160: 1181-
35 1183 (1984)), guanidine-HCl, and Triton X-100 (Naglak and Wang, Enzyme Microb. Technol., 12: 603-611 (1990)) have been used. However, these chemicals are not inert and may have detrimental effects on many recombinant protein products or subsequent purification procedures. Glycine treatment of *E. coli* cells, causing permeabilization of the outer membrane, has also been reported to
40 release the periplasmic contents (Ariga et *al.*, J. Ferm. Bioeng., 68: 243-246 (1989)). These small-scale periplasmic release methods have been designed for specific systems. They do not translate easily and efficiently and are generally unsuitable as large-scale methods.

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The most widely used methods of periplasmic release of recombinant protein are osmotic shock (Nosal and Heppel, J. Biol. Chem., 241: 3055-3062 (1966); Neu and Heppel, J. Biol. Chem., 240: 3685-3692 (1965)), hen eggwhite(HEW)-lysozyme/ethylenediamine tetraacetic acid (EDTA) treatment (Neu and Heppel, J. Biol. Chem., 239: 3893-3900 (1964); Witholt et al., Biochim. Biophys. Acta, 443: 534-544 (1976); Pierce et al., ICHEME Research Event, 2: 995-997 (1995)), and combined HEW-lysozyme/osmotic shock treatment (French et al., Enzyme and Microb. Tech., 19: 332-338 (1996)). Typically, these procedures include an initial disruption in osmotically-stabilizing medium followed by selective release in non-stabilizing medium. The composition of these media (pH, protective agent) and the disruption methods used (chloroform, HEW-lysozyme, EDTA, sonication) vary among specific procedures reported. A variation on the HEW-lysozyme/EDTA treatment using a dipolar ionic detergent in place of EDTA is discussed by Stabel et al., Veterinary Microbiol., 38: 307-314 (1994). For a general review of use of intracellular lytic enzyme systems to disrupt *E. coli*, see Dabora and Cooney in Advances in Biochemical Engineering/Biotechnology, Vol. 43, A. Fiechter, ed. (Springer-Verlag: Berlin, 1990), pp. 11-30.

Conventional methods for the recovery of recombinant protein from the cytoplasm, as soluble protein or refractile particles, involved disintegration of the bacterial cell by mechanical breakage. Mechanical disruption typically involves the generation of local cavitation in a liquid suspension, rapid agitation with rigid beads, sonication, or grinding of cell suspension (Bacterial Cell Surface Techniques, Hancock and Poxton (John Wiley & Sons Ltd, 1988), Chapter 3, p. 55). These processes require significant capital investment and constitute long processing time.

HEW-lysozyme acts biochemically to hydrolyze the peptidoglycan backbone of the cell wall. The method was first developed by Zinder and Arndt, Proc. Natl. Acad. Sci. USA, 42: 586-590 (1956), who treated *E. coli* with egg albumin (which contains HEW-lysozyme) to produce rounded cellular spheres later known as spheroplasts. These structures retained some cell-wall components but had large surface areas in which the cytoplasmic membrane was exposed.

U.S. Pat. No. 5,169,772 discloses a method for purifying heparinase from bacteria comprising disrupting the envelope of the bacteria in an osmotically-stabilized medium, e.g., 20% sucrose solution using, e.g., EDTA, lysozyme, or an organic compound, releasing the non-heparinase-like proteins from the periplasmic space of the disrupted bacteria by exposing the bacteria to a low-ionic-strength buffer, and releasing the heparinase-like proteins by exposing the low-ionic-strength-washed bacteria to a buffered salt solution.

There are several disadvantages to the use of the HEW-lysozyme addition for isolating periplasmic proteins. The cells must be treated with EDTA, detergent, or high pH, all of which aid in weakening the cells. Also, the method is not suitable for lysis of large amounts of cells because the lysozyme

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addition is inefficient and there is difficulty in dispersing the enzyme throughout a large pellet of cells.

Many different modifications of these methods have been used on a wide range of expression systems with varying degrees of success (Joseph-Liazun et al., Gene, 86: 291-295 (1990); Carter et al., Bio/Technology, 10: 163-167 (1992)). Although these methods have worked on a laboratory scale, they involve too many steps for an efficient large-scale recovery process.

Efforts to induce recombinant cell culture to produce lysozyme have been reported. EP 155,189 discloses a means for inducing a recombinant cell culture to produce lysozymes, which would ordinarily be expected to kill such host cells by means of destroying or lysing the cell wall structure. Russian Pat. Nos. 2043415, 2071503, and 2071501 disclose plasmids and corresponding strains for producing recombinant proteins and purifying water-insoluble protein agglomerates involving the lysozyme gene. Specifically, the use of an operon consisting of the lysozyme gene and a gene that codes for recombinant protein enables concurrent synthesis of the recombinant protein and a lysozyme that breaks the polysaccharide membrane of *E. coli*.

U.S. Pat. No. 4,595,658 discloses a method for facilitating externalization of proteins transported to the periplasmic space of *E. coli*. This method allows selective isolation of proteins that locate in the periplasm without the need for lysozyme treatment, mechanical grinding, or osmotic shock treatment of cells. U.S. Pat. No. 4,637,980 discloses producing a bacterial product by transforming a temperature-sensitive lysogen with a DNA molecule that codes, directly or indirectly, for the product, culturing the transformant under permissive conditions to express the gene product intracellularly, and externalizing the product by raising the temperature to induce phage-encoded functions. JP 61-257931 published November 15, 1986 discloses a method for recovering IL-2 using HEW-lysozyme. Asami et al., J. Ferment. and Bioeng., 83: 511-516 (1997) discloses synchronized disruption of *E. coli* cells by T4 phage infection, and Tanji et al., J. Ferment. and Bioeng., 85: 74-78 (1998) discloses controlled expression of lysis genes encoded in T4 phage for the gentle disruption of *E. coli* cells.

The development of an enzymatic release method to recover recombinant periplasmic proteins suitable for large-scale use is reported by French et al., Enzyme and Microbial Technology, 19: 332-338 (1996). This method involves resuspension of the cells in a fractionation buffer followed by recovery of the periplasmic fraction, where osmotic shock immediately follows lysozyme treatment. The effects of overexpression of the recombinant protein, *S. thermoviolaceus* α -amylase, and the growth phase of the host organism on the recovery are also discussed.

In a 10-kiloliter-scale process for recovery of IGF-I polypeptide (Hart et al., Bio/Technology, 12: 1113 (1994)), the authors attempted the typical isolation procedure involving a mechanical cell breakage step followed by a

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centrifugation step to recover the solids. The results were disappointing in that almost 40% of the total product was lost to the supernatant after three passes through the Gaulin homogenizer. Hart et al., Bio/Technology 12: 1113 (1994). See Fig. 2 herein. Product recovery was not significantly improved even when the classical techniques of EDTA and HEW-lysozyme additions were employed.

While HEW-lysozyme is the only practical commercial lysozyme for large-scale processes, lysozyme is expressed by bacteriophages upon infection of host cells. Lysis of *E. coli*, a natural host for bacteriophages, for example the T4 phages, requires the action of two gene products: e and t. Gene e encodes a lysozyme (called T4-lysozyme for the T4 phage) that has been identified as a muramidase (Tsugita and Inouye, J. Biol. Chem., 243: 391 (1968)), while gene t seems to be required for lysis, but does not appear to have lysozyme activity. Gene t is required for the cessation of cellular metabolism that occurs during lysis (Mukai et al., Vir., 33: 398 (1967)) and is believed to degrade or alter the cytoplasmic membrane, thus allowing gene product e to reach the periplasm and gain access to the cell wall (Josslin, Vir., 40: 719 (1970)). Phage are formed by gene t- mutants, but lysis of the *E. coli* host does not occur except by addition of chloroform (Josslin, *supra*). Wild-type T4-lysozyme activity is first detected about eight minutes after T4 infection at 37°C, and it increases through the rest of the infection, even if lysis inhibition is induced. In the absence of secondary adsorption, cells infected by gene e mutants shut down progeny production and metabolism at the normal time, but do not lyse (Molecular Genetics of Bacteriophage T4, J.D. Karam, ed. in chief (American Society for Microbiology, Washington DC, ASM Press, 1994), p. 398).

Recovery of insoluble IGF-I using T4-lysozyme was disclosed on October 28, 1997 at the "Separation Technology VII meeting entitled 'Separations for Clean Production'" in Davos, Switzerland, sponsored by the Engineering Foundation.

Upon cell lysis, genomic DNA leaks out of the cytoplasm into the medium and results in significant increase in fluid viscosity that can impede the sedimentation of solids in a centrifugal field. In the absence of shear forces such as those exerted during mechanical disruption to break down the DNA polymers, the slower sedimentation rate of solids through viscous fluid results in poor separation of solids and liquid during centrifugation. Other than mechanical shear force, there exist nucleolytic enzymes that degrade DNA polymer.

In *E. coli*, the endogenous gene *endA* encodes for an endonuclease (molecular weight of the mature protein is approx. 24.5 kD) that is normally secreted to the periplasm and cleaves DNA into oligodeoxyribonucleotides in an endonucleolytic manner. It has been suggested that *endA* is relatively weakly expressed by *E. coli* (Wackernagel et al., Gene, 154: 55-59 (1995)).

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For controlling cost of goods and minimizing process time, there is a continuing need for increasing the total recovery of heterologous polypeptide from cells. At large scale, there is a significant incentive to avoid mechanical cell breakage to release the soluble or aggregated recombinant polypeptide from the cytoplasmic and periplasmic compartments and to condition the lysate for efficient product recovery in the subsequent step.

Summary of the Invention

Accordingly, this invention provides processes using biochemical disruption to recover both soluble and insoluble heterologous product from bacterial cells.

In one aspect the present invention provides a process for recovering a heterologous polypeptide from bacterial cells comprising:

(a) culturing bacterial cells, which cells comprise nucleic acid encoding phage lysozyme and nucleic acid encoding a protein that displays DNA-digesting activity under the control of a signal sequence for secretion of said DNA-digesting protein, wherein said nucleic acids are linked to a first promoter, and nucleic acid encoding the heterologous polypeptide and a signal sequence for secretion of the heterologous polypeptide, which nucleic acid encoding the heterologous polypeptide is linked to a second promoter, wherein the second promoter is inducible and the first promoter is either a promoter with low basal expression or an inducible promoter, the culturing being under conditions whereby when an inducer is added, expression of the nucleic acid encoding the phage lysozyme and DNA-digesting protein is induced after about 50% or more of the heterologous polypeptide has accumulated, whereby the phage lysozyme accumulates in a cytoplasmic compartment, whereby the DNA-digesting protein is secreted to the periplasm, and whereby the cells are lysed to produce a broth lysate; and

(b) recovering accumulated heterologous polypeptide from the broth lysate.

In yet another aspect, the invention supplies a process for recovering a heterologous polypeptide from bacterial cells in which it is produced comprising:

(a) culturing the bacterial cells, which cells comprise nucleic acid encoding phage lysozyme, gene *t*, and nucleic acid encoding a protein that displays DNA-digesting activity, wherein these nucleic acids are linked to a first promoter, and nucleic acid encoding the heterologous polypeptide, which nucleic acid is linked to a second promoter, wherein the second promoter is inducible and the first promoter is either a promoter with low basal expression or an inducible promoter, the culturing being under conditions whereby when an inducer is added, expression of the nucleic acids encoding the phage lysozyme, gene *t*, and DNA-digesting protein is induced after about 50% or more of the heterologous polypeptide has accumulated, and under conditions whereby the phage lysozyme accumulates in a cytoplasmic compartment, whereby the DNA-

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digesting protein is secreted into the periplasm, and whereby the cells are lysed to produce a broth lysate; and

(b) recovering accumulated heterologous polypeptide from the broth lysate.

5 In a third aspect, the invention provides a process for recovering a heterologous polypeptide from bacterial cells in which it is produced comprising:

(a) culturing the bacterial cells, which cells comprise nucleic acid encoding phage lysozyme, gene *t*, and nucleic acid encoding a protein that
10 displays DNA-digesting activity, wherein the nucleic acid encoding the phage lysozyme and DNA-digesting protein is linked to a first promoter that is inducible or with low basal expression, the gene *t* is linked to a second inducible promoter, and the nucleic acid encoding the heterologous polypeptide is linked to a third inducible promoter, under conditions whereby when an
15 inducer is added and all three promoters are inducible, expression of the nucleic acids encoding the phage lysozyme, gene *t*, and DNA-digesting protein is induced after about 50% or more of the heterologous polypeptide has accumulated, with the third promoter being induced before the first promoter and the second promoter induced after the first promoter, and whereby if the
20 phage lysozyme and DNA-digesting protein are linked to a promoter with low basal expression, expression of the gene *t* is induced after about 50% or more of the heterologous polypeptide has accumulated, and under conditions whereby the phage lysozyme accumulates in a cytoplasmic compartment, whereby the DNA-digesting protein is secreted into the periplasm, and whereby the cells are
25 lysed to produce a broth lysate; and

(b) recovering accumulated heterologous polypeptide from the broth lysate.

Biochemical lysis or biochemically-assisted mechanical lysis is superior to mechanical disruption for recovering heterologous polypeptide from bacterial
30 cells. Coordinated expression of nucleic acid encoding phage lysozyme with gene *t* and DNA-digesting protein, and nucleic acid encoding the heterologous polypeptide of interest provides a highly effective method for releasing insoluble or soluble polypeptide from the entanglement with the peptidoglycan layer, as well as releasing product trapped in the cytoplasm. When the phage
35 lysozyme gene is cloned behind a tightly-controlled promoter, for example, the pBAD promoter (also referred to as the ara promoter), cytoplasmic accumulation of phage lysozyme may be induced by the addition of an inducer (such as arabinose) at an appropriate time near the end of fermentation. By placing the nucleic acid expression of heterologous polypeptide and lytic enzymes under
40 separate promoter control, one can independently regulate their production during fermentation. Without a signal sequence, the accumulated phage lysozyme is tightly locked up in the cytoplasmic compartment, and gene *t* functions to release the phage lysozyme to degrade the peptidoglycan layer. Furthermore,

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the optimal pH for T4-phage-lysozyme activity, which is a preferred embodiment, is about 7.3, which is about the neutral pH of most typical harvest broths.

The induction of the genes encoding the bacteriophage lysozyme, DNA-digesting protein, and gene *t* after expression of the nucleic acid encoding the heterologous polypeptide results in a significant amount of insoluble or soluble heterologous polypeptide recovered from the cytoplasm or periplasm of bacteria. Besides product yield, the success of a recovery process is judged by the ease of operation, the process flow, the turn-around time, as well as the operation cost. The present invention alleviates several if not all these bottlenecks encountered in the large-scale recovery process.

The processes herein also allow use of biochemical cell lysis at high cell density and increased scale. At high density, excessive expression of T4-lysozyme, gene *t*, and *endA* could have disastrous results, such as premature cell lysis and reduction in heterologous polypeptide production. Further, it would not be expected that induction at the end of a long fermentation process and after substantial product accumulation would produce enough of the lytic enzymes to be effective. The present processes do not pose problems at high cell densities such as increased viscosity and excessive foaming during the fermentation process. It is expected that the processes herein will enable the attainment of high cell density, effective induction and action of the system, and the processing of broth lysates derived from high-density cultures.

Brief Description of the Drawings

Figure 1 depicts a schematic diagram of how a polypeptide product is disposed in the cytoplasm and in the periplasm, that is, it forms an aggregate, proteolyzed fragment, or folded soluble polypeptide.

Figure 2 depicts IGF-I aggregate recovery from the supernatant and pellet by the typical isolation procedure involving mechanical cell disruption followed by centrifugation, after three passes through the Gaulin homogenizer.

Figure 3 depicts a plasmid map of pS1130, an expression plasmid for rhuMAb CD18 F(ab')₂-leucine zipper precursor (herein also referred to as anti-CD18 antibody fragment).

Figures 4A-4B show the sequence of the expression cassette of pS1130 (SEQ ID NO:1 and NO:2).

Figure 5 shows plasmid construction of pJJ154 used to co-express T4-lysozyme and *endA* (*E. coli* DNase).

Figure 6 shows a plasmid map of pLBIGF57 used to express IGF-I.

Figure 7 shows plasmid construction of pJJ155 used to express T4-lysozyme, *endA*, and gene *t*, which construction is from pJJ154.

Figure 8 depicts a schematic of the two-plasmid system for co-expression of T4-lysozyme, a preferred phage lysozyme, *endA*, a preferred DNA-digesting protein, and gene *t* (pJJ155) with IGF-I-encoding nucleic acid in accordance with an example of this invention.

Figures 9A-9E disclose photographs from phase-contrast microscopy of the harvest broth and resuspended pellets from centrifugation of fermentation broth with and without co-expression of T4-lysozyme and endA and t-gene before and after EDTA addition. Specifically, the photographs show the resuspended pellet
 5 from centrifugation of control broth with no lytic enzyme co-expression before and after EDTA addition respectively (Figs. 9A and 9B), the fermentation harvest undiluted whole broth resulting from co-expression of IGF-I with the three lytic enzymes, T4-lysozyme, endA, and t-gene (Fig. 9C), the resuspended pellet from centrifugation of harvest broth with co-expression of IGF-I with
 10 the three lytic enzymes and no EDTA addition (Fig. 9D), and the resuspended pellet from centrifugation of harvest broth with the co-expression of IGF-I with the three lytic enzymes and EDTA addition (Fig. 9E).

Figures 10A and 10B show, respectively, nucleic acid quantitation in the supernatant and pellet by OD260 determination for IGF-I-expressing *E. coli* with
 15 co-expression of the three lytic enzymes versus control, and total protein in the supernatant and pellet from IGF-I-expressing *E. coli* with co-expression of the three lytic enzymes versus no co-expression control.

Figure 11 shows IGF-I product recovery by centrifugation using three lytic enzymes versus no-lysis control broth for various centrifugation speeds.

20 Figure 12 shows solids recovery during centrifugation using three lytic enzymes co-expressed with IGF-I versus no-lysis control broth for various centrifugation speeds.

Detailed Description of the Preferred Embodiments

A. Definitions

25 As used herein, "phage lysozyme" refers to a cytoplasmic enzyme that facilitates lysis of phage-infected bacterial cells, thereby releasing replicated phage particles. The lysozyme may be from any bacteriophage source, including T7, T4, lambda, and mu bacteriophages. The preferred such lysozyme herein is T4-lysozyme.

30 As used herein, "T4-lysozyme" or "E protein" refers to a cytoplasmic muramidase that facilitates lysis of T4 phage-infected bacterial cells, thereby releasing replicated phage particles (Tsugita and Inouye, J. Mol. Biol., 37: 201-12 (1968); Tsugita and Inouye, J. Biol. Chem., 243: 391-97 (1968)). It is encoded by gene e of T4 bacteriophage and hydrolyzes bonds between N-acetylglucosamine and N-acetylmuramic acid residues in the rigid peptidoglycan
 35 layer of the *E. coli* cell envelope. The enzyme is a single polypeptide chain of a molecular weight of 18.3 kd. It is approximately 250-fold more active than HEW-lysozyme against bacterial peptidoglycan (Matthews et al., J. Mol. Biol., 147: 545-558 (1981)). The optimal pH for T4-lysozyme enzyme activity
 40 is 7.3, versus 9 for HEW-lysozyme (The Worthington Manual; pp 219-221).

As used herein, "gene t" or "t gene" or "holin" refers to a lytic gene of bacteriophage T4 that is required for lysis but does not appear to have

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lysozyme activity. See also Molecular Genetics of Bacteriophage T4, supra, p. 398-399.

The term "protein that displays DNA-digesting activity" or "DNA-digesting protein" refers to a protein that will digest DNA such as, for example, mammalian or bacterial DNase. Preferably, the DNA-digesting protein is human DNase or bacterial endA.

As used herein, the phrase "lytic enzymes" refers collectively to at least phage lysozyme and DNA-digesting protein; where applicable it also refers to a phage gene t gene product or equivalent in combination with phage lysozyme and DNA-digesting protein.

As used herein, the phrase "agent that disrupts the outer cell wall" of bacteria refers to a molecule that increases permeability of the outer cell wall of bacteria, such as chelating agents, e.g., EDTA, and zwitterions.

As used herein, the term "bacteria" refers to any bacterium that produces proteins that are transported to the periplasmic space. Generally, the bacteria, whether gram positive or gram negative, has phage lysozyme and nuclease expression under control so that they are only expressed near the end of the fermentation, a preferred embodiment, or expressed at a low level during fermentation. The nuclease is generally relatively stable when secreted to the periplasm or medium. The term "non-temperature-sensitive bacteria" refers to any bacterium that is not significantly sensitive to temperature changes. One preferred embodiment herein is bacteria that are not temperature sensitive. The most preferred bacteria herein are gram-negative bacteria.

As used herein, "a time sufficient to release the polypeptide contained in the cytoplasm or periplasm" refers to an amount of time sufficient to allow the lysozyme to digest the peptidoglycan to a sufficient degree to release the cytoplasmic or periplasmic aggregate or soluble heterologous polypeptide.

As used herein, "signal sequence" or "signal polypeptide" refers to a peptide that can be used to secrete the heterologous polypeptide or protein that displays DNA-digesting activity into the periplasm of the bacteria. The signals for the heterologous polypeptide or DNA-digesting protein may be homologous to the bacteria, or they may be heterologous, including signals native to the heterologous polypeptide or DNA-digesting protein being produced in the bacteria.

The promoters of this invention may be "inducible" promoters, i.e., promoters that direct transcription at an increased or decreased rate upon binding of a transcription factor.

As used herein, a promoter "with low basal expression" or a "low-basal-expression promoter" is a promoter that is slightly leaky, i.e., it provides a sufficiently low basal expression level so as not to affect cell growth or product accumulation and provides a sufficiently low level of promotion not to result in premature cell lysis.

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"Transcription factors" as used herein include any factors that can bind to a regulatory or control region of a promoter and thereby effect transcription. The synthesis or the promoter-binding ability of a transcription factor within the host cell can be controlled by exposing the host to an "inducer" or removing a "repressor" from the host cell medium. Accordingly, to regulate expression of an inducible promoter, an inducer is added or a repressor removed from the growth medium of the host cell.

As used herein, the phrase "induce expression" means to increase the amount of transcription from specific genes by exposure of the cells containing such genes to an effector or inducer.

An "inducer" is a chemical or physical agent which, when given to a population of cells, will increase the amount of transcription from specific genes. These are usually small molecules whose effects are specific to particular operons or groups of genes, and can include sugars, alcohol, metal ions, hormones, heat, cold, and the like. For example, isopropylthio- β -galactoside (IPTG) and lactose are inducers of the *tacII* promoter, and L-arabinose is a suitable inducer of the arabinose promoter.

A "repressor" is a factor that directly or indirectly leads to cessation of promoter action or decreases promoter action. One example of a repressor is phosphate. As the repressor phosphate is depleted from the medium, the alkaline phosphatase (AP) promoter is induced.

As used herein, "polypeptide" or "polypeptide of interest" refers generally to peptides and proteins having more than about ten amino acids. The polypeptides are "heterologous," i.e., foreign to the host cell being utilized, such as a human protein produced by *E. coli*. The polypeptide may be produced as an insoluble aggregate or as a soluble polypeptide in the periplasmic space or cytoplasm.

Examples of mammalian polypeptides include molecules such as, e.g., renin, a growth hormone, including human growth hormone; bovine growth hormone; growth hormone releasing factor; parathyroid hormone; thyroid stimulating hormone; lipoproteins; α 1-antitrypsin; insulin A-chain; insulin B-chain; proinsulin; thrombopoietin; follicle stimulating hormone; calcitonin; luteinizing hormone; glucagon; clotting factors such as factor VIIIC, factor IX, tissue factor, and von Willebrands factor; anti-clotting factors such as Protein C; atrial natrietic factor; lung surfactant; a plasminogen activator, such as urokinase or human urine or tissue-type plasminogen activator (t-PA); bombesin; thrombin; hemopoietic growth factor; tumor necrosis factor-alpha and -beta; enkephalinase; a serum albumin such as human serum albumin; mullerian-inhibiting substance; relaxin A-chain; relaxin B-chain; prorelaxin; mouse gonadotropin-associated peptide; a microbial protein, such as beta-lactamase; DNase; inhibin; activin; vascular endothelial growth factor (VEGF); receptors for hormones or growth factors; integrin; protein A or D; rheumatoid factors; a neurotrophic factor such as brain-derived neurotrophic factor (BDNF),

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neurotrophin-3, -4, -5, or -6 (NT-3, NT-4, NT-5, or NT-6), or a nerve growth factor such as NGF- β ; cardiotrophins (cardiac hypertrophy factor) such as cardiotrophin-1 (CT-1); platelet-derived growth factor (PDGF); fibroblast growth factor such as aFGF and bFGF; epidermal growth factor (EGF);
 5 transforming growth factor (TGF) such as TGF- α and TGF- β , including TGF- β 1, TGF- β 2, TGF- β 3, TGF- β 4, or TGF- β 5; insulin-like growth factor-I and -II (IGF-I and IGF-II); des(1-3)-IGF-I (brain IGF-I), insulin-like growth factor binding proteins; CD proteins such as CD-3, CD-4, CD-8, and CD-19; erythropoietin; osteoinductive factors; immunotoxins; a bone morphogenetic
 10 protein (BMP); an interferon such as interferon- α , - β , and - γ ; colony stimulating factors (CSFs), e.g., M-CSF, GM-CSF, and G-CSF; interleukins (ILs), e.g., IL-1 to IL-10; anti-HER-2 antibody; superoxide dismutase; T-cell receptors; surface membrane proteins; decay accelerating factor; viral antigen such as, for example, a portion of the AIDS envelope;
 15 transport proteins; homing receptors; addressins; regulatory proteins; antibodies; and fragments of any of the above-listed polypeptides.

The preferred exogenous polypeptides of interest are mammalian polypeptides, most preferably human polypeptides. Examples of such mammalian polypeptides include t-PA, VEGF, gp120, anti-HER-2, anti-CD11a, anti-CD18,
 20 DNase, IGF-I, IGF-II, brain IGF-I, growth hormone, relaxin chains, growth hormone releasing factor, insulin chains or pro-insulin, urokinase, immunotoxins, neurotrophins, and antigens. Particularly preferred mammalian polypeptides include, e.g., IGF-I, DNase, or VEGF, most preferably IGF-I, if the polypeptide is produced as an insoluble aggregate in the periplasm, and
 25 anti-CD18 antibodies or fragments thereof such as anti-recombinant human CD18 Fab, Fab' and (Fab')₂ fragments, if the polypeptide is produced in a soluble form in the periplasm.

As used herein, "IGF-I" refers to insulin-like growth factor from any species, including bovine, ovine, porcine, equine, and preferably human, in
 30 native-sequence or in variant form and recombinantly produced. In a preferred method, the IGF-I is cloned and its DNA expressed, e.g., by the process described in EP 128,733 published December 19, 1984.

The expression "control sequences" refers to DNA sequences necessary for the expression of an operably-linked coding sequence in a particular host
 35 organism. The control sequences that are suitable for bacteria include a promoter such as the alkaline phosphatase promoter, optionally an operator sequence, and a ribosome-binding site.

Nucleic acid is "operably linked" when it is placed into a functional relationship with another nucleic acid sequence. For example, DNA for a
 40 presequence or secretory leader is operably linked to DNA for a heterologous polypeptide if it is expressed as a preprotein that participates in the secretion of the polypeptide; a promoter or enhancer is operably linked to a coding sequence if it affects the transcription of the sequence; or a ribosome

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binding site is operably linked to a coding sequence if it is positioned so as to facilitate translation. Generally, "operably linked" means that the DNA sequences being linked are contiguous and, in the case of a secretory leader, contiguous and in reading frame. Linking is accomplished by ligation at
5 convenient restriction sites. If such sites do not exist, the synthetic oligonucleotide adaptors or linkers are used in accordance with conventional practice.

As used herein, the expressions "cell," "cell line," and "cell culture" are used interchangeably and all such designations include progeny. Thus, the
10 words "transformants" and "transformed cells" include the primary subject cell and cultures derived therefrom without regard for the number of transfers. It is also understood that all progeny may not be precisely identical in DNA content, due to deliberate or inadvertent mutations. Mutant progeny that have the same function or biological activity as screened for in the originally
15 transformed cell are included. Where distinct designations are intended, it will be clear from the context.

B. Modes for Carrying Out the Invention

In one embodiment, the invention provides a process for recovering a heterologous polypeptide, soluble or insoluble, from bacterial cells in which
20 it is produced. This process involves, in a first step, culturing the bacterial cells, which cells comprise nucleic acid encoding the lytic enzymes, wherein these nucleic acids are linked to a first promoter, and nucleic acid encoding the heterologous polypeptide, which nucleic acid is linked to a second inducible promoter. In an alternative embodiment, the phage lysozyme and DNA-
25 digesting protein are linked to a first inducible promoter or a promoter with low basal expression, the t-gene is linked to a second inducible promoter, and the heterologous polypeptide is linked to a third inducible promoter.

The culturing takes place under conditions whereby expression of the nucleic acids encoding the lytic enzymes, when induced, commences after about
30 50% or more of the heterologous polypeptide has accumulated, and under conditions whereby the phage lysozyme accumulates in a cytoplasmic compartment and the DNA-digesting protein is secreted into the periplasmic compartment.

In the processes herein, induction of the promoters is preferred; however, the processes also contemplate the use of a promoter for the phage
35 lysozyme and DNA-digesting protein that is a promoter with low basal expression (slightly leaky), wherein no induction is carried out. This type of promoter has a leakiness that is low enough not to result in premature cell lysis and results in a sufficiently low basal expression level so as not to affect cell growth or product accumulation.

40 In a second step, the accumulated heterologous polypeptide is recovered from the bacterial cells. An agent that increases permeability of the outer cell wall of the bacterial cells may be added, as described in detail below, before the recovery step is carried out. The need to disrupt cells mechanically

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to release the phage lysozyme is either reduced or is completely avoided. In a preferred embodiment, after lytic enzyme expression the cells are incubated for a time sufficient to release the heterologous polypeptide contained in the cytoplasm or periplasm.

5 While the processes can apply to the recovery of insoluble aggregates such as IGF-I, VEGF, and DNase by sedimentation of product, they are also applicable to heterologous polypeptides that are soluble in the cytoplasm or periplasm, such as, for example, anti-CD18 antibody fragment. Advantages for recovery of soluble heterologous polypeptides by biochemical cell lysis include
10 avoiding or reducing the need for mechanical lysis, thereby avoiding loss of heat-labile proteins, and obtaining a low and consistent fluid viscosity compatible with downstream recovery processes such as expanded bed absorption technology and centrifugation.

Expanded bed absorption (EBA) chromatography, described, for example, in
15 "Expanded Bed Adsorption: Principles and Methods", Pharmacia Biotech, ISBN 91-630-5519-8), is useful for the initial recovery of target proteins from crude feed-stock or cell culture. The process steps of clarification, concentration, and initial purification can be combined into one unit operation, providing increased process economy due to a decreased number of
20 process steps, increased yield, shorter overall process time, reduced labor cost, and reduced cost. In EBA chromatography an adsorbent is expanded and equilibrated by applying an upward liquid flow to the column. A stable fluidized bed is formed when the adsorbent particles are suspended in equilibrium due to the balance between particle sedimentation velocity and
25 upward liquid flow velocity. Crude cell mixture or broth lysate is applied to the expanded bed with an upward flow. Target proteins are bound to the adsorbent while cell debris and other contaminants pass through unhindered. Weakly bound material is washed from the expanded bed using upward flow of a wash buffer. Flow is then stopped and the adsorbent is allowed to settle in
30 the column. The column adaptor is then lowered to the surface of the sedimented bed. Flow is reversed and the captured proteins are eluted from the sedimented bed using an appropriate buffer. The eluate contains the target protein in a reduced elution pool volume, partially purified in preparation for packed bed chromatography (Pharmacia Biotech, supra). EBA, wherein the whole
35 cell lysate containing soluble product is pumped up through the column and the protein is absorbed onto a resin (fluidized bed) and the cell debris flows through, utilizes only one chromatography step, thereby saving a step.

In another embodiment, the invention provides a process for recovering soluble heterologous polypeptide from the cytoplasm or periplasm of bacterial
40 cells. This process involves culturing bacterial cells, which cells comprise nucleic acid encoding phage lysozyme and nucleic acid encoding a DNA-digesting protein that displays DNA-digesting activity under the control of a signal sequence for secretion of said DNA-digesting protein. In this process, the

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nucleic acids are linked to a first promoter, and nucleic acid encoding the heterologous polypeptide and a signal sequence for secretion of the heterologous polypeptide, which nucleic acid encoding the heterologous polypeptide is linked to a second inducible promoter. This culturing takes
5 place under conditions whereby over-expression of the nucleic acid encoding the phage lysozyme and DNA-digesting protein is weakly and constitutively promoted or, if induced, commences after about 50% or more of the heterologous polypeptide has accumulated, and under conditions whereby the heterologous polypeptide and DNA-digesting protein are secreted into the periplasm of the
10 bacteria and the phage lysozyme accumulates in a cytoplasmic compartment.

In a second step, the resulting heterologous polypeptide is recovered from the broth lysate.

In a third embodiment, the invention provides a process for recovering a heterologous polypeptide from bacterial cells in which three different
15 promoters are used. Specifically, in the first step, the bacterial cells are cultured, where the cells comprise nucleic acid encoding phage lysozyme, gene *t*, and nucleic acid encoding a protein that displays DNA-digesting activity, as well as nucleic acid encoding the heterologous polypeptide. The nucleic acid encoding the lysozyme and DNA-digesting protein is linked to a first
20 promoter that is inducible or with low basal expression, the gene *t* is linked to a second inducible promoter, and the nucleic acid encoding the heterologous polypeptide is linked to a third inducible promoter.

The culturing is carried out under conditions whereby when an inducer is added and all three promoters are inducible, expression of the nucleic acids
25 encoding the phage lysozyme, gene *t*, and DNA-digesting protein is induced after about 50% or more of the heterologous polypeptide has accumulated, with the third promoter being induced before the first promoter, and the second promoter induced last, and whereby if the phage lysozyme and DNA-digesting protein are linked to a promoter with low basal expression, expression of the gene *t* is
30 induced after about 50% or more of the heterologous polypeptide has accumulated. Culturing is also carried out under conditions whereby the phage lysozyme accumulates in a cytoplasmic compartment, whereby the DNA-digesting protein is secreted to and accumulates in the periplasm, and whereby the cells are lysed to produce a broth lysate.

35 In a second step, accumulated heterologous polypeptide is recovered from the broth lysate.

In the above processes, while the signal sequence for the DNA-digesting protein may be any sequence, preferably, it is a native sequence of the DNA-digesting protein. Also, in a preferred embodiment, the DNA-digesting protein
40 is DNase or bacterial, e.g., *E. coli* endA product.

In a preferred embodiment, the culturing step takes place under conditions of high cell density, that is, generally at a cell density of about 15 to 150 g dry weight/liter, preferably at least about 40, more preferably

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about 40-150, most preferably about 40 to 100. In optical density, 120 OD₅₅₀ (A₅₅₀) is about 50 g dry wt./liter. In addition, the culturing can be accomplished using any scale, even very large scales of 100,000 liters. Preferably, the scale is about 100 liters or greater, more preferably at least
5 about 500 liters, and most preferably from about 500 liters to 100,000 liters.

The nucleic acids encoding the lytic enzymes are linked to one promoter, i.e., put in tandem, as by placing a linker between the nucleic acids. The promoter for the heterologous polypeptide expression is different from that used for the lytic enzymes, such that one is induced before the other. While
10 the promoters may be any suitable promoters for this purpose, preferably, the promoters for the lytic enzymes with or without gene t and heterologous polypeptide are, respectively, arabinose promoter and alkaline phosphatase promoter.

The promoters for the heterologous polypeptide and for the lytic enzymes
15 for all three processes herein must be different, such that the nucleic-acid-encoded heterologous polypeptide expression is induced before expression of nucleic-acid-encoded lytic enzymes or at a much higher level, when the promoters are inducible. While the promoters may be any suitable promoters for this purpose, preferably, the promoters for the phage lysozyme and heterologous
20 polypeptide are, respectively, arabinose promoter and alkaline phosphatase promoter. Alternatively, the compartmentalization of the phage lysozyme and DNA-digesting protein may allow for the use of a promoter with low basal expression for expression of the nucleic acid encoding phage lysozyme and DNA-digesting protein. If a promoter with low basal expression is employed, such
25 as arabinose as opposed to tac or trp promoter, then an active step of induction is not required.

The induction of expression of the nucleic acid encoding the lytic enzymes is preferably carried out by adding an inducer to the culture medium. While, in this respect, the inducers for the promoters may be added in any
30 amount, preferably if the inducer is arabinose, it is added in an amount of about 0-1% by weight, and if inducer is added, 0.1-1% by weight.

In the processes described above, typically the expression elements are introduced into the cells by transformation therein, but they may also be integrated into the genome or chromosome of the cells along with their promoter
35 regions. This applies to any of the lytic enzymes or the heterologous polypeptide gene. The bacterial cells may be transformed with one or more expression vectors containing the nucleic acid encoding the lytic enzymes, and the nucleic acid encoding the heterologous polypeptide. In one such embodiment, the bacterial cells are transformed with two vectors respectively
40 containing the nucleic acid encoding the lytic enzymes and the nucleic acid encoding the heterologous polypeptide. In another embodiment, the nucleic acid encoding the lytic enzymes and the nucleic acid encoding the heterologous polypeptide are contained on one vector with which the bacterial cells are

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transformed. In another specific embodiment that may be preferred, the phage lysozyme and DNA-digesting enzyme are carried on a plasmid to ensure high copy number and the gene *t* is integrated into the host chromosome to down-regulate expression and prevent premature cell lysis to avoid leakiness.

5 In the first step of the above processes, the heterologous nucleic acid (e.g., cDNA or genomic DNA) is suitably inserted into a replicable vector for expression in the bacterium under the control of a suitable promoter for bacteria. Many vectors are available for this purpose, and selection of the appropriate vector will depend mainly on the size of the nucleic acid to be
10 inserted into the vector and the particular host cell to be transformed with the vector. Each vector contains various components depending on its function (amplification of DNA or expression of DNA) and the particular host cell with which it is compatible. The vector components for bacterial transformation may include a signal sequence for the heterologous polypeptide and will include a
15 signal sequence for the DNA-digesting protein and will also include an inducible promoter for the heterologous polypeptide and gene *t* and an inducible promoter or a non-inducible one with low basal expression for the other lytic enzymes. They also generally include an origin of replication and one or more marker genes.

20 In general, plasmid vectors containing replicon and control sequences that are derived from species compatible with the host cell are used in connection with bacterial hosts. The vector ordinarily carries a replication site, as well as marking sequences that are capable of providing phenotypic selection in transformed cells. For example, *E. coli* is typically transformed
25 using pBR322, a plasmid derived from an *E. coli* species. See, e.g., Bolivar et al., Gene, 2: 95 (1977). pBR322 contains genes conferring ampicillin and tetracycline resistance and thus provides an easy means for identifying transformed cells. The pBR322 plasmid, or other microbial plasmid or phage, also generally contains, or is modified to contain, promoters that can be used
30 by the bacterial organism for expression of the selectable marker genes.

If the heterologous polypeptide is to be secreted, the DNA encoding the heterologous polypeptide of interest herein contains a signal sequence, such as one at the N-terminus of the mature heterologous polypeptide. In general, the signal sequence may be a component of the vector, or it may be a part of
35 the heterologous polypeptide DNA that is inserted into the vector. The heterologous signal sequence selected should be one that is recognized and processed (i.e., cleaved by a signal peptidase) by the host cell. For bacterial host cells that do not recognize and process the native heterologous polypeptide signal sequence, the signal sequence is substituted by a bacterial
40 signal sequence selected, for example, from the group consisting of the alkaline phosphatase, penicillinase, *lpp*, or heat-stable enterotoxin II leaders.

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Expression vectors contain a nucleic acid sequence that enables the vector to replicate in one or more selected host cells. Such sequences are well known for a variety of bacteria. The origin of replication from the plasmid pBR322 is suitable for most Gram-negative bacteria.

5 Expression vectors also generally contain a selection gene, also termed a selectable marker. This gene encodes a protein necessary for the survival or growth of transformed host cells grown in a selective culture medium. Host cells not transformed with the vector containing the selection gene will not survive in the culture medium. Typical selection genes encode proteins that
 10 (a) confer resistance to antibiotics or other toxins, e.g., ampicillin, neomycin, methotrexate, or tetracycline, (b) complement auxotrophic deficiencies, or (c) supply critical nutrients not available from complex media, e.g., the gene encoding D-alanine racemase for *Bacilli*. One example of a selection scheme utilizes a drug to arrest growth of a host cell. Those
 15 cells that are successfully transformed with a heterologous gene produce a protein conferring drug resistance and thus survive the selection regimen.

The expression vector for producing a heterologous polypeptide also contains an inducible promoter that is recognized by the host bacterial organism and is operably linked to the nucleic acid encoding the heterologous
 20 polypeptide of interest. It also contains a separate inducible or low-basal-expression promoter operably linked to the nucleic acid encoding the lytic enzymes. Inducible promoters suitable for use with bacterial hosts include the β -lactamase and lactose promoter systems (Chang et al., Nature, 275: 615 (1978); Goeddel et al., Nature, 281: 544 (1979)), the arabinose promoter
 25 system, including the araBAD promoter (Guzman et al., J. Bacteriol., 174: 7716-7728 (1992); Guzman et al., J. Bacteriol., 177: 4121-4130 (1995); Siegele and Hu, Proc. Natl. Acad. Sci. USA, 94: 8168-8172 (1997)), the rhamnose promoter (Haldimann et al., J. Bacteriol., 180: 1277-1286 (1998)), the alkaline phosphatase promoter, a tryptophan (*trp*) promoter system (Goeddel, Nucleic
 30 Acids Res., 8: 4057 (1980) and EP 36,776), the $P_{LtetO-1}$ and $P_{lac/ara-1}$ promoters (Lutz and Bujard, Nucleic Acids Res., 25: 1203-1210 (1997)), and hybrid promoters such as the *tac* promoter. deBoer et al., Proc. Natl. Acad. Sci. USA, 80: 21-25 (1983). However, other known bacterial inducible promoters and low-basal-expression promoters are suitable. Their nucleotide sequences have been
 35 published, thereby enabling a skilled worker operably to ligate them to DNA encoding the heterologous polypeptide of interest or to the nucleic acids encoding the lytic enzymes (Siebenlist et al., Cell, 20: 269 (1980)) using linkers or adaptors to supply any required restriction sites. If a strong and highly leaky promoter, such as the *trp* promoter, is used, it is generally used
 40 only for expression of the nucleic acid encoding the heterologous polypeptide and not for lytic-enzyme-encoding nucleic acid. The *tac* and P_L promoters could be used for either, but not both, the heterologous polypeptide and the lytic

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enzymes, but are not preferred. Preferred are the alkaline phosphatase promoter for the product and the arabinose promoter for the lytic enzymes.

Promoters for use in bacterial systems also generally contain a Shine-Dalgarno (S.D.) sequence operably linked to the DNA encoding the heterologous polypeptide of interest. The promoter can be removed from the bacterial source DNA by restriction enzyme digestion and inserted into the vector containing the desired DNA. The *phoA* promoter can be removed from the bacterial- source DNA by restriction enzyme digestion and inserted into the vector containing the desired DNA.

Construction of suitable vectors containing one or more of the above-listed components employs standard ligation techniques. Isolated plasmids or DNA fragments are cleaved, tailored, and re-ligated in the form desired to generate the plasmids required.

For analysis to confirm correct sequences in plasmids constructed, the ligation mixtures are used to transform *E. coli* K12 strain 294 (ATCC 31,446) or other strains, and successful transformants are selected by ampicillin or tetracycline resistance where appropriate. Plasmids from the transformants are prepared, analyzed by restriction endonuclease digestion, and/or sequenced by the method of Sanger et al., Proc. Natl. Acad. Sci. USA, 74: 5463-5467 (1977) or Messing et al., Nucleic Acids Res., 9: 309 (1981), or by the method of Maxam et al., Methods in Enzymology, 65: 499 (1980).

Suitable bacteria for this purpose include archaebacteria and eubacteria, especially eubacteria, more preferably Gram-negative bacteria, and most preferably *Enterobacteriaceae*. Examples of useful bacteria include *Escherichia*, *Enterobacter*, *Azotobacter*, *Erwinia*, *Bacillus*, *Pseudomonas*, *Klebsiella*, *Proteus*, *Salmonella*, *Serratia*, *Shigella*, *Rhizobia*, *Vitreoscilla*, and *Paracoccus*. Suitable *E. coli* hosts include *E. coli* W3110 (ATCC 27,325), *E. coli* 294 (ATCC 31,446), *E. coli* B, and *E. coli* X1776 (ATCC 31,537). These examples are illustrative rather than limiting. Mutant cells of any of the above-mentioned bacteria may also be employed. It is, of course, necessary to select the appropriate bacteria taking into consideration replicability of the replicon in the cells of a bacterium. For example, *E. coli*, *Serratia*, or *Salmonella* species can be suitably used as the host when well-known plasmids such as pBR322, pBR325, pACYC177, or pKN410 are used to supply the replicon.

E. coli strain W3110 is a preferred host because it is a common host strain for recombinant DNA product fermentations. Preferably, the host cell should secrete minimal amounts of proteolytic enzymes. For example, strain W3110 may be modified to effect a genetic mutation in the genes encoding proteins, with examples of such hosts including *E. coli* W3110 strain 1A2, which has the complete genotype *tonAΔ* (also known as $\Delta fhuA$); *E. coli* W3110 strain 9E4, which has the complete genotype *tonAΔ ptr3*; *E. coli* W3110 strain 27C7 (ATCC 55,244), which has the complete genotype *tonAΔ ptr3 phoAΔE15 Δ(argF-*

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lac)169 ompTΔ degP41kan^r; *E. coli* W3110 strain 37D6, which has the complete genotype tonAΔ ptr3 phoAΔE15 Δ(argF-lac)169 ompTΔ degP41kan^r rbs7Δ ilvG; *E. coli* W3110 strain 40B4, which is strain 37D6 with a non-kanamycin resistant degP deletion mutation; *E. coli* W3110 strain 33D3, which has the complete
 5 genotype tonA ptr3 lacIq LacL8 ompT degP kan^r; *E. coli* W3110 strain 36F8, which has the complete genotype tonA phoA Δ(argF-lac) ptr3 degP kan^r ilvG+, and is temperature resistant at 37°C; *E. coli* W3110 strain 45F8, which has the complete genotype fhuA(tonA) Δ(argF-lac) ptr3 degP41(kanS) Δ omp Δ(nmpc-fepE) ilvG+ phoA+ phoS*(T10Y); *E. coli* W3110 strain 33B8, which has the complete
 10 genotype tonA phoA Δ(argF-lac) 189 deoC degP IlvG+(kanS); *E. coli* W3110 strain 43E7, which has the complete genotype fhuA(tonA) Δ(argF-lac) ptr3 degP41(kanS) ΔompTΔ(nmpc-fepE) ilvG+ phoA+; and an *E. coli* strain having the mutant periplasmic protease(s) disclosed in U.S. Pat. No. 4,946,783 issued August 7, 1990.

15 Host cells are transformed with the above-described expression vectors of this invention and cultured in conventional nutrient media modified as appropriate for inducing the various promoters if induction is carried out.

Transformation means introducing DNA into an organism so that the DNA is replicable, either as an extrachromosomal element or as chromosomal
 20 integration. Depending on the host cell used, transformation is done using standard techniques appropriate to such cells. The calcium treatment employing calcium chloride, as described in section 1.82 of Sambrook et al., Molecular Cloning: A Laboratory Manual (New York: Cold Spring Harbor Laboratory Press, 1989), is generally used for bacterial cells that contain substantial cell-wall
 25 barriers. Another method for transformation employs polyethylene glycol/DMSO, as described in Chung and Miller, Nucleic Acids Res., 16: 3580 (1988). Yet another method is the use of the technique termed electroporation.

Bacterial cells used to produce the heterologous polypeptide of interest described in this invention are cultured in suitable media in which the
 30 promoters can be induced as described generally, e.g., in Sambrook et al., *supra*.

Any other necessary supplements besides carbon, nitrogen, and inorganic phosphate sources may also be included at appropriate concentrations, introduced alone or as a mixture with another supplement or medium such as a
 35 complex nitrogen source. The pH of the medium may be any pH from about 5-9, depending mainly on the host organism.

For induction, typically the cells are cultured until a certain optical density is achieved, e.g., a A₅₅₀ of about 80-100, at which point induction is initiated (e.g., by addition of an inducer, by depletion of a repressor,
 40 suppressor, or medium component, etc.), to induce expression of the gene encoding the heterologous polypeptide. When about 50% or more of the heterologous polypeptide has accumulated (as determined, e.g., by the optical density reaching a target amount observed in the past to correlate with the

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desired heterologous polypeptide accumulation, e.g., a A_{550} of about 120-140), induction of the promoter is effected for the lysis enzymes. The induction typically takes place at a point in time post-inoculation about 75-90%, preferably about 80-90%, of the total fermentation process time, as determined
5 from prior experience and assays. For example, induction of the promoter may take place at from about 30 hours, preferably 32 hours, up to about 36 hours post-inoculation of a 40-hour fermentation process.

Gene expression may be measured in a sample directly, for example, by conventional northern blotting to quantitate the transcription of mRNA (Thomas,
10 Proc. Natl. Acad. Sci. USA, 77: 5201-5205 (1980)). Various labels may be employed, most commonly radioisotopes, particularly ^{32}P . However, other techniques may also be employed, such as using biotin-modified nucleotides for introduction into a polynucleotide. The biotin then serves as the site for binding to avidin or antibodies, which may be labeled with a wide variety of
15 labels, such as radionuclides, fluorescers, enzymes, or the like.

For accumulation of an expressed gene product, the host cell is cultured under conditions sufficient for accumulation of the gene product. Such conditions include, e.g., temperature, nutrient, and cell-density conditions that permit protein expression and accumulation by the cell. Moreover, such
20 conditions are those under which the cell can perform basic cellular functions of transcription, translation, and passage of proteins from one cellular compartment to another for the secreted proteins, as are known to those skilled in the art.

After product accumulation, when the cells have been lysed by the lytic
25 enzymes expressed, optionally before product recovery the broth lysate is incubated for a period of time sufficient to release the heterologous polypeptide contained in the cells. This period of time will depend, for example, on the type of heterologous polypeptide being recovered and the temperature involved, but preferably will range from about 1 to 24 hours, more
30 preferably 2 to 24 hours, and most preferably 2 to 3 hours. If there is overdigestion with the enzyme, the improvement in recovery of product will not be as great.

In the second step of this invention, the heterologous polypeptide, as a soluble or insoluble product released from the cellular matrix, is recovered
35 from the lysate, in a manner that minimizes co-recovery of cellular debris with the product. The recovery may be done by any means, but preferably comprises sedimenting refractile particles containing the heterologous polypeptide or collecting supernatant containing soluble product. An example of sedimentation is centrifugation. In this case, the recovery preferably takes place, before
40 EBA or sedimentation, in the presence of an agent that disrupts the outer cell wall to increase permeability and allows more solids to be recovered. Examples of such agents include a chelating agent such as EDTA or a zwitterion such as, for example, a dipolar ionic detergent such as ZWITTERGENT 316™ detergent. See

Stabel et al., supra. Most preferably, the recovery takes place in the presence of EDTA. Another technique for the recovery of soluble product is EBA, as described above.

If centrifugation is used for recovery, the relative centrifugal force (RCF) is an important factor. The RCF is adjusted to minimize co-sedimentation of cellular debris with the refractile particles released from the cell wall at lysis. The specific RCF used for this purpose will vary with, for example, the type of product to be recovered, but preferably is at least about 3000 x g, more preferably about 3500-6000 x g, and most preferably about 4000-6000 x g. For the case with t-gene co-expression, about 6000 rpm provides as good a recovery of refractile particles from lysed broth as for intact cells.

The duration of centrifugation will depend on several factors. The sedimentation rate will depend upon, e.g., the size, shape, and density of the refractile particle and the density and viscosity of the fluid. The sedimentation time for solids will depend, e.g., on the sedimentation distance and rate. It is reasonable to expect that the continuous disc-stack centrifuges would work well for the recovery of the released heterologous polypeptide aggregates or for the removal of cellular debris at large scale, since these centrifuges can process at high fluid velocities because of their relatively large centrifugal force and the relatively small sedimentation distance.

The heterologous polypeptide captured in the initial recovery step may then be further purified from the contaminating protein. In a preferred embodiment, the aggregated heterologous polypeptide is isolated, followed by a simultaneous solubilization and refolding of the polypeptide, as disclosed in U.S. Pat. No. 5,288,931. Alternatively, the soluble product is recovered by standard techniques.

The following procedures are exemplary of suitable purification procedures for the soluble heterologous polypeptide released from the periplasm or the cytoplasm: fractionation on immunoaffinity or ion-exchange columns; ethanol precipitation; reverse-phase HPLC; chromatography on silica or on a cation-exchange resin such as DEAE; chromatofocusing; SDS-PAGE; ammonium sulfate precipitation; and gel filtration using, for example, SEPHADEX™ G-75.

The following examples are offered by way of illustration and not by way of limitation.

EXAMPLE I

Co-expression of Lytic Enzymes with Soluble Product

A. Co-expression with T4-lysozyme and endA endonuclease:

40 Background:

rhuMAb CD18 is a recombinant F(ab')₂ antibody fragment with two 214-residue light chains and two 241-residue heavy chains. It binds to the MAC-1 (CD11b/CD18) receptor, effectively blocking the binding of neutrophils to the

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endothelium. In the fermentation process described below, rhuMab CD18 is produced as a F(ab')₂-leucine zipper precursor in *E. coli* and secreted into the periplasm. The desired recovery process targets the soluble fraction of the accumulated product and depends on the F(ab')₂-leucine zipper being released
 5 from the periplasm for initial capture.

T4-lysozyme co-expression was introduced to weaken the peptidoglycan sacculus, and the over-expression of endA protein was introduced to degrade genomic DNA released from the cells under conditions such that the cells are permeabilized or lysed.

10 In *E. coli*, the gene endA encodes for an endonuclease normally secreted to the periplasm that cleaves DNA into oligodeoxyribonucleotides in an endonucleolytic manner. It has been suggested that endA is relatively weakly expressed by *E. coli* (Wackernagel et al., supra). However, one could over-express the endonuclease with the use of a compatible plasmid. By
 15 inserting the endA gene with its signal sequence behind the ara-T4-lysozyme cassette in the compatible plasmid pJJ153, now pJJ154, expression of both T4-lysozyme and endonuclease will be induced upon addition of arabinose. While T4-lysozyme is locked inside the cytoplasm, endonuclease is secreted into the periplasmic space and kept away from the genomic DNA located in the cytoplasm
 20 during the fermentation process. An effective enzymatic degradation of DNA upon cell lysis is expected to reduce or even eliminate multiple passes through the mechanical disruption device, an operation often needed for both cell disruption and viscosity reduction. Success in doing so would bring significant time and cost reduction to the recovery process.

25 Materials and Methods:

pS1130 Plasmid Construction: Plasmid pS1130 (Fig. 3) was constructed to direct the production of the rhuMab CD18 F(ab')₂-leucine zipper precursor in *E. coli*. It is based on the well-characterized plasmid pBR322 with a 2138-bp expression cassette (Fig. 4; SEQ ID NO:1 and NO:2) inserted into the EcoRI restriction
 30 site. The plasmid encodes for resistance to both tetracycline and beta-lactam antibiotics. The expression cassette contains a single copy of each gene linked in tandem. Transcription of each gene into a single dicistronic mRNA is directed by the *E. coli* phoA promoter (Chang et al., Gene, 44: 121-125 (1986)) and ends at the phage lambda t₀ terminator (Scholtissek and Grosse,
 35 Nuc. Acids Res., 15: 3185 (1987)). Translation initiation signals for each chain are provided by *E. coli* STII (heat-stable enterotoxin) (Picken et al., Infection and Immunity, 42: 269-275 (1983)) Shine-Dalgarno sequences.

rhuMab CD18 was created by humanization of the murine monoclonal antibody muMab H52 (Hildreth and August, J. Immunology, 134: 3272-3280 (1985)) using a
 40 process previously described for other antibodies (Carter et al., Proc. Natl. Acad. Sci. USA, 89: 4285-4289 (1992); Shalaby et al., J. Exp. Med., 175: 217-225 (1992); Presta et al., J. Immunol., 151: 2623-2632 (1993)). Briefly, cDNAs encoding the muMab H52 variable light (V_L) and variable heavy (V_H) chain domains

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were isolated using RT-PCR from a hybridoma cell line licensed from Hildreth (Hildreth and August, *supra*). The complementarity-determining regions (CDRs) of the muMAb H52 were transplanted into the human antibody framework gene encoding huMAb UCHT1-1 (Shalaby et al., *supra*) by site-directed mutagenesis.

- 5 Non-CDR, murine framework residues that might influence the affinity of the humanized antibody for its target, human CD18, were identified using molecular modeling. These residues were altered by site-directed mutagenesis and their influence on CD18 binding was tested. Those framework residues that significantly improved affinity were incorporated into the humanized antibody.
- 10 The expression vector encoding the final humanized version of muMAb H52 in an Fab' format was named pH52-10.0 and it is a derivative of pAK19 (Carter et al., *Bio/Technology*, 10: 163-167 (1992)).

Plasmid pS1130 differs from pH52-10.0 in the heavy-chain coding region. The C-terminus of the heavy chain was extended from CysProPro to the natural hinge sequence CysProProCysProAlaProLeuLeuGlyGly (SEQ ID NO:3) and then fused to the 33-residue leucine zipper domain of the yeast transcription factor GCN4. As described above, the leucine zipper domains dimerize to bring two Fab' molecules together and drive F(ab')₂ complex formation. The two cysteine residues in the heavy-chain hinge region then disulfide bond to those from an adjacent Fab' to form a covalently-linked F(ab')₂.

20

Plasmid pS1130 was constructed in a multi-step process outlined below:

First, a filamentous phage (f1) origin of replication was introduced into pH52-10.0 to create plasmid pS0858. Plasmid pS0858 was constructed by ligating the 1977-bp HindIII-HindIII fragment, containing the Fab' expression cassette of pH52-10.0, with the 4870-bp HindIII-HindIII fragment of plasmid pS0191 (referred to as pHGhr (1-238) in Fuh et al., *J. Biol. Chem.*, 265: 3111-3115 (1990)).

25

Second, oligonucleotide-directed mutagenesis was performed on pS0858 to create plasmid zip1#6. The heavy-chain coding region was extended to include the 2-hinge cysteine residues and pepsin cleavage site: (CysProProCysProAlaProLeuLeuGlyGly; SEQ ID NO:3). A NotI restriction site was also introduced. The sequence of the introduced DNA was confirmed by DNA sequencing.

30

Third, a DNA fragment encoding the GCN4 leucine zipper domain flanked by NotI and SphI restriction sites was generated (WO98/37200 published August 27, 1998). This 107-bp NotI-SphI DNA fragment was subsequently cloned into similarly-cut zip1#6 to create plasmid pS1111.

35

Fourth, DNA sequencing of the GCN4 leucine zipper fragment revealed an error in the coding sequence. This error was corrected by oligonucleotide-directed mutagenesis and confirmed by DNA sequencing. The resulting correct plasmid was named pS1117.

40

The final step in the construction of pS1130 was to restore the tetracycline-resistance gene and remove the f1 origin from pS1117. This was

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accomplished by ligating the 2884-bp PstI-SphI fragment of pS1117 containing the Fab'-zipper expression cassette with the 3615-bp PstI-SphI fragment of pH52-10.0.

5 pJJ154 Plasmid Construction: Plasmid pJJ154 (Fig. 5) is a pACYC177 derivative that is compatible with pBR322 vectors. To construct pJJ154, pJJ153 as described below was digested with MluI and the vector fragment was ligated with PCR-amplified endA gene designed to encode MluI ends. The correct orientation of the plasmid was screened for by restriction digest to produce pJJ154.

10 The construction of pJJ153 (a pACYC177 derivative that is compatible with pBR322 vectors) is shown in Figure 5. The ClaI/AlwNI fragment from pBR322 was inserted into ClaI/AlwNI-digested pBAD18 (Guzman et al., supra) to produce pJJ70. One round of site-directed mutagenesis was then performed, changing HindIII to StuI to obtain pJJ75. A second round of site-directed mutagenesis
15 was done to change MluI to SacII, to produce pJJ76. Then XbaI/HindIII fragments from pJJ76 and from pBKIGF2B were ligated, and XbaI/HindIII fragments from this ligation product and from a T4 lysozyme/tac plasmid were ligated to produce pT4LysAra. Then BamHI (filled in)/ScaI-digested pACYC177 was ligated with ClaI/HindIII (both ends filled in)-digested pT4LysAra to produce pJJ153.
20 The maps for pACYC177, pT4LysAra, and pJJ153 are shown in Fig. 5.

Bacterial Strains and Growth Conditions: Strain 33B8 (*E. coli* W3110 *tonA phoA* $\Delta(\text{argF-lac})$ 189 *deoC degP ilvG+(kanS)*) was used as the production host for the co-expression of T4-lysozyme and DNA-digesting protein from plasmid pJJ154 and
25 the expression of rhuMab CD18 F(ab')₂-leucine zipper from plasmid pS1130. Competent cells of 33B8 were co-transformed with pJJ154 and pS1130 using standard procedures. Transformants were picked from LB plates containing 20 ug/ml tetracycline and 50 ug/ml kanamycin (LB+Tet20+Kan50), streak-purified, and grown in LB broth with 20 ug/ml tetracycline and 50 ug/ml kanamycin in a
30 37°C or 30°C shaker/incubator before being stored in DMSO at -80°C.

For control runs, the host 33B8 was transformed with pS1130 and pJJ96 (analogous to pJJ154 except no nucleic acids encoding the T4-lysozyme and endA product were inserted into the vector) and isolated from similar selective medium.

35

rhuMab CD18 F(ab')₂-Leucine Zipper Fermentation Process: A shake flask inoculum was prepared by inoculating sterile medium using a freshly thawed stock culture vial. Appropriate antibiotics were included in the medium to provide selective pressure to ensure retention of the plasmid. The shake flask
40 medium composition is given in Table 1. Shake flasks were incubated with shaking at about 30°C (28°C-32°C) for 14-18 hours. This culture was then used to inoculate the production fermentation vessel. The inoculation volume was between 0.1% and 10% of the initial volume of medium.

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The production of the F(ab')₂-zipper precursor of rhuMAb CD18 was carried out in the production medium given in Table 2. The fermentation process was carried out at about 30°C (28-32°C) and about pH 7.0 (6.5-7.9). The aeration rate and the agitation rate were set to provide adequate transfer of oxygen to the culture. Production of the F(ab')₂-zipper precursor of rhuMAb CD18 occurred when the phosphate in the medium was depleted, typically 36-60 hours after inoculation.

Table 1
Shake Flask Medium Composition

10	Ingredient	Quantity/Liter
	Tetracycline	4-20 mg
	Tryptone	8-12 g
	Yeast extract	4-6 g
	Sodium chloride	8-12 g
15	Sodium phosphate, added as pH7 solution	4-6 mmol

Table 2
Production Medium Composition

20	Ingredient	Quantity/Liter
	Tetracycline	4-20 mg
	Glucose ^a	10-250 g
	Ammonium sulfate ^a	2-8 g
25	Sodium phosphate, monobasic, dihydrate ^a	1-5 g
	Potassium phosphate, dibasic ^a	1-5 g
	Potassium phosphate, monobasic ^a	0.5-5 g
	Sodium citrate, dihydrate ^a	0.5-5 g
	Magnesium sulfate, heptahydrate ^a	1.0-10 g
30	FERMAX TM ^a (antifoam)	0-5 ml
	Ferric chloride, hexahydrate ^a	20-200 mg
	Zinc sulfate, heptahydrate ^a	0.2-20 mg
	Cobalt chloride, hexahydrate ^a	0.2-20 mg
	Sodium molybdate, dihydrate ^a	0.2-20 mg
35	Cupric sulfate, pentahydrate ^a	0.2-20 mg
	Boric acid ^a	0.2-20 mg
	Manganese sulfate, monohydrate ^a	0.2-20 mg
	Casein digest	15-25 g
	Methionine ^a	0-5 g
40	Leucine ^a	0-5 g

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^a A portion of these ingredients was added to the fermentor initially, and the remainder was fed during the fermentation. Ammonium hydroxide was added as required to control pH.

5 The timing of arabinose addition ranged from 50 to 65 hours post-inoculation. Bolus additions of 0.1% to 1% (final concentration) arabinose were tested for the induction of co-expression of T4-lysozyme and endA endonuclease.

The fermentation was allowed to proceed for about 65 hours (60 to 72
10 hours), after which the broth was harvested for subsequent treatment for product recovery.

Assessment of Reduction of Broth Viscosity by endA Endonuclease Over-expression: Aliquots of harvested broth from the rhuMAb CD18 F(ab')₂-leucine zipper fermentation with or without the co-expression of endA product in
15 addition to phage lysozyme described above was subjected to one cycle of freeze-thaw. The thawed broth was diluted 1:3 into water or 20 mM MgCl₂ before incubation in a 37°C water bath with agitation. Samples were removed at intervals and the viscosity of the diluted broth was measured by using the
20 Falling Ball viscometer.

Results:

Effect of Over-Expression of EndA in Addition to T4-Lysozyme on Broth Viscosity: As shown in Table 3, diluted freeze-thawed harvest broth from the
25 above fermentation process in the absence of endA over-expression had broth viscosity in excess of 800 cP at the start of the 37°C incubation. After 60 minutes of incubation, there was little change in the H₂O-diluted freeze-thawed fermentation broth viscosity, while the MgCl₂-buffer-diluted broth showed significant reduction in the broth viscosity. Upon extended 37°C incubation
30 for up to over 2.5 hours, the viscosity of the freeze-thawed diluted harvest broth with no over-expression of endA in addition to T4-lysozyme leveled off at about 40 cP. The viscosity of the diluted freeze-thawed harvest broth with over-expression of endA was less than 20 cP even before any 37°C incubation.

Table 3

35 Co-expression	Treatment	37°C Incubation (min)	Broth Viscosity (cP)
T4-lysozyme + endA (pJJ154)	H ₂ O control	0	<20
	+ 20 mM MgCl ₂	0	<20
	H ₂ O control	60	<20
	+ 20 mM MgCl ₂	60	<20
T4-lysozyme only (pJJ153)	H ₂ O control	0	>800
	+ 20 mM MgCl ₂	0	>800
	H ₂ O control	60	>800
	+ 20 mM MgCl ₂	60	36

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	H ₂ O control + 20 mM MgCl ₂	120 120	41 36
	H ₂ O control + 20 mM MgCl ₂	165 165	40 42

B. Co-expression of T4-Lysozyme, Gene t, and EndA Endonuclease:

Background:

As described in Example IA, over-expression of endA brings significant benefit in lowering the viscosity of permeabilized or lysed broth. It helps in conditioning the fermentation broth for the subsequent product recovery step. By co-expressing T4-lysozyme and t-gene in addition to endA, cells can be biochemically lysed and at the same time yield a well-conditioned broth lysate with fluid viscosity sufficiently low and compatible with product isolation steps such as centrifugation or EBA.

The fermentation process described above was used to produce rhuMAb CD18 as a F(ab')₂-leucine zipper precursor directed by plasmid pS1130 in *E. coli*, with the co-expression of lytic enzymes and DNA-digesting protein directed by the plasmid pJJ155. in *E. coli*. The antibody fragment product was secreted and accumulated in the periplasm. The lytic enzymes were compartmentalized away from their substrate until released by the action of the t-gene product. The desired recovery process targets the soluble fraction of the F(ab')₂-leucine zipper released from the periplasm for initial capture.

Materials & Methods:

pJJ155 Plasmid Construction: Like pJJ154, pJJ155 is a pACYC177 derivative that is compatible with pBR322 vectors. To construct pJJ155, pJJ154 as described above was digested with KpnI and the vector fragment was ligated with PCR-amplified t-gene designed to encode KpnI ends. The correct orientation of the plasmid was screened for by restriction digest to product pJJ155. A map for pJJ155 is shown in Fig. 7.

Bacterial Strains and Growth Conditions: Most experiments were carried out with transformed 33B8 as described above except that pJJ154 was replaced by pJJ155.

Fermentation Process Description: See Example IA.

Results:

Cell growth of 33B8 co-transformed with pS1130 and pJJ155 (33B8/pS1130/pJJ155) was not significantly different from that of the control (33B8 transformed with pS1130 only). After addition of 0.5% to 1% arabinose at 50-65 hours to induce the co-expression of the lytic enzymes and DNA-digesting protein, OD550 of the 33B8/pS1130/pJJ155 culture steadily dropped to 30-40% of peak cell density, suggesting cell lysis.

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Table 4 shows the effect of co-expression of T4-lysozyme + endA + t-gene on the release of soluble anti-CD18 antibody fragment into the medium. The supernatant from centrifugation of the harvested broth lysate after incubation in the presence of 25 mM EDTA was assayed by ion-exchange HPLC chromatography for product quantitation. Greater than 80% of the soluble anti-CD18 antibody fragments was found in the supernatant fraction for the experimental condition where co-expression of lytic enzymes and DNA-digesting protein was induced, compared to less than 10% found for the control and the condition with no t-gene (pJJ154) or mechanical disruption.

Table 4

Co-Expression	% of Total Product Released
None (control)	<10
T4-Lysozyme + endA (pJJ154)	<10
T4-Lysozyme + endA + t-gene (pJJ155)	>80

Conclusions:

Endonuclease degrades DNA and lowers broth viscosity. Over-expression of *E. coli* endogenous endonuclease in addition to T4-lysozyme reduces the need for mechanical cell disruption for the shearing of released DNA. The release of the phage lysozyme from the cytoplasmic compartment mediated by the expressed t-gene protein initiates the biochemical disruption process, resulting in cell lysis and the release of cellular contents including heterologous polypeptide, genomic DNA, and the DNA-digesting protein, which was trapped in either the periplasm or the cytoplasm up to this time. By holding the broth lysate for appropriate digestion of substrates by the lytic enzymes and DNA-digesting protein co-expressed, the broth viscosity and product release from cellular matrix were improved for better product recovery.

EXAMPLE II

Co-expression of Lytic Enzymes with IGF-I

Background:

IGF-I was selected as a heterologous polypeptide for evaluation of refractile particle recovery due to large-scale needs. Co-expression of lytic enzymes and DNA-digesting protein was used to improve the release of the IGF-I refractile particles from cell-wall structures in the absence of mechanical disruption.

Upon cell lysis, in addition to releasing T4-lysozyme from the cytoplasmic compartment, genomic DNA released from the cytoplasm would have contributed significant viscosity to the broth lysate fluid. Hence, the co-expression of an *E. coli* endonuclease together with lytic enzymes was useful in reducing fluid viscosity following cell lysis and improving product recovery during centrifugation.

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Materials & Methods:

pLBIGF57 Plasmid Construction: The plasmid pLBIGF57 for the expression of IGF-I (Fig. 6) was constructed from a basic backbone of pBR322. The transcriptional and translational sequences required for the expression of nucleic acid encoding IGF-I were provided by the *phoA* promoter and *trp* Shine-Dalgarno sequence. Secretion of the protein was directed by a TIR variant of the *lamB* signal sequence. This TIR variant does not alter the primary amino acid sequence of the *lamB* signal; however, silent nucleotide sequence changes result, in this particular variant, in an increased level of translated protein.

The details of pLBIGF57 construction follow. A codon library of the *lamB* signal sequence was constructed to screen for translational initiation region (TIR) variants of differing strength. Specifically, the third position of codons 3 to 7 of the *lamB* signal sequence was varied. This design conserved the wild-type amino acid sequence and yet allowed for divergence within the nucleotide sequence.

As previously described for the screening of the STII signal sequence codon library (S. African Pat. No. ZA 96/1688; Simmons and Yansura, Nature Biotechnology, 14: 629-634 (1996)), the *phoA* gene product served as a reporter for the selection of the *lamB* TIR variants. The codon library of the *lamB* signal sequence was inserted downstream of the *phoA* promoter and *trp* Shine-Dalgarno and upstream of the *phoA* gene. Under conditions of low transcriptional activity, the quantity of alkaline phosphatase secreted by each construct was now dependent on the efficiency of translational initiation provided by each TIR variant in the library. Using this method, *lamB* TIR variants were selected covering an approximate 10-fold activity range. Specifically, *lamB* TIR variant #57 provides an approximately 1.8-fold stronger TIR than the wild-type *lamB* codons based on the *phoA* activity assay.

The vector fragment for the construction of pLBIGF57 was generated by digesting pBK131Ran with *Xba*I and *Sph*I. This *Xba*I-*Sph*I vector contains the *phoA* promoter and *trp* Shine-Dalgarno sequences. The coding sequences for IGF-I and the lambda *t_o* transcription terminator were isolated from pBKIGF-2B (U.S. Pat. No. 5,342,763) following digestion with *Nco*I-*Sph*I. The *lamB* signal sequence fragment was isolated from pLBPhoTBK#57 (TIR variant #57; generated as described above) following digestion with *Xba*I-*Nco*I. These three fragments were then ligated together to construct pLBIGF57.

Bacterial Strains and Growth Conditions: Most experiments were carried out with strain 43E7 (*E. coli* W3110 *fhuA(tonA)* Δ (*argF-lac*) *ptr3 degP41(kanS)* Δ *ompT4(nmpc-fepE)* *ilvG⁺ phoA⁺*). A double-plasmid system involving the product plasmid (pLBIGF57) and pJJ155 for the lytic enzymes was employed. Competent cells of 43E7 were co-transformed with pLBIGF57 and pJJ155 using the standard procedure. Transformants were picked after growth on an LB plate containing

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50µg/mL carbenicillin (LB + CARB50™) and 50 ug/ml kanamycin, streak-purified and grown in LB broth with 50 µg/mL CARB50™ and 50 ug/ml kanamycin in a 37°C shaker/incubator before being tested in the fermentor.

For comparison, 43E7 transformed with pLBIGF57 alone was used in the control case conducted under similar conditions. pLBIGF57 confers both carbenicillin and tetracycline resistance to the production host and allows 43E7/pLBIGF57 to grow in the presence of either antibiotic.

Fermentation Process: The fermentation medium composition and experimental protocol used for the co-expression of nucleic acid encoding IGF-I, endA, T4-lysozyme, and t-gene if used were similar to those of the scaled-down high-metabolic rate, high-yield 10-kiloliter IGF-I process. Briefly, a shake flask seed culture of 43E7/pLBIGF57 or 43E7/pLBIGF57/pJJ155 was used to inoculate the rich production medium. The composition of the medium (with the quantities of each component utilized per liter of initial medium) is described below:

	<u>Ingredient</u>	<u>Quantity/L</u>
20	Glucose*	200-500 g
	Ammonium Sulfate	2-10 g
	Sodium Phosphate, Monobasic Dihydrate	1-5 g
25	Potassium Phosphate, Dibasic	1-5 g
	Sodium Citrate, Dihydrate	0.5-5 g
30	Potassium Chloride	0.5-5 g
	Magnesium Sulfate, Heptahydrate	0.5-5 g
	PLURONIC™ Polyol, L61	0.1-5 mL
35	Ferric Chloride, Heptahydrate	10-100 mg
	Zinc Sulfate, Heptahydrate	0.1-10 mg
40	Cobalt Chloride, Hexahydrate	0.1-10 mg
	Sodium Molybdate, Dihydrate	0.1-10 mg
	Cupric Sulfate, Pentahydrate	0.1-10 mg
45	Boric Acid	0.1-10 mg
	Manganese Sulfate, Monohydrate	0.1-10 mg
50	Hydrochloric Acid	10-100 mg
	Tetracycline	4-30 mg
	Yeast Extract*	5-25 g
55	NZ Amine AS*	5-25 g

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	Methionine*	0-5 g
	Ammonium Hydroxide	as required to control pH
5	Sulfuric Acid	as required to control pH

10 *A portion of the glucose, yeast extract, NZ Amine AS, and methionine is added to the medium initially, with the remainder being fed throughout the fermentation.

15 The fermentation was a fed-batch process with fermentation parameters set as follow:

Agitation: Initially at 800 RPM, increased to 1000 RPM at 8 OD

20 Aeration: 15.0 slpm

pH control: 7.3

Temp.: 37 °C

25 Back pressure: 0.7 bar

Glucose feed: computer-controlled using an algorithm which regulates the growth rate at approximately 95% of the maximum early in the fermentation and which then controls the dissolved oxygen concentration (DO₂) at 30% of air saturation after the DO₂ drops to 30%.

35 Complex nitrogen feed: constant feed rate of 0.5 mL/min throughout the run

Run Duration: 40 hours

40 The timing of arabinose addition ranged from 24 hr to 36 hr. Bolus additions of 0.1% to 1% (final concentration) arabinose were tested to define the induction strength necessary for producing the most preferred amounts of T4-lysozyme for better product recovery at the centrifugation step.

45 Recovery of Refractile Particles from Harvested Broth: Broth was harvested at the end of fermentation when a target drop in OD₅₅₀ was observed and was either processed soon after or stored briefly at 4°C prior to use. The test protocol used involved four process steps:

50 I. Add 1M EDTA to the harvest broth to bring the final concentration of EDTA to 25 mM. EDTA chelates the divalent cations and disrupts the outer cell surface structure. This makes the peptidoglycan layer inside unbroken cells accessible to degradation by T4-lysozyme and weakens the cell wall to promote cell lysis.

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II. Hold the lysate at room temperature or incubate at 37°C for further degradation of cell wall. This step simulates the longer process times associated with the larger-scale process.

5 III. Recover refractile particles and solids from the lysate by centrifugation. Bench-scale centrifugation in a SORVALL™ GSA rotor at different speeds (3000 rpm to 6000 rpm; equivalent to RCF's of approximately 2500 g to 6000 g at rmax, respectively) was used to collect the solids as pellets.

10 An additional step to wash the pellet with buffer would remove the lysate entrained by the pellet and minimize the amount of contaminating *E. coli* proteins in the refractile particle preparations.

Samples of the supernatant and pellet from centrifugation of broth lysate resuspended in buffer were evaluated for product recovery. The amount of product present in the samples was analyzed by a HPLC reverse-phase method.
15 Product recovery efficiency was calculated by expressing the amount of product recovered in the pellet by the process step as a percent of the total product present in the pellet and supernatant combined. To evaluate the quality of the refractile particles recovered, the amount of total protein present in the pellet and the supernatant was measured by the Lowry method (J. Biol. Chem.,
20 193: 265 (1951)).

The contribution of endonuclease activity was assessed by the efficiency of solids recovery during sedimentation from the broth lysate by centrifugation. Also, the amount of nucleic acids present in the pellet and the supernatant was measured by OD₂₆₀ readings.

25 Results:

IGF-I Fermentation and Product Expression:

Figure 8 shows in general the two-plasmid system employed in this Example for co-expression of lytic enzymes and endA with IGF-I using pJJ155. The initial growth rate of 43E7/pLBIGF57/pJJ155 showed no significant difference
30 from that of the 43E7/pLBIGF57 control. Peak cell densities reached in these broths were similar. However, compared to the control, a significant loss in optical density was observed in cultures after induction for lytic enzyme co-expression, indicating cell lysis. Examination of the harvest broth by phase-contrast microscopy showed that, in comparison to the no-co-expression
35 control, very few intact *E. coli* cells were present and freed refractile particles were evident as a result of the co-expression of lytic enzymes and DNA-digesting protein. See Figures 9A-9E.

The respiration rates across this collection of runs looked very similar to the control except for significant continuous loss in oxygen uptake rate
40 (OUR) with a concomitant loss in kla soon after the arabinose addition.

The success of the biochemical cell lysis technique as described in this invention is evident from the differences in the partitioning of nucleic acids and total protein between the solid (pellet) and liquid (supernatant) fractions

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as a result of the co-expression of the lytic enzymes and DNA-digesting protein versus the control with no co-expression (Figs. 10A and 10B, respectively). The percent of total nucleic acids calculated from A260 readings and the percent of total protein as measured by the Lowry protein assay both increased
5 in the supernatant from the centrifugation of biochemically lysed broth over that from control broth.

The product recovery from the two conditions is summarized in Fig. 11. With the biochemically-lysed IGF-I broth, IGF-I product was released together with degraded DNA polymer into the broth lysate. The efficiency of recovering
10 the small dense refractile particles increased with the RCF used during centrifugation. As higher g force was used, the percent of the lysed broth recovered as pellet (reported as % pellet) increased (Fig. 12), and so did the amount of IGF-I product in the pellet. At approximately 6000 x g, close to 95% of the product was captured in the pellet.

15 Conclusion:

As disclosed herein, a simple manipulation of gene expression during the fermentation process resulted in a biochemical cell lysis that could replace the conventional mechanical disruption traditionally used for product recovery at production scale. In vivo co-expression or coordinated expression of T4-
20 lysozyme and t-gene product is a highly effective technique for the disintegration of cells while the over-expressed endA protein degrades the leaked DNA, lowers broth viscosity, and efficiently conditions the broth lysate for product recovery in the initial product capture step. Biochemical cell lysis is applicable to the recovery of soluble as well as insoluble product.
25 The compartmentalization of the co-expressed enzymes away from their substrates until the desired moment for cell lysis is essential and a critical design in the invention. The invention brings significant reduction in process cost, process time, and hence opportunity cost to other products that may be sharing the same production facility.

30

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WHAT IS CLAIMED IS:

1. A process for recovering a heterologous polypeptide from bacterial cells comprising:
 - (a) culturing the cells, which comprise a first nucleic acid encoding phage lysozyme and a second nucleic acid encoding a protein that displays DNA-digesting activity under the control of a signal sequence for secretion of the DNA-digesting protein, wherein said first and second nucleic acids are operatively linked to a first promoter that is the same for both and wherein both are linked on the same nucleic acid construct, and a third nucleic acid encoding the heterologous polypeptide and a signal sequence for secretion of the heterologous polypeptide, which third nucleic acid is linked to a second promoter, wherein the second promoter is inducible and the first promoter is different from the second promoter and is either (i) inducible or (ii) a weak constitutive promoter or a promoter with a low basal level that does not require the addition of an inducer to function as a promoter,
 - (b) adding an inducer specific for induction of expression of the nucleic acid encoding the heterologous polypeptide from the second, inducible promoter,
 - (c) when the first promoter driving expression of the nucleic acids encoding the DNA-digesting protein and the phage lysozyme is an inducible promoter, adding an inducer specific for the first promoter after accumulation of about 50% or more of the maximum accumulation of the heterologous polypeptide to be recovered,
 - (d) lysing the cells, wherein the lysing results in a broth lysate, and
 - (e) recovering accumulated heterologous polypeptide from the broth lysate.
2. The process of claim 1 wherein the heterologous polypeptide is a mammalian polypeptide.
3. The process of claim 1 or 2 wherein the heterologous polypeptide is anti-CD18 antibody or an anti-CD18 antibody fragment.
4. The process of any one of claims 1-3 wherein the recovery step is performed using expanded bed absorption or sedimentation.
5. The process of any one of claims 1-4 wherein the DNA-digesting protein is a eukaryotic DNase or bacterial endA.
6. The process of any one of claims 1-5 wherein the bacterial cells are gram-negative cells.

7. The process of any one of claims 1-6 wherein the phage lysozyme is phage T4-lysozyme.

8. The process of any one of claims 1-7 wherein the recovery step takes place in the presence of an agent that disrupts the outer cell wall of the bacterial cells.

5

9. The process of claim 8 wherein the agent is a chelating agent or zwitterion.

10. The process of any one of claims 1-9 wherein, before recovery, the cell lysate is incubated for a period of time sufficient to release the heterologous polypeptide contained in the cells.

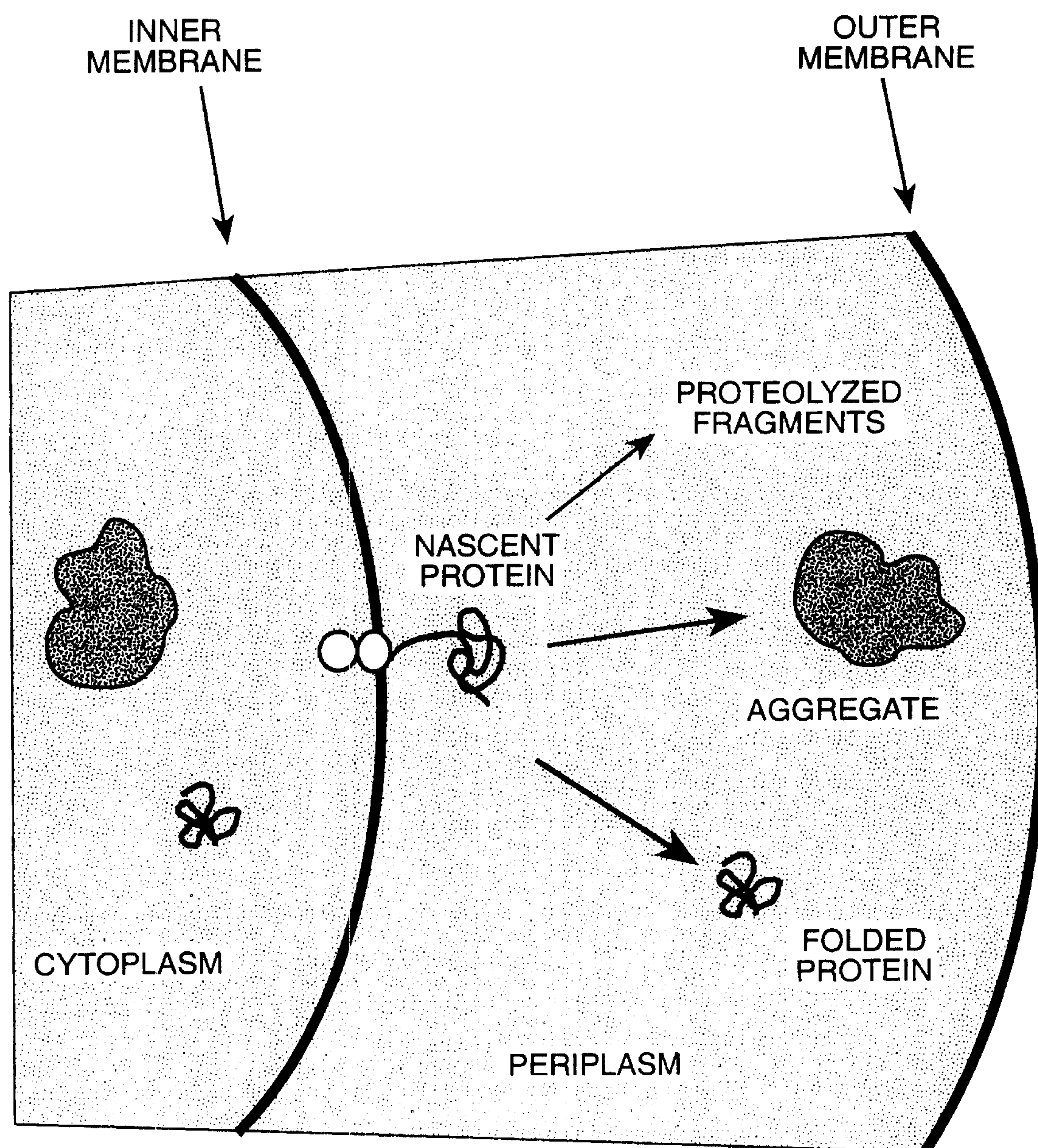
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11. The process of any one of claims 1-10 wherein one or more of the nucleic acids, including the promoter therefor, is integrated into the genome of the bacterial cells.

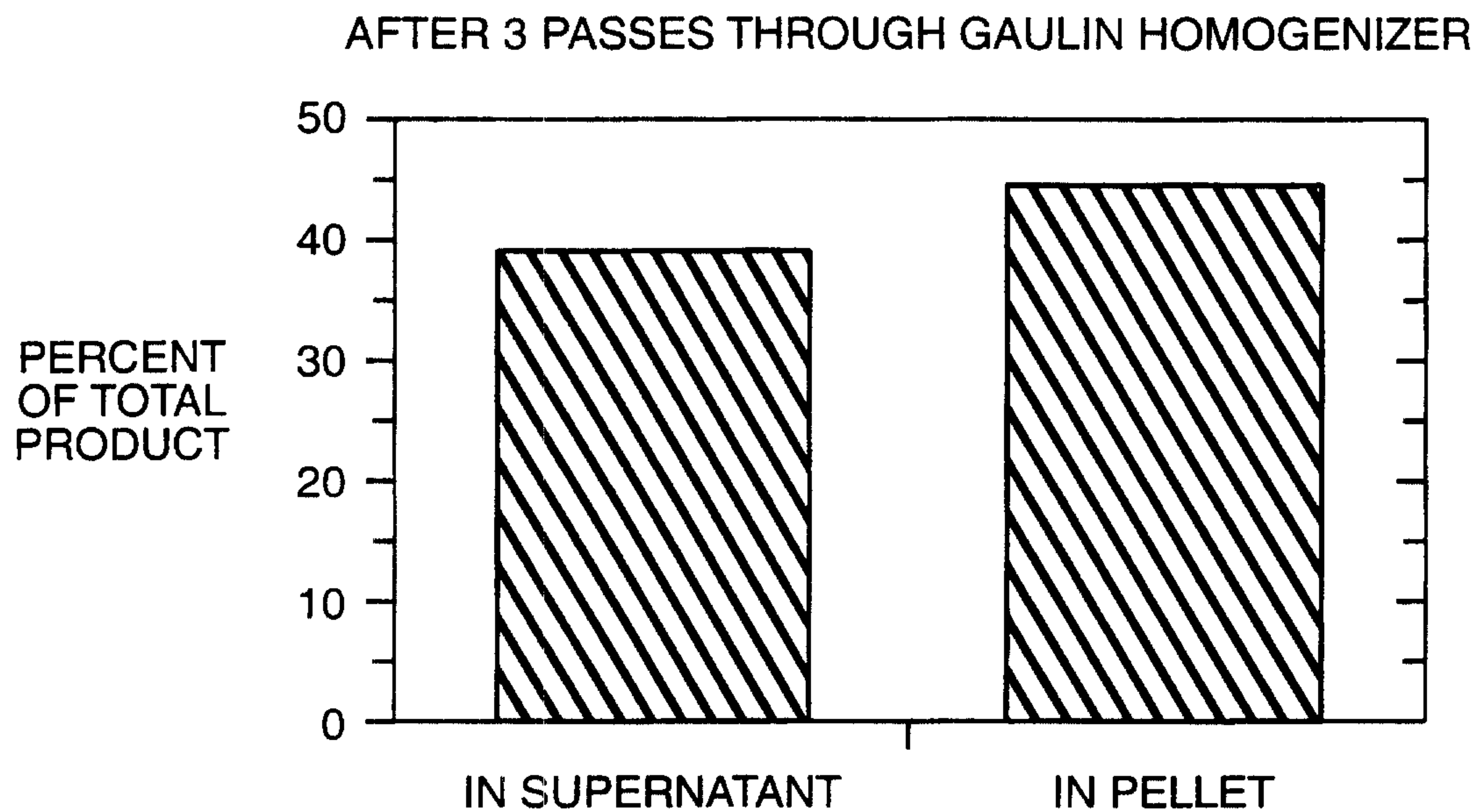
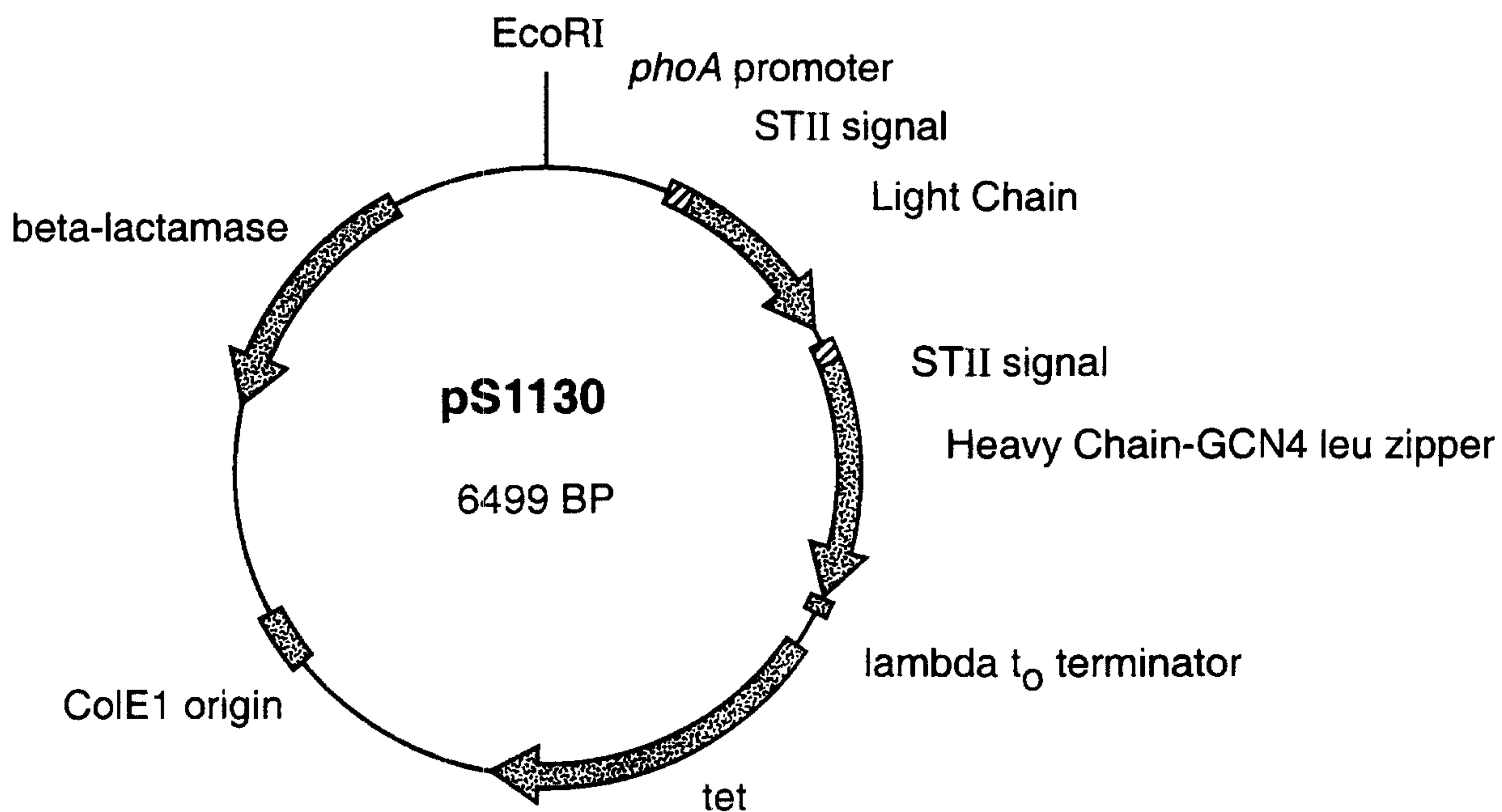
12. The process of any one of claims 1-11 wherein the culturing takes place under conditions whereby the heterologous polypeptide and DNA-digesting protein are secreted into the periplasm of the bacteria.

15

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**FIG. 1**

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**FIG._2****FIG._3**

Start of expression cassette
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-14 A S M F V F S I A T N A Y A D I
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3 Q M T Q S P S S L S A S V G D R
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19 V T I T C R A S Q D I N N Y L N
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35 W Y Q Q K P G K A P K L L I Y Y
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51 T S T L H S G V P S R F S G C

FIG._4A-1

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701 TTC GCA ACT TAT TAC TGT CAG CAA GGT AAT ACT CTG CCG CCG ACG TTC
83 F A T Y Y C Q Q G N T L P P T F

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FIG.-4A-2

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-5	T	N	A	Y	A	E	V	Q	L	V	E	S	G	G	G	L
1283	GTG	CAG	CCA	GGG	GGC	TCA	CTC	CGT	TTG	TCC	TGT	GCA	ACT	TCT	GGC	TAC
12	V	Q	P	G	G	S	L	R	L	S	C	A	T	S	G	Y
1331	ACC	TTT	ACC	GAA	TAC	ACT	ATG	CAC	TGG	ATG	CGT	CAG	GCC	CCG	GGT	AAG
28	T	F	T	E	Y	T	M	H	W	M	R	Q	A	P	G	K
1379	GGC	CTG	GAA	TGG	GTT	GCA	GGG	ATT	AAT	CCT	AAA	AAC	GGT	GGT	ACC	AGC
44	G	L	E	W	V	A	G	I	N	P	K	N	G	G	T	S
1427	CAC	AAC	CAG	AGG	TTC	ATG	GAC	CGT	TTC	ACT	ATA	AGC	GTA	GAT	AAA	TCC
60	H	N	Q	R	F	M	D	R	F	T	I	S	V	D	K	S
1475	ACC	AGT	ACA	GCC	TAC	ATG	CAA	ATG	AAC	AGC	CTG	CGT	GCT	GAG	GAC	ACT
76	T	S	T	A	Y	M	Q	M	N	S	L	R	A	E	D	T
1523	GCC	GTC	TAT	TAT	TGT	GCT	AGA	TGG	CGA	GGC	CTG	AAC	TAC	GGC	TTT	GAC
92	A	V	Y	Y	C	A	R	W	R	G	L	N	Y	G	F	D
1571	GTC	CGT	TAT	TTT	GAC	GTC	TGG	GGT	CAA	GGA	ACC	CTG	GTC	ACC	GTC	TCC
108	V	R	Y	F	D	V	W	G	Q	G	T	L	V	T	V	S
1619	TCG	GCC	TCC	ACC	AAG	GGC	CCA	TCG	GTC	TTC	CCC	CTG	GCA	CCC	TCC	TCC
124	S	A	S	T	K	G	P	S	V	F	P	L	A	P	S	S

FIG._4B-1

1667 AAG AGC ACC TCT GGG GGC ACA GCG GCC CTG GGC TGC CTG GTC AAG GAC
140 K S T S G G G T A A A L G C L V K D

1715 TAC TTC CCC GAA CCG GTG ACG GTG TCG TGG AAC TCA GGC GCC CTG ACC
156 Y F P E P V T V S S W N S G A L T

1763 AGC GGC GTG CAC ACC TTC CCG GCT GTC CTA CAG TCC TCA GGA CTC TAC
172 S G V H T F P A V L Q S S G L Y

1811 TCC CTC AGC AGC GTG GTG ACC GTG CCC TCC AGC AGC TTT GGC ACC CAG
188 S L S S S V V T P S S S L G T Q

1859 ACC TAC ATC TGC AAC GTG AAT CAC AAG CCC AGC AAC ACC AAG GTC GAC
204 T Y I C C N V N H K P S N T K V D

1907 AAG AAA GTT GAG CCC AAA TCT TGT GAC AAA ACT CAC ACA TGC CCG CCG
220 K K V E P P K K S C D K T H T C P P

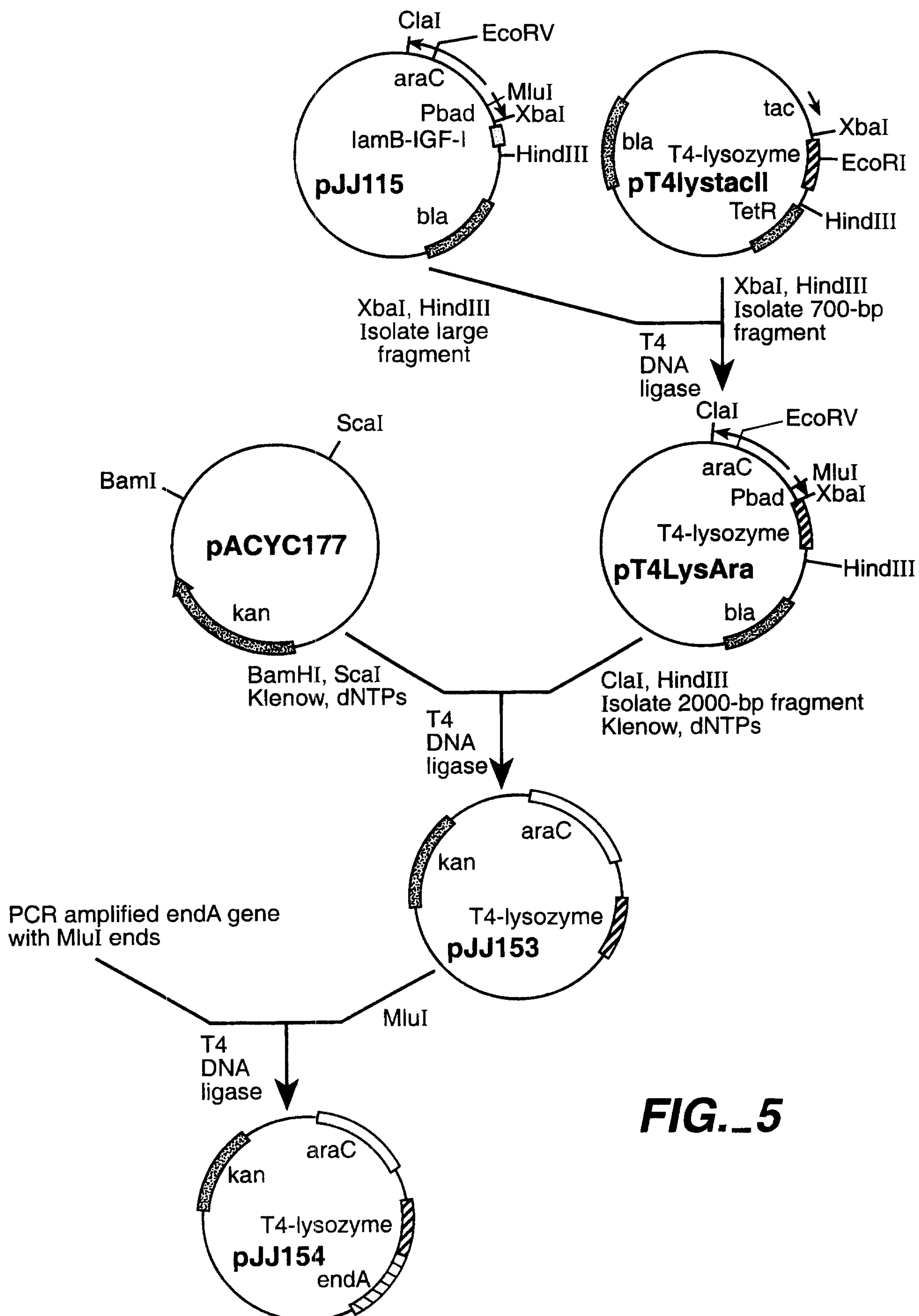
1955 TGC CCA GCA CCA GAA CTG CTG GGC GGC ATG AAA CAG CTA GAG GAC
236 C P A P E L L L G G R M K Q L E D

2003 AAG GTC GAA GAG CTA CTC TCC AAG AAC TAC CAC CTA GAG AAT GAA GTG
252 K V E E L L S K N Y H L E N E V

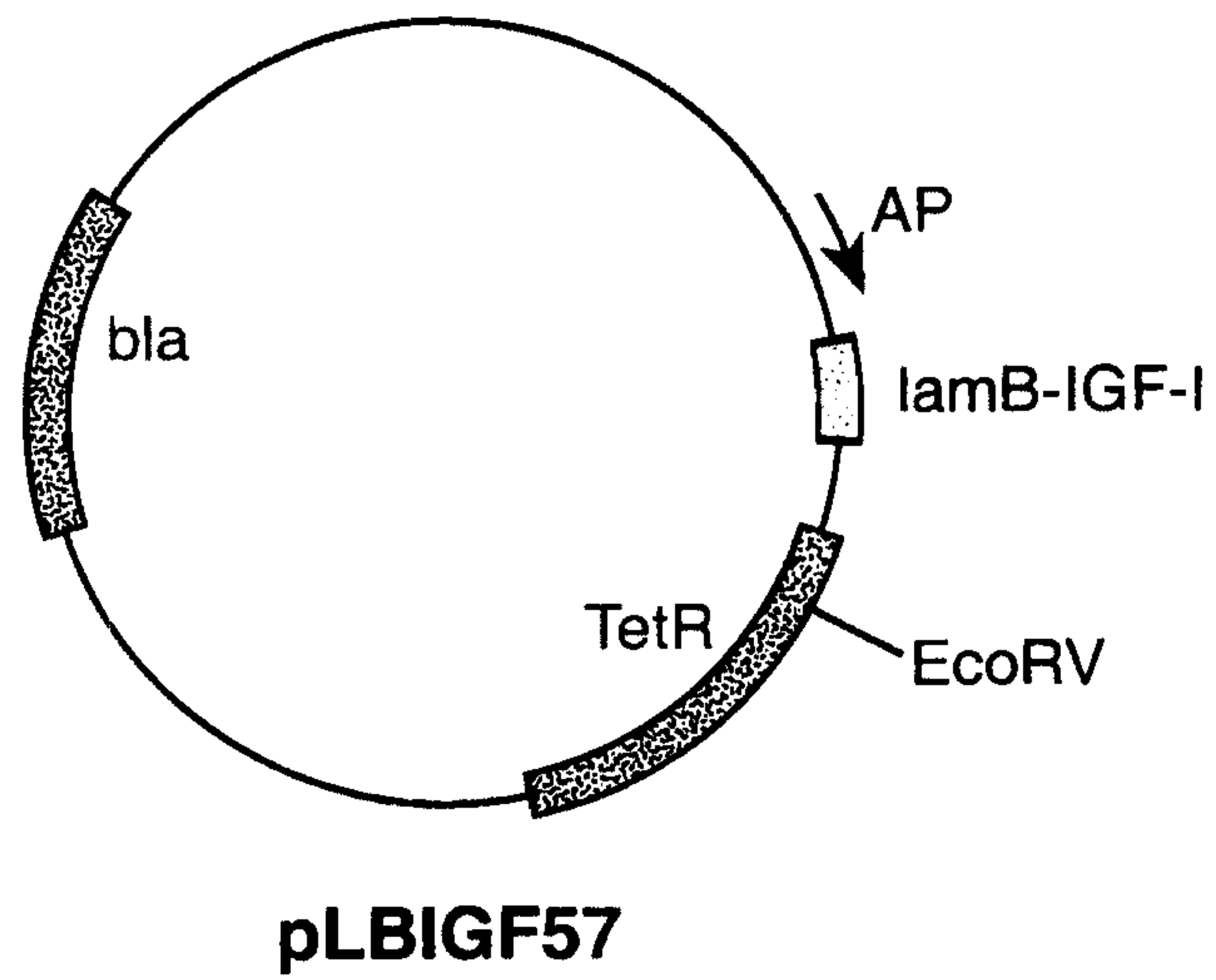
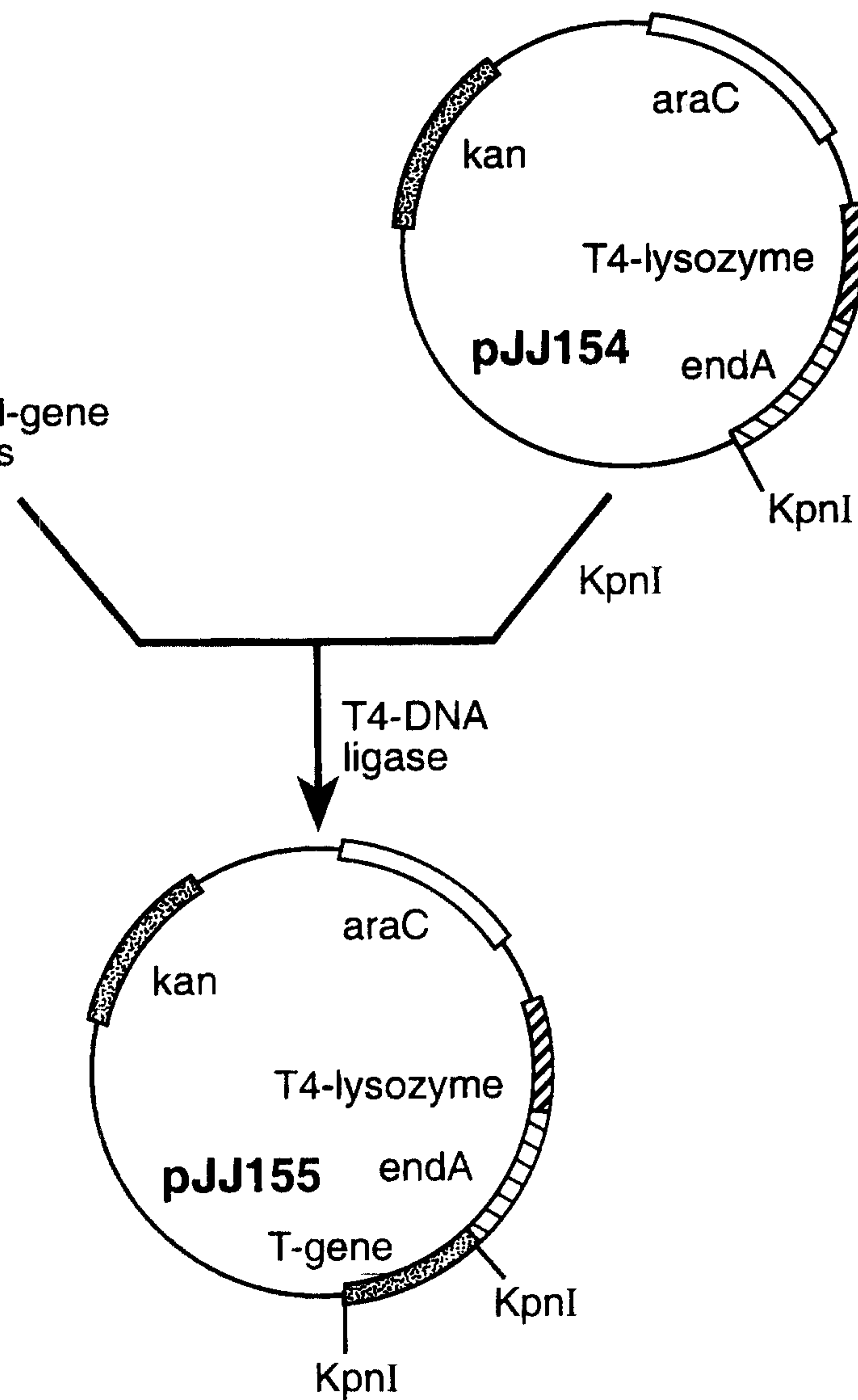
2051 GCA AGA CTC AAA AAG CTT GTC GGG GAG CGC TAA GCATGCG ACGGCCCTAG
268 A R L K K L V G E R

2101 AGTCCCCTAAC GCTCGGTGCG CGCCGGGCGT TTTTATTGT TAA

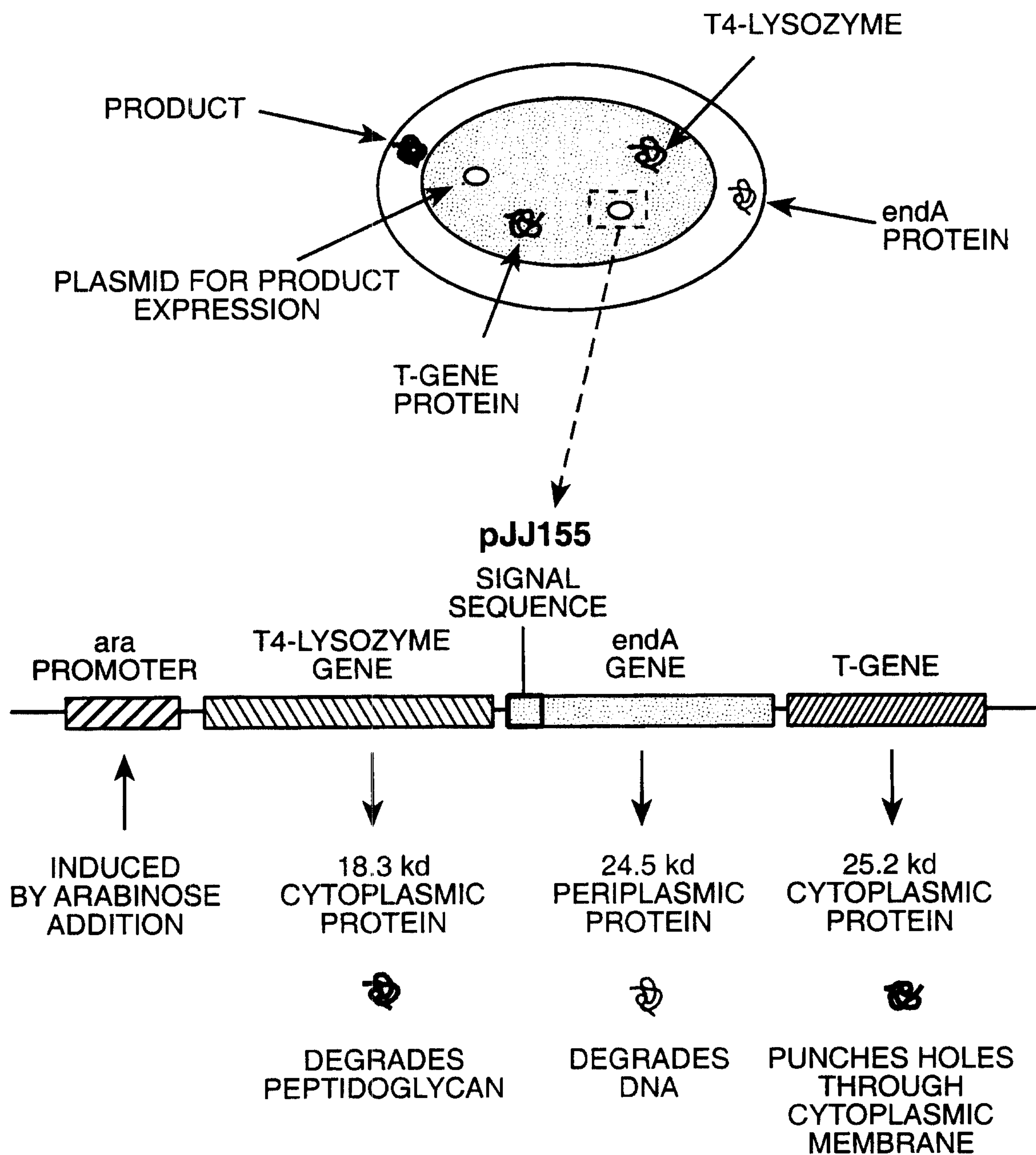
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**FIG. 5**

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FIG._6PCR amplified-gene
with KpnI ends**FIG._7**

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**FIG. 8**

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PCT/US99/24696

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CONTROL BROTH BEFORE EDTA ADDITION
RESUSPENDED PELLET

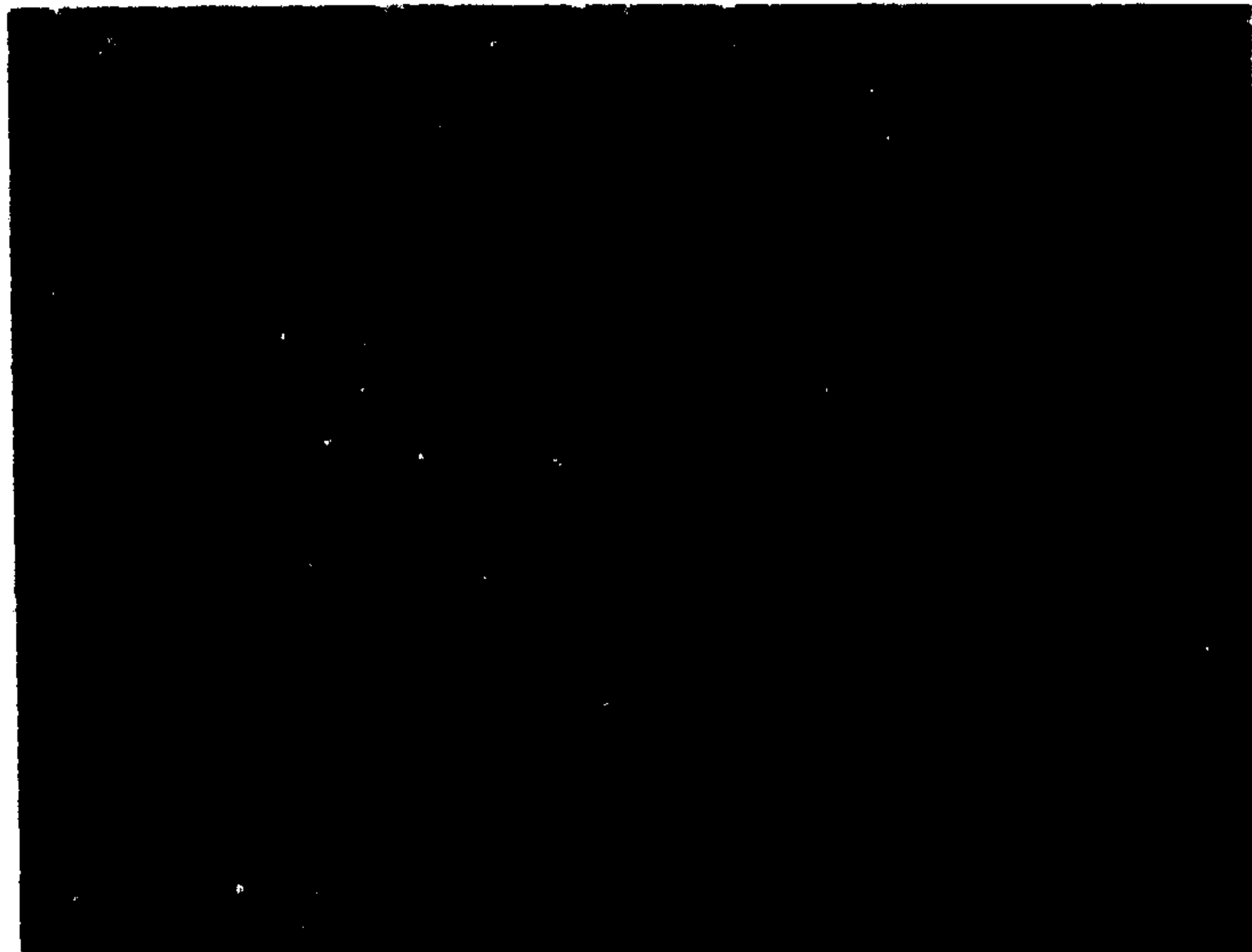


FIG._9A

CONTROL BROTH AFTER EDTA ADDITION
RESUSPENDED PELLET

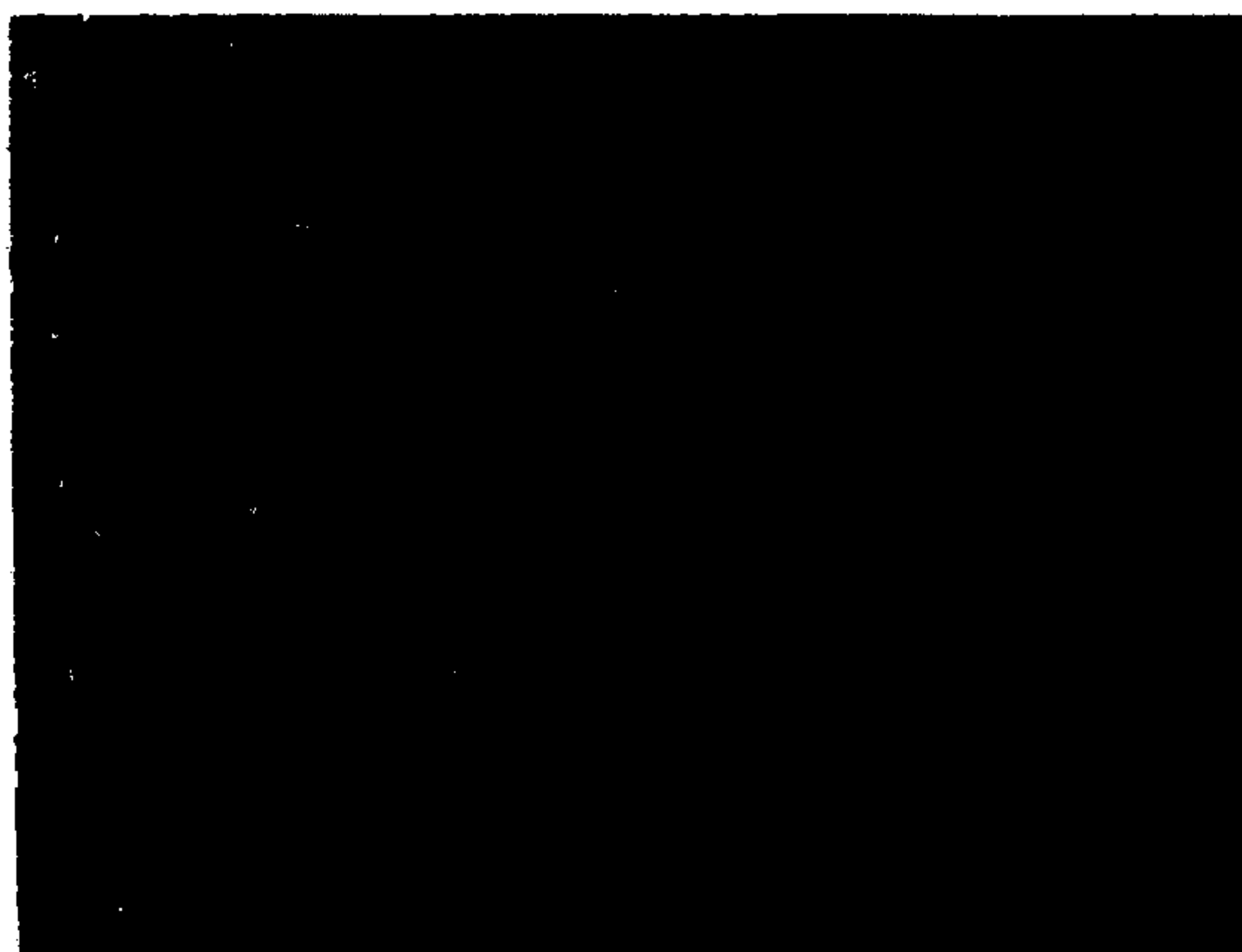


FIG._9B

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BROTH WITH T4-LYSOZYME +endA +t-GENE
CO-EXPRESSION FERMENTATION HARVEST
WHOLE BROTH - UNDILUTED WHOLE BROTH

FIG._9C



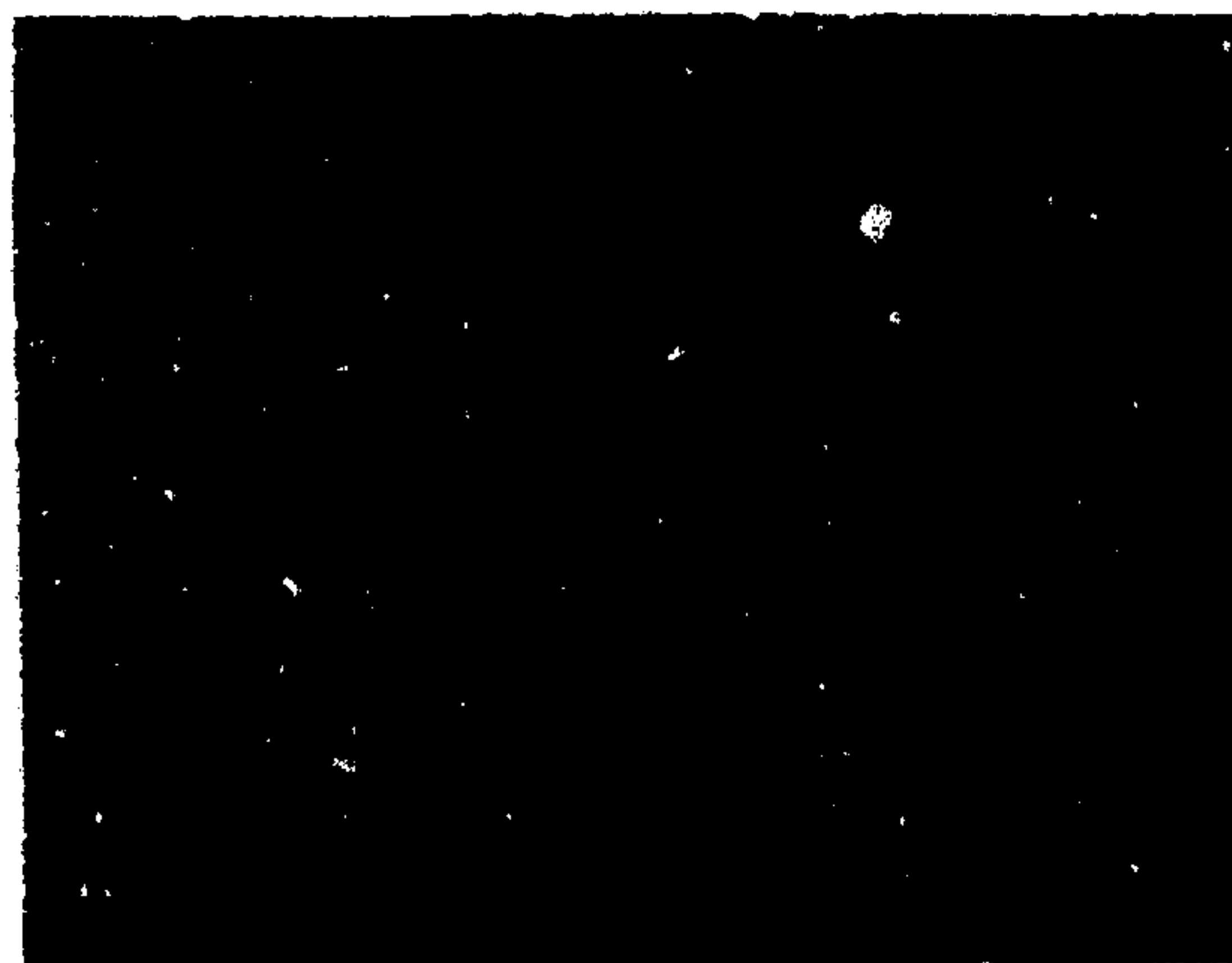
BROTH WITH T4-LYSOZYME +endA +t-GENE
CO-EXPRESSION BEFORE EDTA ADDITION -
RESUSPENDED PELLET

FIG._9D

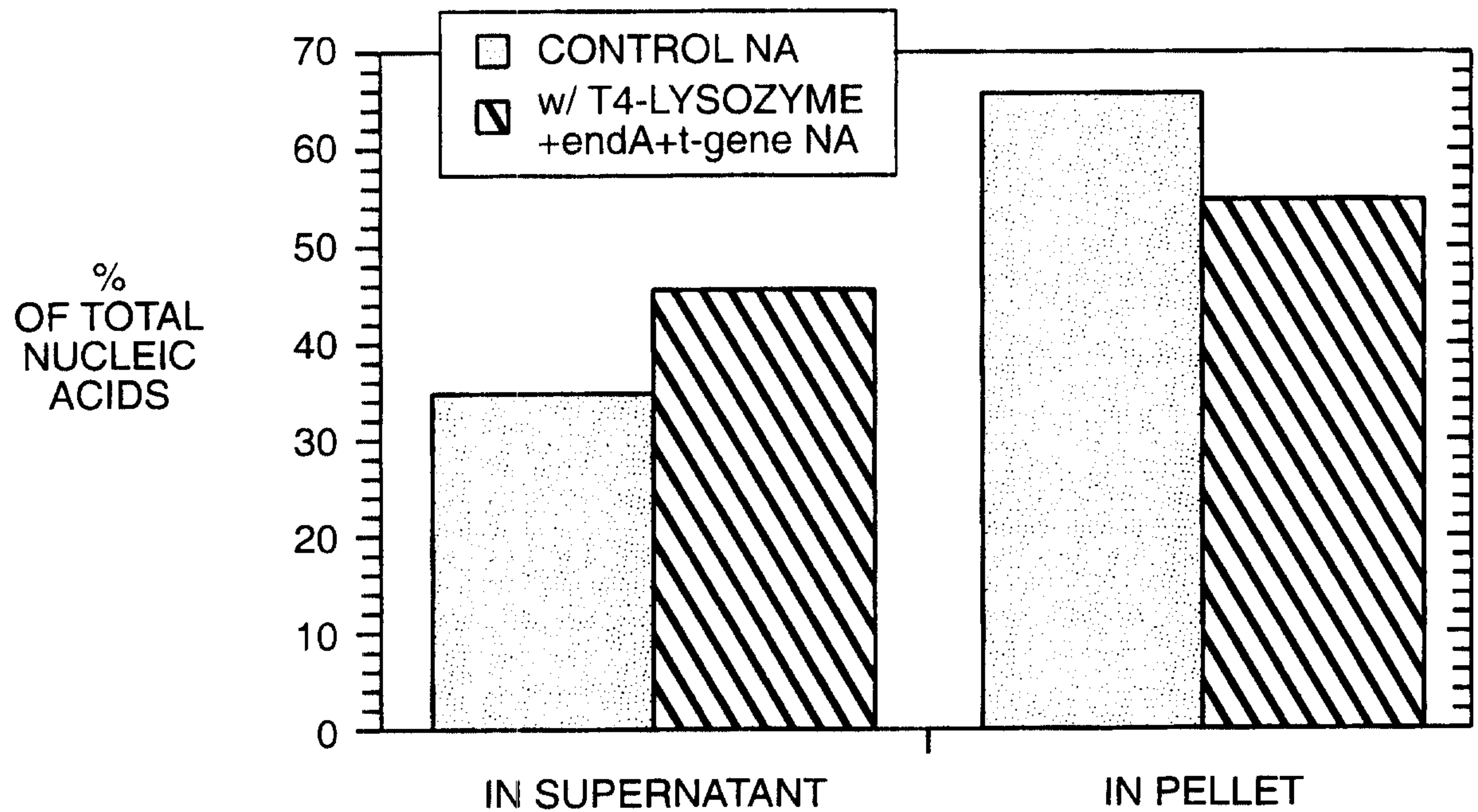
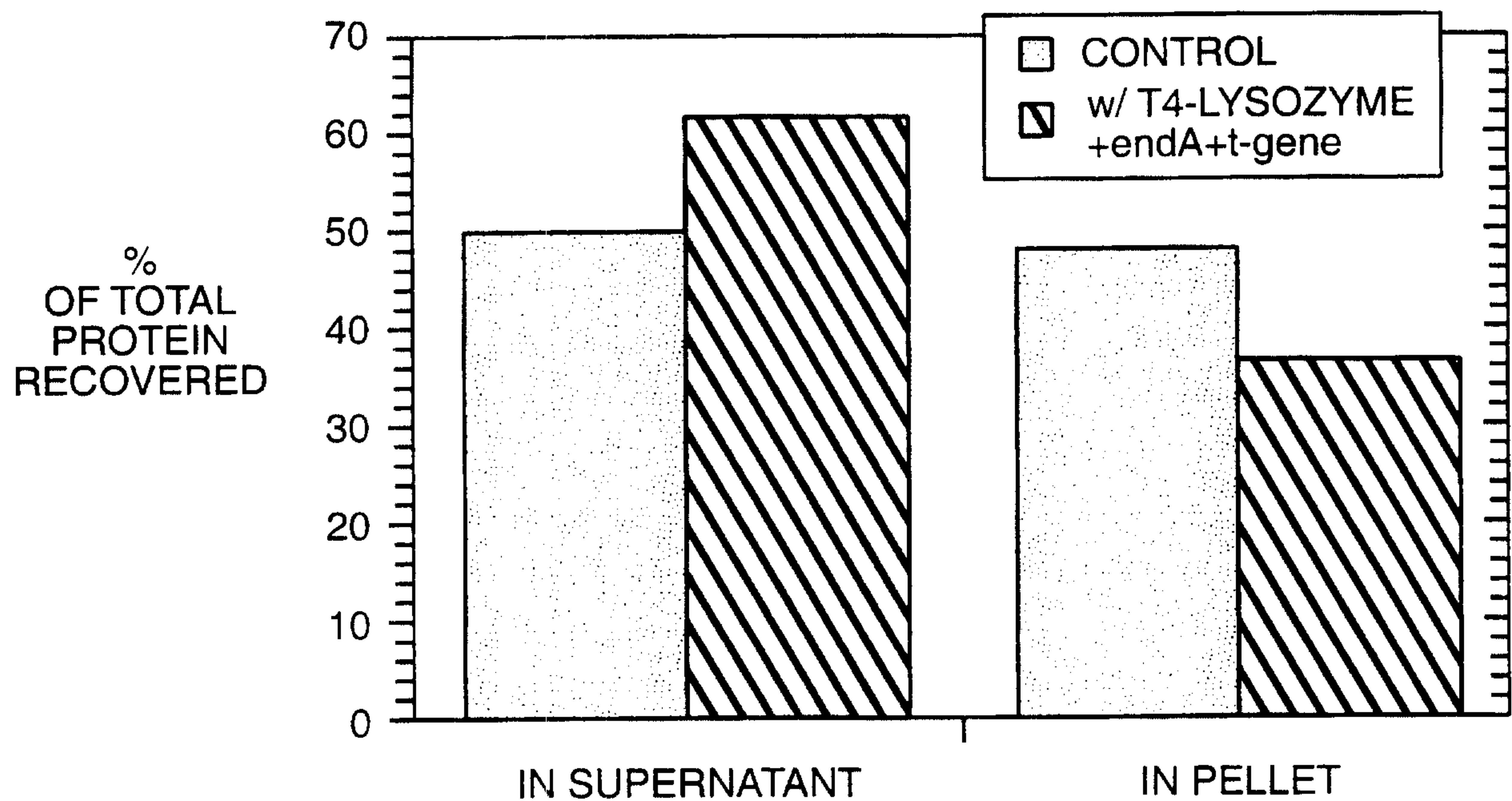


BROTH WITH T4-LYSOZYME +endA +t-GENE
CO-EXPRESSION AFTER EDTA ADDITION -
RESUSPENDED PELLET

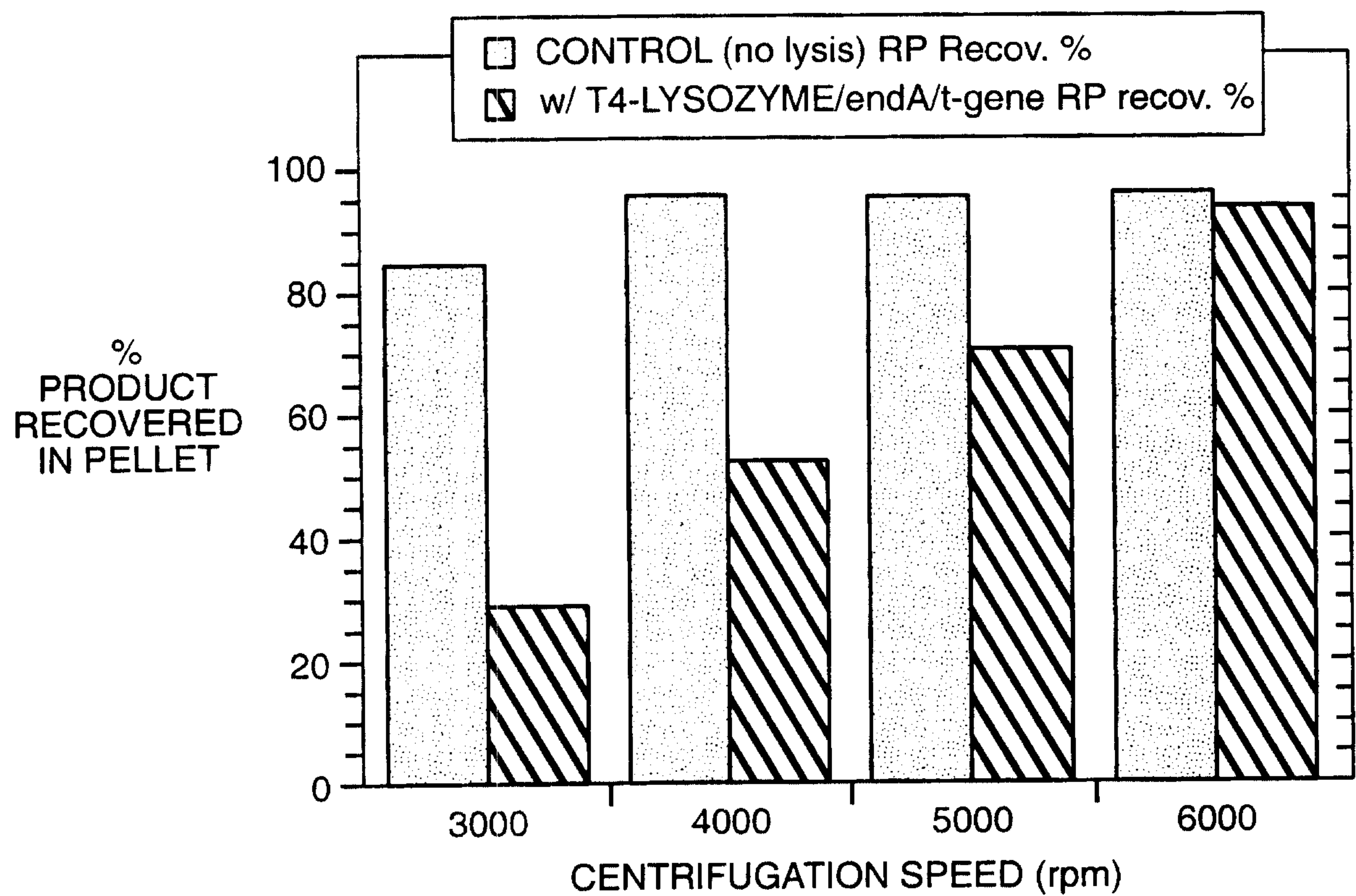
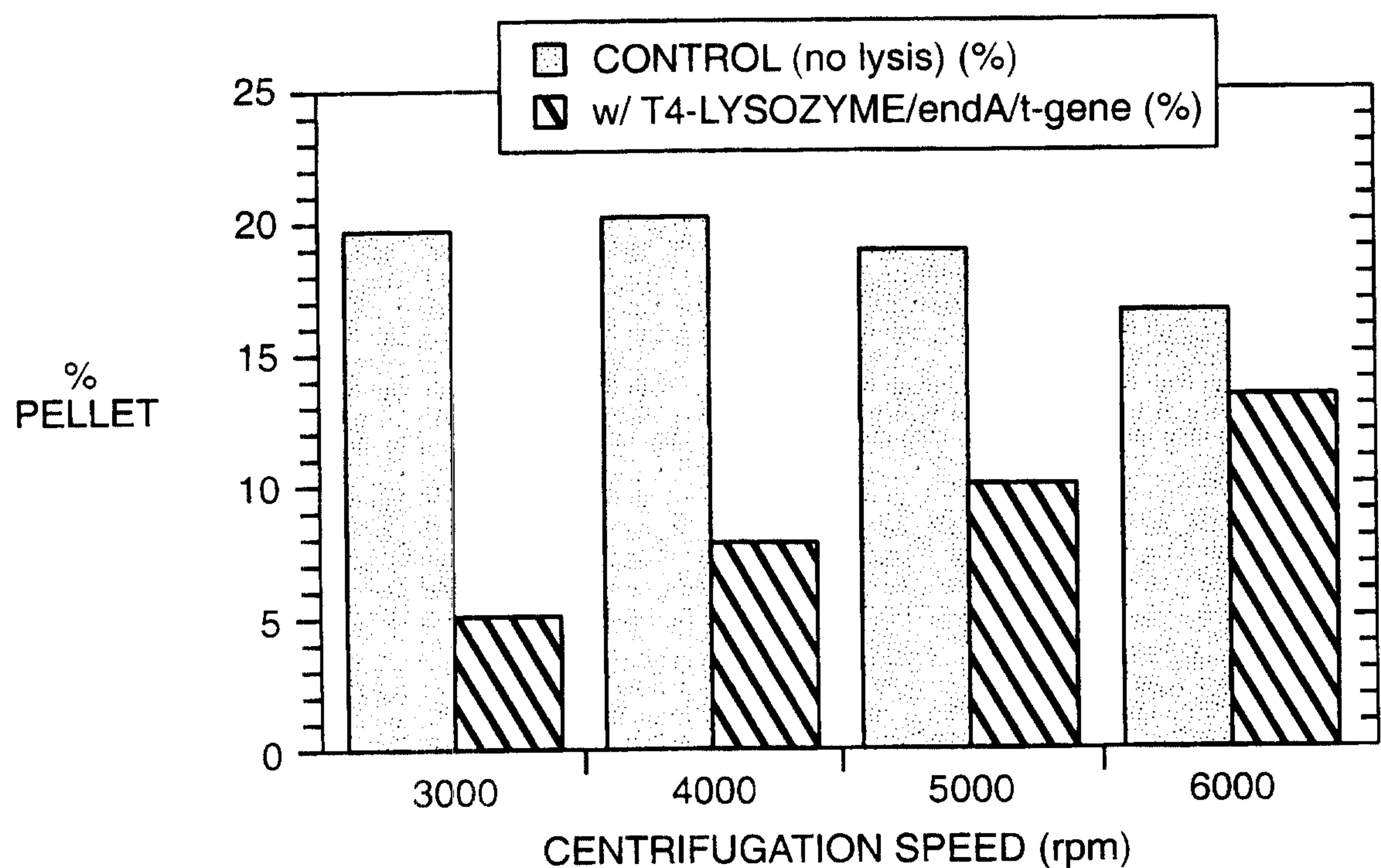
FIG._9E



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**FIG._10A****FIG._10B**

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**FIG. 11****FIG. 12**

